25

ELECTRICAL POWER SYSTEM

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Before delving into the systems aspects of supplying electric power to the project, it should be noted that the project is a national facility for scientific research. It is anticipated that the present power system will continuously be subjected to unforeseen requirements for expansion, conversion, or change in emphasis of power usage, especially in the research areas.

The two-mile accelerator project as now installed has a connected load of 105 MVA. The peak demand in 1967 is expected to be 60 MVA. The demand is expected to triple within the next 5 yr. The SLAC load experience and forecast of maximum megawatt demands as estimated in 1967 are shown in Fig. 25-1.

A prime consideration in the design of the power system was its reliability of operation. The reliability of the many components was, therefore, studied and analyzed in depth. The major questions to be answered were: (1) how reliable should the system be, and (2) how much of the available funds should be spent to obtain a higher degree of reliability?

In mid-1962, a firm criterion for power system reliability was established. In essence, it was realized that the project is not a critical process plant in which loss of power could cause months of cleaning and rebuilding time. The accelerator needs reliable power, but the project will frequently shut down for readjustment, maintenance, and/or repair. Short-time outages lasting from fractions of a second to a few minutes will turn the accelerator off, but it can be readily restarted. Outages of a few minutes to a few hours will necessitate some readjustment to prevent damage to equipment, but the critical vacuum system can be maintained. Outages of more than a few hours could cause a loss of vacuum in some systems and loss of temperature control which would require vacuum pumping and some adjustments to get the accelerator back into operation.

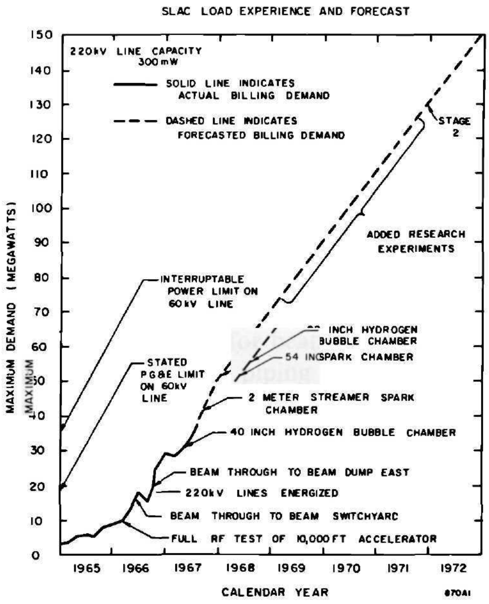
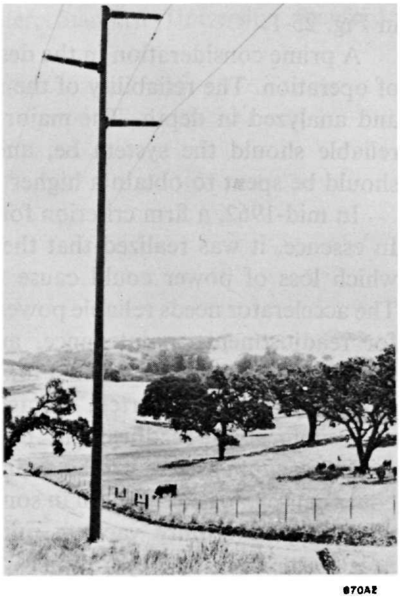


Figure 25-1 SLAC load experience and forecast.

Figure 25-2 Single 220-kV line on tubular steel poles.



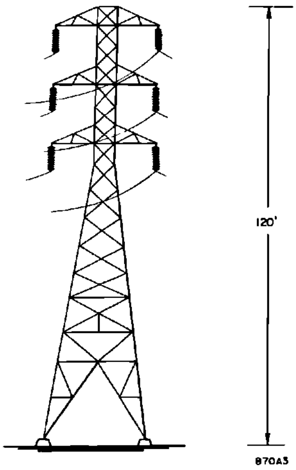
The above concept of reliability led to the following design criteria:

1. Two 220-kV overhead supply circuits, each capable of delivering 300 MVA to the project.
2. Two 40-MVA, 220–12.47-kV transformers.
3. Two 12.47-kV buses connected through a tie circuit breaker.
4. Dual cable service throughout the project.
5. Double-ended substations for critical loads.

The community of Woodside objected to an overhead power line serving the project. Unfortunately, it was necessary to use an overhead power line instead of an underground cable because of its much lower cost. However, their concern resulted in extensive studies to find how best to reduce the impact of such an installation. It was decided to use tubular steel poles (see Fig. 25-2) rather than the conventional trussed towers (see Fig. 25-3), and the design of the line was modified. This provides an installation of greatly improved appearance as compared with a steel lattice-work mast design. In modifying the appearance of the line, the primary service had to be reduced to one 220-kV 300-MVA circuit. The single circuit service concept, together with the limited standby source of 60-kV power and further economic considerations, resulted in a recommendation to use one 83-MVA, 220–12.47-kV transformer and two 15-MVA, 60–12.47-kV transformers. The change in concept for the 220-kV line reduced the reliability of items 1, 2, and 3 above. Items 4 and 5 remained the same.

The final decisions and actual electrical system installation are outlined in this chapter.

Figure 25-3 Conventional trussed tower for 220-kV line.



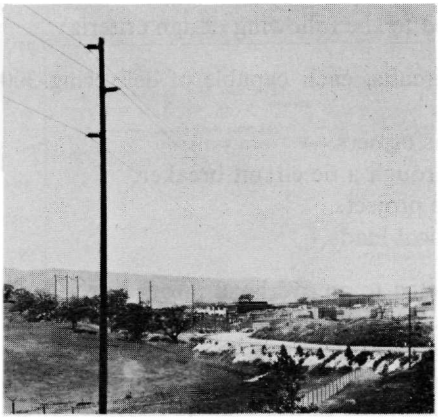


Figure 25-4 Single 60-kV line carried on wood poles.

25-1 Primary services (PCE, AAT)

There are two ac power services to the SLAC site. The first is the 60-kV service. This service supplied power for construction and the initial operational tests of the accelerator. It now serves as a second source of power and provides a backup for the major source. The 60-kV service is classified a second source because the available power is limited to 18 MW with an ultimate capacity of 30 MW. Moreover, the nature of this 60-kV transmission system makes it subject to more interruptions than are acceptable to project operations.

The second is the 220-kV service, which is the major source of power for SLAC. It supplies energy for all the site loads because this service's capacity is adequate for the project power demands and, of the available sources, it is the least subject to unplanned outages.

The 60-kV service will be used when the 220-kV is not available during maintenance work on the project's transmission line or transformer or during the rare instances of 220-kV interruption.

The 220-kV service is tapped from the Pacific Gas and Electric Company (PG & E) Jefferson-Monta Vista transmission line west of the accelerator site and the 60-kV service is connected to SLAC's master substation by a short PG & E transmission line from a nearby 60-kV line east of the accelerator site. This 60-kV line is insulated by post-type insulators which are mounted on wood poles (see Fig. 25-4). The location of the site ac power service sources is shown on Fig. 25-5. The 220-kV tap line (1113 MCM, all aluminum conductor) has an ultimate capability of 300 MVA based on current PG & E system loading limits.

The project's 220-kV service line, which is 6 miles long, utilizes post-type insulators and hollow steel tapered masts where possible. The design of this

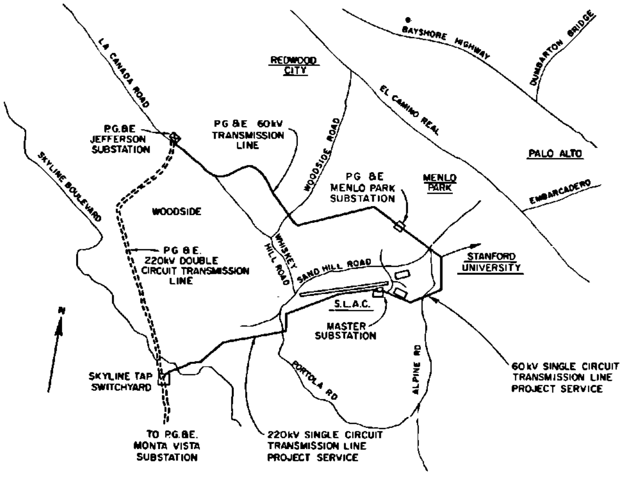
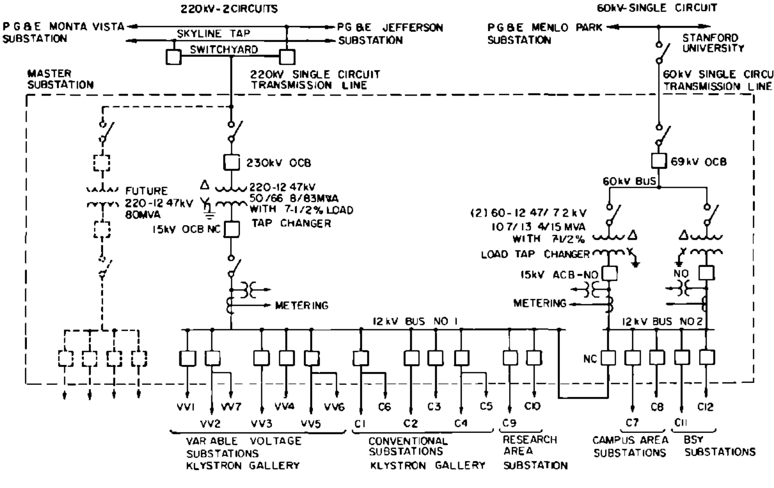


Figure 25-5 Location of site ac power service source.

line is based on considerations of safety, minimum sight impact on neighboring communities, and minimum interference with nearby scientific research activities. The line as constructed blends into the terrain. The adjacent Stanford University radioscience projects are not affected by the operation of the 220-kV line and associated apparatus.

The terminal point for the 220- and 60-kV ac power service lines is the SLAC master substation shown in Fig. 25-6. The site ac power is supplied by

Figure 25-6 Single-line diagram of site ac power service and master substation.



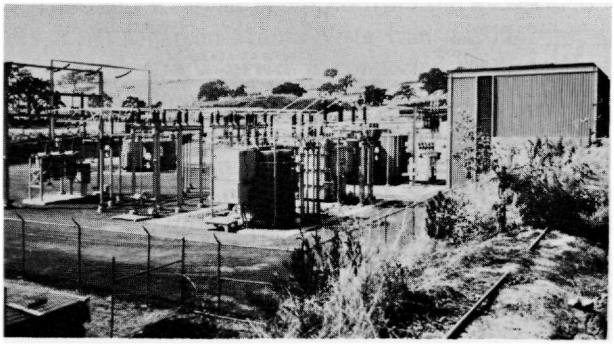
the PG & E at transmission voltages and, therefore, SLAC provides the transformation to 12.47 kV which is distributed throughout the site by an underground cable system. The 60- and 220-kV services cannot be interconnected through the site 12.47-kV system because interconnection at this point is unacceptable from utility operation and safety considerations and because the two high-voltage systems are not in phase.

The project's master substation (see Fig. 25-7) is located near the geographical center of the electrical loads. This substation is a part of the original facilities construction program and is operated by SLAC. The decision favoring project construction and operation as compared with PG & E construction, ownership, and operation is based upon (1) avoiding the commitment of project funds to guarantee to PG & E the installation cost (plus removal expense but minus salvage value) of the substation; (2) the small savings in the power bill resulting from taking the ac power service at transmission voltages; (3) the more effective handling of the fifteen 12.47-kV distribution feeders radiating from the master substation; and (4) the desirability of direct SLAC responsibility for apparatus specification, construction, supervision, and operation management without limitation other than contractual stipulations.

The master substation provides essential features in the receiving, voltage transformation, control, and metering of electric energy. This is briefly described by the one-line diagram, Fig. 25-6. The substation consists of an outdoor high-voltage yard, a switch house, and an outgoing feeder cable vault under the switch house. The substation outline plan is shown in Fig. 25-8.

The high-voltage yard contains the 60- and 220-kV switchgear, the 220–12.47-kV transformer, the two 60–12.47-kV transformers, a 230-kV class oil circuit breaker, a 69-kV class oil circuit breaker, and a 15-kV class oil circuit breaker. All high-voltage apparatus, insulators, energized components, and bus hardware are in accordance with low radio noise influence factor specifications. The 220-kV bus work is designed for 1050-kV basic

Figure 25-7 View of master substation.



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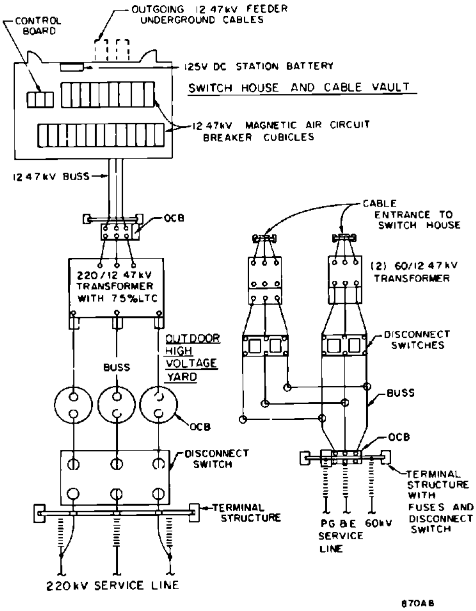


Figure 25-8
Outline plan of master substation.

insulation level (BIL). The 220–12.47-kV transformer is reduced to 825-kV BIL using 75% rated lightning arrestors. The 12.47-kV switchgear is rated at 110-kV BIL. The transmission-line terminal structure, high-voltage buses, support insulators and structure are low profile-type units as shown in the photograph, Fig. 25-7, in order to achieve a more acceptable appearance than that resulting from conventional substation structures. The 12.47-kV distribution voltage at the site matches PG & E's practice, thus increasing the possibility of rapid transformer replacements in the event of failure. Also, PG & E's local area 12-kV distribution is usable if required to supply temporary power to a portion of the project. This low-voltage service was used during initial construction phases prior to the availability of the 60–12.47-kV transformer and switchyard. The power transformer installations are fitted with a high-pressure water sprinkler system, automatically turned on by flame-sensing devices. This provides an effective damage control in the event a power transformer tank ruptures allowing oil to pour out and feed a fire. Rock-filled oil sumps are provided under the major oil filled apparatus. These sumps have adequate capacity for both oil and water and the rock fill insulates the oil from the flame.

The power transformers are oil-insulated and oil-cooled. They are manufactured to rigorous industrial standards and are provided with air cooled radiators through which the oil is circulated. Fans are installed on the radiators to allow an increased power capacity over the self-cooled rating. The

220–12.47-kV transformer has a set of oil pumps that circulate oil through the radiators. This additional circulation feature adds to the cooling effectiveness which increases the rating of the transformer from 50 to 83 MVA.

The switch house contains a 125-volt dc station control battery, dc rectifier, and battery charger. The battery is composed of nickel–cadmium cells, which do not require ventilation hoods, and specially enclosed racks. Included in the switch house are 1600 and 2000-A magnetic blowout air circuit breakers, three PG & E revenue metering sets, switchgear controls, dead front and back switchgear cubicles, and power demand monitoring information transmitters. Provisions are made for portable metering arrangements to monitor incoming or outgoing volts, amperes, watts, and vars.

Protective relaying is included in the apparatus to sense line-to-ground faults, line-to-line short circuits, and low system voltage. Interruptible power is defined by means of underfrequency relays.

The SLAC load requirements are supplied by the PG & E high-voltage transmission network. Present (1967) total generating capacity of this network is 8034 MW. The PG & E maximum demand reported for 1966 is 7392 MW. The project load is of a magnitude that requires consideration in the circuit of the whole PG & E system. For example, uncontrolled switching of the total SLAC load affects the PG & E system stability and produces a transient swing of frequency. Because of the system's reactance, the sudden switching of 26 MVA of load produces a phase angle shift of the voltage at the load bus as compared with the phase angle of the generated voltage. The sudden shift is equivalent to a 0.3-Hz phase modulation for a fraction of a second.

The source impedance of the 220-kV ac power service is 0.5% resistance and 4.85% reactance on a 100-MVA base. The 220–12.47-kV, 50-MVA power transformer adds to this value to make the total at the master substation (bus No. 1) 2.07% resistance and 29.85% reactance on a 100-MVA base. The ohmic values are 0.032 ohm resistance and 0.46 ohm reactance. These values will decrease somewhat as the PG & E system grows. The voltage drop that results from loading the system is automatically compensated by two features that return the voltage to the desired level within 10 to 15 sec. The first is the regulation control of the PG & E system output voltage. The second is the automatic tap changing device on the 220–12.47-kV power transformer. This device operates under load and is designated as a load tap changer (LTC) on Fig. 25-6. Bus No. 1 voltage at the master substation is regulated by these two means to within ±0.8%. This provides a stable base from which to operate the system.

The source impedance of the 60-kV ac power service is 2% resistance and 17.4% reactance on a 100-MVA base. The 60–12.47-kV, 10.7-MVA power transformer adds to this value to make the total at the master substation bus No. 2, 7.1% resistance and 87.4% reactance on a 100-MVA base. The

Table 25-1 Tabulation of limited research and accelerator operation with ac power service from 60-kV system

Support and service area	3.0 MW
Klystron gallery house power	5.2 MW
Beam switchyard and Data Assembly Building	1.3 MW
End station house power	1.5 MW
Subtotal	11.0 MW
Accelerator operation, 18 GeV and 60 pulses/sec	3.7 MW
Beam switchyard operation, 18 GeV	0.4 MW
End station B, transport system operation, 12 GeV	2.9 MW
Total	18.0 MW

ohmic values are 0.11 ohm resistance and 1.4 ohms reactance at the 12.47-kV bus No. 2. The 60-kV transformers are supplied with load tap changing features. The PG & E 220–60-kV power transformers in the Jefferson substation are also regulated by load tap changing gear. Bus No. 2 voltage at the master substation is regulated by these two means to within ±0.8%.

The limit of 18 MW when power is supplied only by the 60-kV line imposes restrictions on the project's operations. For example, the accelerator can operate at low pulse rate and support limited research as shown in Table 25-1.

25-2 On-site, 12.47-kV power distribution (PCE, FFH)

The present 12.47-kV on-site distribution system was selected through many stages of developments. As noted previously, the 12.47-kV distribution voltage matches PG & E's 12-kV practice, thus increasing the possibility of rapid transformer replacement and permitting use of the local area 12-kV system if required to supply temporary power to a portion of the project. It is interesting to note that early studies of on-site power distribution for the project considered voltages from 480 to 13,800 V, with overhead pole lines, cables through the klystron gallery, direct burial cable, and an underground cable-duct system. The above-grade pole line system while being the least expensive was quickly discarded for aesthetic reasons and because it would be hazardous for cranes and moving equipment. Some consideration was given to serving the klystron gallery complex with a cable system running on trays the length of the gallery. This was dropped because of the high temperature at the gallery roof and because the gallery space was needed for vacuum, water, local power, and control lines. The direct-burial cable system was discarded because of inflexibility and possible lengthy downtime in case of an outage. To meet flexibility, reliability, and minimum maintenance criteria, an underground cable-in-duct bank system was adopted.

Distribution voltage was determined from accelerator equipment requirements. In the early stages of the project it was planned that some 24 MVA of ac power would serve a central dc facility located adjacent to the master substation. Power would be distributed along the klystron gallery at 23-kV dc to the modulators. The central dc facility was to consist of sixteen variable-voltage rectifying units with a range of about ±30% of the nominal voltage. The manufacturing limitations for the induction voltage regulators was 16 kV which would represent the +30% control point. To satisfy these limitations, a nominal distribution voltage of 12 kV was selected after checking with the equipment manufacturers.

In mid-1962 the central dc facility was abandoned due to technical problems. The 12-kV–480-V Test Laboratory substation and the 60–12-kV substation were on order and, hence, it was too late to change the voltage rating without seriously delaying the overall schedule. With the aim of increasing the distribution voltage within the capability of the Test Laboratory and 60-kV substations, it was recommended that the nominal voltage be increased to 12.47 kV. This increase from 12 to 12.47 kV reduced the duct-bank heating losses by 7% and made better use of the cable equipment rated at 15 kV.

The underground duct-bank and cable system was adopted early in the design. The design objective was to provide a system with component materials which had proven their reliability over a period of years. After careful study it was agreed to use 15-kV three-conductor, paper-insulated, lead-covered cable (PILC) with an exterior jacket of neoprene. PILC cable was chosen over the newer insulation materials such as polyethylene, cross-linked polyethylene, and butyl rubber because of the "year-miles" experience record. PILC cable has greater overload capacity than the newer insulations; also the three-conductor PILC cable costs less.

In accordance with the reliability criteria that were established in mid-1962, the project is served by a dual cable system. Each distribution unit substation is served by two 12.47-kV cables; one is for normal service and one is for emergency service. Both cables, however, normally carry a full load. The emergency cable can be overloaded during the emergency connection period for a maximum of 3 days. This overload condition requirement was considered in the selection of and sizing of the PILC cables.

A detailed analysis was made of each duct-bank system, particularly with regard to thermal capability of each cable and of the duct-bank as a whole. The thermal and cable-sizing studies covered thermal conductivity of the soil, soil moisture content, mass of concrete in the duct-bank, duct materials, cable materials, normal cable loading, emergency 3-day cable loading, and short-circuit current vs time characteristics of the system and of the cable.

Two duct-cable systems were critical: the klystron gallery service and the service to the research area substation. Studies for the klystron gallery system resulted in a cable system with tapered wire size. In areas where the klystron gallery earth fill is high above original grade, additional concrete was added to the duct-bank to increase the duct surface area to compensate for the below-normal soil thermal conductivity. The design criteria and operating limits for the klystron gallery cable system are outlined in Tables 25-2 and 25-3. The duct-bank system includes thermal capacity to allow for one 5-MVA cable to serve the area at Sector 10 and two 5-MVA cables to serve the area at Sector 20 (the future colliding beam area), but the ducts and cable must be added in the future.

The duct-cable system serving the research area substation is of unusually large capacity. Two 2000-A circuit breakers in the master substation serve the research area substation. For the initial installation, these two circuits each consist of two parallel three-conductor cables. With both circuits in service, the initial system can deliver 30 MVA continuously. With one circuit out of service, the in-service circuit can deliver 30 MVA for a 3-day period.

Table 25-2 Klystron gallery cable loads, conventional substations

Substation			*Feeder cable No.*			
No.	*kVA rating*	*Max. demand (kVA)*	*1*	*2*	*3*	*4*
1A	750	700	N[a]	E[b]	—	—
1B	750	700	E	N	—	—
2	750	700	N	E	—	—
3	750	700	N	—	E	—
4	750	700	N	—	E	—
CT-1	500	500	E	N	—	—
5	1000	1000	—	N	E	—
PSI	1500	1300	—	N	—	—
6	750	700	—	E	N	—
7	750	700	E	—	N	—
8	750	700	E	—	N	—
9	750	700	—	E	N	—
10	1000	1000	—	N	—	E
11	750	700	E	—	—	N
CT-2	500	500	E	N	—	—
12	750	700	E	—	—	N
13	750	700	—	E	—	N
14	1000	1000	—	—	E	N
15	1000	1000	N	—	—	E
Total normal load		17,075	4000 kVA	4100 kVA	4000 kVA	4275 kVA

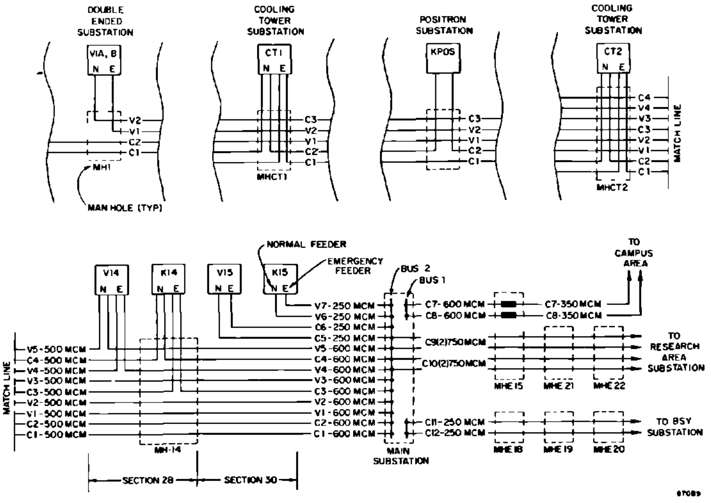
[a] N = normal.

[b] E = emergency.

Table 25-3 Klystron gallery cable loads, variable-voltage substations

Substation			*Feeder cable No.*				
No.	*kVA rating*	*Max. demand (kVA)*	*VV-1*	*VV-2*	*VV-3*	*VV-4*	*VV-5*
VV-1A	1750	975	N	E	—	—	—
1B	1750	775	E	N	—	—	—
2	1750	1550	N	E	—	—	—
3	1750	1550	N	E	—	—	—
4	1750	1550	E	N	—	—	—
5	1750	1550	E	N	—	—	—
6	1750	1550	—	E	N	—	—
7	1750	1550	—	E	N	—	—
8	1750	1550	E	—	N	—	—
9	1750	1550	E	—	—	N	—
10	1750	1550	—	E	—	N	—
11	1750	1550	—	—	E	N	—
12	1750	1550	—	E	—	—	N
13	1750	1550	—	—	E	—	N
14	1750	1550	—	—	—	E	N
15	1750	1550	—	N	—	—	E
Total normal load		23,450	4075	4225	4650	4650	4650

Figure 25-9 Power distribution of site utilities system.



The duct-bank is designed to handle the future maximum loading of the research area substation, when each of the existing two circuits serving the research area substation will be doubled to four three-conductor cables per circuit. With the installation of these cables, the two circuits operating together can deliver about 52 MVA. With one circuit out of service, the in-service circuit consisting of four parallel three-conductor cables will be able to deliver about 43 MVA for a 3-day period.

Figure 25-9 shows the site 12.47-kV utilities system power distribution.

25-3 Secondary distribution

Klystron gallery (ILK, FGP)

Two ac systems serve the accelerator housing and klystron gallery. One furnishes three phase, 480 and 208Y/120 V for building services, vacuum, instrumentation and control, machine cooling water, microwave, alignment, and injection subsystems. The other provides variable voltage (258–595-V) services to modulators.

Sources for each system are unit substations located in alcoves along the klystron gallery, which transform the 12.47-kV distribution voltage to the utilization voltage. Each substation generally serves two sectors of the klystron gallery (666 ft, 8 in.) and the accelerator housing below; hence fifteen substations are required to supply the modulators. One substation supplies the positron source. In addition, each substation at Sector 2 is double-ended to provide extra reliability to the power sources for the main injector and Sectors 1 and 2. Finally, two substations, each in its own alcove, serve the machine water-cooling towers. These substations are equivalent in design and reliability to industrial systems of similar capacity. Standby power is provided only for the vacuum and beam guidance systems. In the case of failure of a sector substation, a second feeder from an adjacent substation may be connected by a manual transfer switch to energize the vacuum and beam guidance systems in the down sectors, permitting the beam to drift through them. Sectors 1 and 2 require continuity of operation for the injector and the first three "beam-stiffening" klystrons. Therefore, they are served by double-ended substations.

Auxiliaries (including cooling towers, but not the positron source) in the klystron gallery are served by an installed transformer capacity of 13,750/18,000 kVA AA/FA (self-cooled/forced air cooled), with a Stage I demand load of 5200 kVA and connected load of 17,000 kVA. Projected Stage II demand is 13,000 kVA and connected load 21,500 kVA.

Modulators served by an installed transformer capacity of 28,000 kVA have a Stage I maximum demand of 22,240 kVA and a connected load of 26,545 kVA. Figure 25-10 is a one-line diagram of a typical variable-voltage substation.

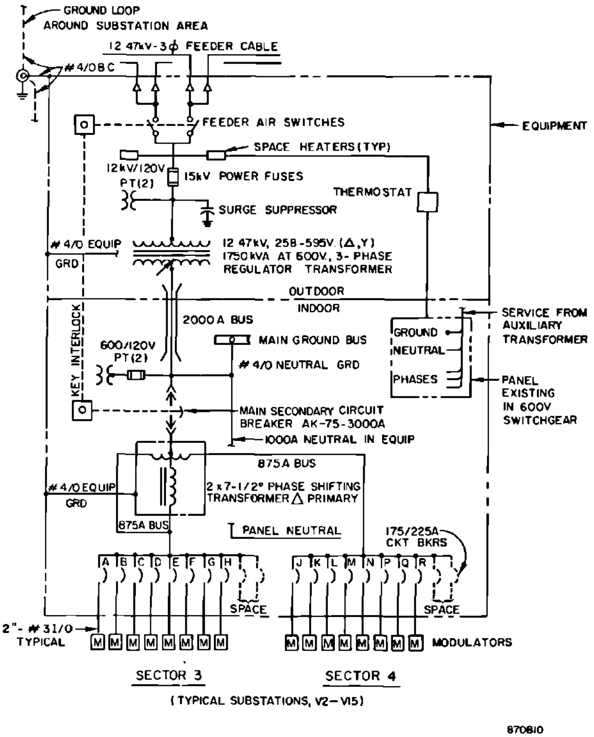
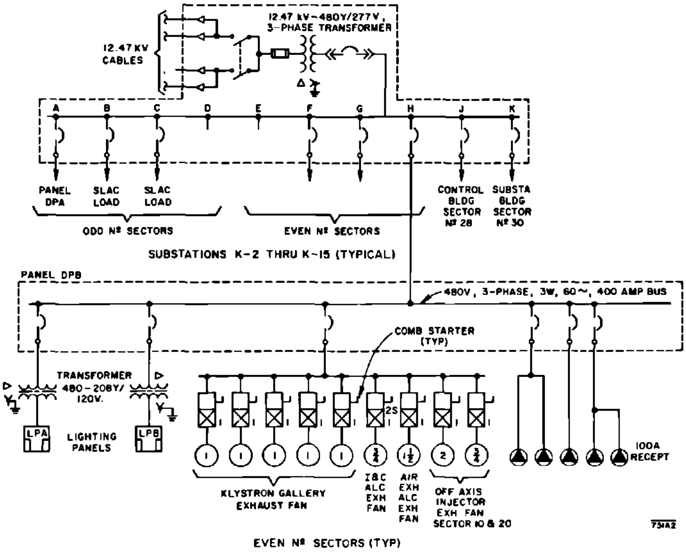


Figure 25-10 One-line diagram of klystron gallery variable-voltage sub-stations.

Figure 25-11 One-line diagram of klystron gallery auxiliary services.



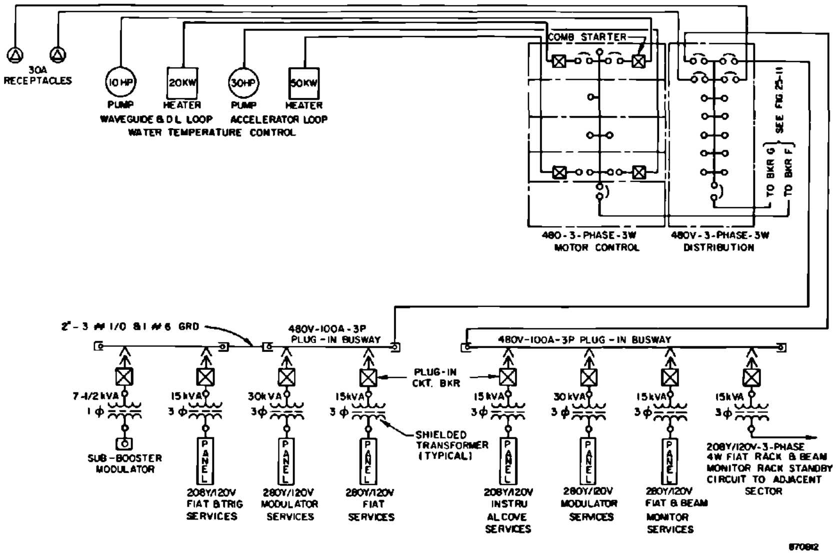


Figure 25-12 One-line diagram of klystron gallery modulator auxiliary services.

Figures 25-11 and 25-12 are one-line diagrams of a typical sector showing auxiliary services and modulator services.

Substations for auxiliary services are ventilated, dry-type, Class H insulated, dual rated, self-cooled or forced air cooled (in sizes over 500 kVA) with 500-MVA power fused primary switches designed to withstand 40,000 A momentary test with secondary breakers in cascade arrangement. Substations are located indoors for architectural reasons.

Variable-voltage substations for modulator services are similar to substations for the auxiliary services except that the primary incorporates a water-cooled oil-insulated induction voltage regulator which is not located indoors. The regulator is bused to a phase-shifting transformer in the indoor section which serves two output buses such that the phase angle on a 60-cycle base between these buses is 15°. Modulator loads provide the equivalent of a twelve-phase system, and the 15° phase shift between buses establishes twenty-four-phase dispersion at the substation secondary. The regulator, controlled by a bistable amplifier, adjusts substation output voltage within ±2 V of approximately 5 times a reference signal of 50 to 120 V from central control. The main secondary circuit breaker is equipped with adjustable time-delay undervoltage trips.

Power for the auxiliary services (secondary distribution system) in each successive pair of sectors originates at one substation. Distribution, however, is on a per sector basis. Each sector is served by three 480 V, three phase, three wire power feeders. One serves a distribution panel from which subfeeders extend to vent fans, receptacles, and lighting. A second serves a motor control center which, in turn, feeds water pumps and heaters for machine temperature regulating and cooling. The third distributes 480 V along the sector by means of plug-in bus ducts. The bus duct is used for its economy, salvage value, and to permit maximum flexibility of subfeeder location for modulator auxiliaries, vacuum, instrumentation and control, trigger, and microwave services.

Four hundred and eighty-volt circuit breakers in distribution panelboards and plug-in bus duct have not less than 15-kA asymmetrical interrupting ratings. Where circuit breakers are used in combination with starters, this rating applies to the combination. Circuit breakers used in 208Y/120- and 120/240-V panelboards have a minimum interrupting rating of 7500 A asymmetrical. A 24-V dc, 125-A power supply with a 200-A-hour floating battery provides power for instrumentation and control in each sector. The cables, rated at 600 V, are insulated by cross-linked polyethylene for economy and radiation resistance.[1]

Lighting and receptacle services for each sector's accelerator housing run down that sector's man accessway. All other services to the accelerator are brought down through the penetrations which connect the accelerator housing to the gallery at 20-ft intervals.

Interference is reduced by the use of shielded transformers throughout the installation and by physical separation, i.e., power wiring is run along the south and instrumentation along the north walls of the klystron gallery wherever possible.

Positron source (MAM)

Sector 11 is equipped with one dry-type, indoor, 1500/2000 kVA (self-cooled/forced air cooled), 12.47-kV–480/277-V substation for the positron source. The substation feeds power supplies serving three dc solenoids with a total demand of 1300 kW and two klystron modulators rated at 125 kVA each.

Output voltage to the modulators is controlled by two 125-A, 260–600-V automatic three-phase induction voltage regulators. The regulators perform essentially the same functions as the regulators in the variable-voltage substations described earlier, with the exception that each regulator feeds only one modulator, thus allowing independent voltage control.

Power for positron instrumentation racks as well as for the 150-kVA heat exchanger is derived from the conventional substation in Sector 10 because of economy in feeder length. Unlike the other substations in the klystron gallery, the positron substation is not provided with a 12.47-kV emergency feeder nor is there standby power for the instrumentation and control racks and the special quadrupole triplets associated with the positron source.

In addition to the conventional short circuit and overload protection, phase undervoltage relays trip the main secondary breaker to protect the power supplies from single phase operation.

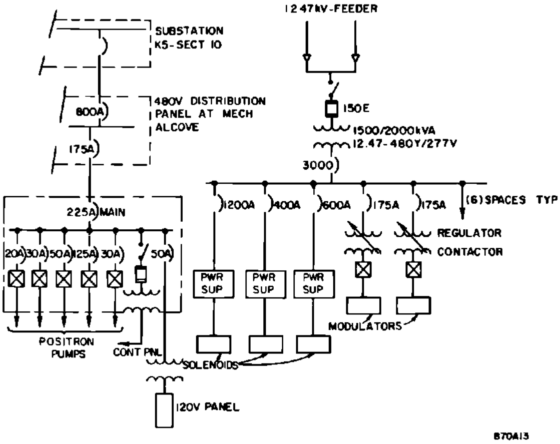


Figure 25-13 One-line diagram of positron area substation.

The induction voltage regulator output contactors are provided with a permissive interlock from the personnel and machine protection system of the accelerator.

Figure 25-13 is the one-line diagram for the positron source electrical services.

Beam switchyard (ILK, AAT)

Two double-ended indoor substations located in a building near the Data Assembly Building (DAB) supply power for the beam switchyard (BSY). One serves power supplies for switchyard magnets, magnet auxiliaries, and instrumentation and control. The other serves A-beam dump magnet power supplies and pumping stations for all switchyard and end-station cooling water. It also supplies house power requirements for the switchyard substation building, DAB, and the switchyard itself, 40 ft below grade.

Emergency power for minimal crane, ventilation, and lighting requirements in the switchyard and end stations is provided by a Diesel generator. Power supplies with batteries in parallel furnish instrumentation and control services.

Power for the BSY is supplied by means of two 250-MCM 3/C PILC, 12.47-kV feeder cables underground from the master substation to BSY substation. Each serves an individual 12.47-kV bus. The two substations are connected to the buses through fused switches to permit one or both substations to be connected to either bus (see Fig. 25-14). Substations are sized for switchyard operation at the 25-GeV beam energy level. At this level, the loads are such that the substations have to be forced air cooled. Switchyard magnets, power supply auxiliaries, and instrumentation requirements

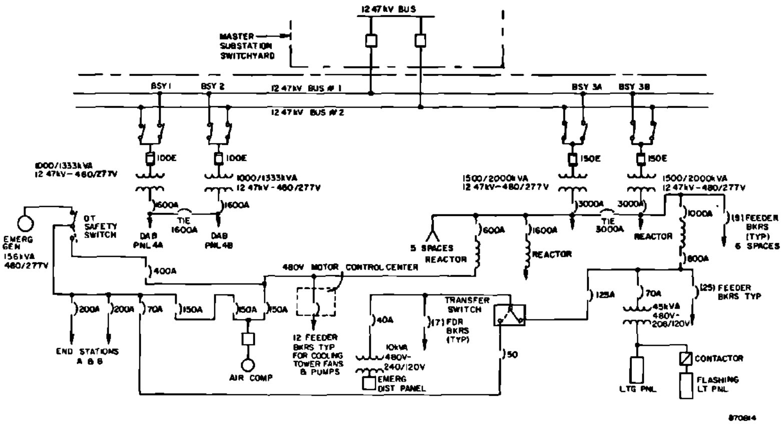


Figure 25-14 Single-line diagram of beam switchyard substation.

are served by substations Nos. 1 and 2, totaling 2000/2666 kVA, AA/FA (self-cooled/forced air cooled) of installed transformer capacity with a demand load of 1760 kVA and a connected load of 1900 kVA. Switchyard site services, cooling-water pumps, and A-beam dump requirements are served by substations Nos. 3A and 3B, totaling 3000/4000 kVA, AA/FA (self-cooled/forced air cooled) of installed transformer capacity with a demand load of 3100 kVA and a connected load of 3900 kVA.

The substations mentioned above are double-ended, ventilated, dry-type, class H insulated. Substations Nos. 1 and 2 each have transformers rated 1000/1333 kVA, AA/FA. Substations Nos. 3A and 3B each have transformers rated 1500/2000 kVA, AA/FA. The primary switches have 500-MVA rated power fuses and are designed to withstand forces due to 40,000-A asymmetrical short circuits. Secondary breakers are in cascade arrangement. Substations Nos. 1 and 2 have a key-interlocked 1600-A tie breaker and 1600-A, main secondary circuit breakers with adjustable time delay, undervoltage, and underfrequency tripping devices. Substations Nos. 3A and 3B have 3000-A main secondary circuit breakers connected to trip on low or unbalanced voltage and automatically close the 3000-A tie. Selection is available for manual or automatic operation. Large pump motors are all controlled directly by circuit breakers. All circuit breakers in feeders to the DAB may be remotely tripped from the DAB.

Secondary distribution at 480 V, three-phase, three-wire serves building needs, cranes, vacuum systems, cooling-water pumps, power supplies, and instrumentation. Dry-type, class H insulated, shielded, 480/208Y/120-V transformers are furnished near application points for lighting, convenience outlets, instrumentation and control, and miscellaneous 120-V needs. Motor and building loads are electrically separated from precision power supplies so far as economically feasible in order to improve regulation and to reduce high-frequency electrical noise.

Four hundred and eighty-volt circuit breakers in the DAB are capable of interrupting not less than 25 kA asymmetrical at 480-V ac. Where breakers are used in combination with starters, this rating applies to the combination. Circuit breakers used for 208Y/120-V circuits are capable of interrupting 7.5 kA asymmetrical at 240-V ac.

Power services outside of the switchyard are run in conduits and ducts using conventional building wire. Inside the switchyard, lighting, receptacle, and crane services use polyethylene-insulated wire in conduit. For convenience and economy, all magnet, instrumentation, and communication cables are run in cable trays from their origin in the DAB to their destination in the BSY. Services are brought into the switchyard through duct banks and through lockable radiation labyrinths. Radiation levels inside the switchyard are such[2,3] as to require that the cabling in the upper housing be cross-linked polyethylene. Cables in the lower housing are, in general, fiberglass- and mica-insulated; in particularly high-radiation areas, such as the vicinity of the slits and collimators, magnesium oxide-insulated (MI) cables are used. The magnesium oxide-insulated cables are stainless steel jacketed to limit corrosion. Terminations at both magnets and instruments are radiation-resistant and are remote operable, e.g., capable of being opened or made up by rods through holes in the floor of a shielded maintenance cab in the upper housing. Where disconnects cannot be remotely opened and closed, the magnet or instrument itself may be drawn into the maintenance cab to be disconnected manually. Sufficient slack is left in all cables at connection points to permit a wide range of remote manipulation.

To maintain service continuity and to isolate the klystron gallery instrumentation from the BSY instrumentation, two 24-V power supplies with parallel batteries are furnished. A 200-A power supply with a 400-A-hour parallel positive-grounded battery serves controls, relays, and both klystron gallery and BSY status needs. A 125-A power supply with a 200-A-hour parallel negative-grounded battery serves computer logic circuits and that part of the interlock system which uses commercially available, solid-state circuits. The battery ground is common and is tied to the main SLAC ground bus.

End station area (PCE, AAT)

Electric energy for the various end station facilities (see Figs. 25-15 and 25-16) and for the research operations is served from the research area substation, except for a limited standby service which is assigned to critical loads requiring emergency service. The emergency service is supplied by a Diesel engine generator set located in the BSY area substation.

The research area substation, located adjacent to the end station A counting house, provides 480-V, 4160-V, and 12.47-kV power for the entire end station area. The substation has two 12.47-kV buses designed to permit transfer of power from one end station area to another with the progression

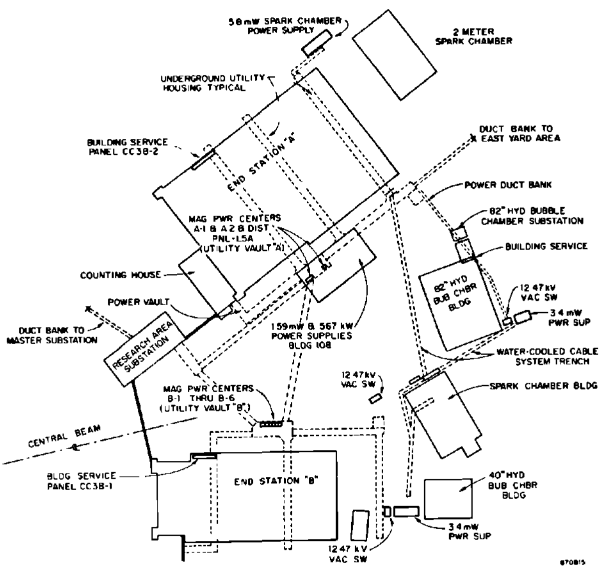


Figure 25-15 Electrical plot plan of end station area.

of research operations. The capability of the installed cables from the master substation is 30 MVA to the research area substation. The duct bank from the master substation is available for future cable installation to carry an ultimate capacity of 52 MVA.

The research area substation houses four 12.47-kV–480-V unit substations, one 12.47-kV–4160-V unit substation, the substation house power services,

Figure 25-16 Single-line diagram of research area substation.

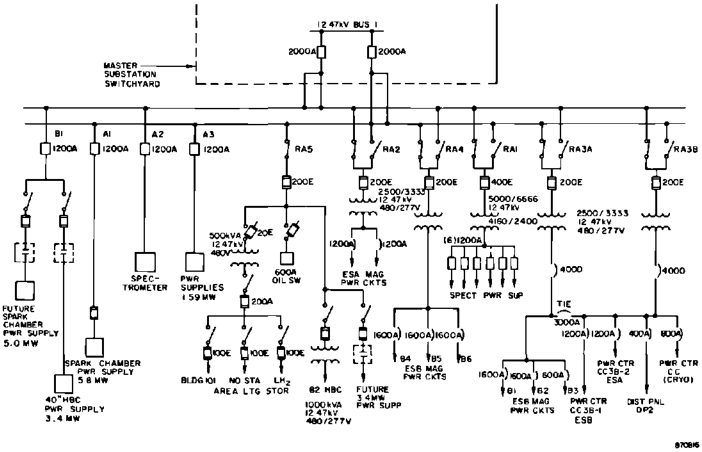


Table 25-4 Transformer capacity

Service	Unit rating (kVA)	Transformer installed capacity Self-cooled (kVA)	Transformer installed capacity Fan-cooled (kVA)
480 V	(4) 2500/3333	10,000	13,333
4160 V	(1) 5000/6667	5,000	6,667
		15,000	20,000

a 125-V dc control power battery bank, a motor control center, six 4160-V feeder circuit breakers, and four 12.47-kV feeder circuit breakers. The end station area electrical secondary distribution plan, Fig. 25-16, shows a single-line diagram of the major features.

The total transformer capacity is 15 MVA on a self-cooled basis and 20 MVA on a forced air-cooled basis (see Table 25-4.)

These transformers are ventilated, dry-type, and air insulated for 50-kV BIL. The materials and construction are class H, which permits operation at 150°C average winding rise above a 40°C ambient within the unit substation metal enclosure. Taps are provided in the high-voltage winding to permit compensation for 2½ and 5% supply voltage above and below 12.47 kV. These can be used also to decrease the output by 2½ and 5%, which decreases the 12.47-kV circuit current by 2½ and 5%. Fans are installed for air cooling to permit operation at a load higher than the self-cooled rating. The 12.47-kV–480-V transformers are manufactured to higher (10.3%) than normal (5.6%) impedance, thus limiting the short-circuit current below 30,000 A at the substation bus and 25,000 A at the load distribution magnet power centers in order to permit use of molded case K frame circuit breakers with 25,000-A interrupting capacity in power distribution panels and in power utilization devices.

The substation's primary switchgear is arranged in a lineup of six 15-kV class, indoor-type, metal-enclosed, load interrupter selector switch assemblies and four 15-kV class, rollout, indoor-type, metal-enclosed, magnetic air circuit breakers. The basic insulation level for this switchgear is 95-kV BIL. The load interrupter selector switches are rated for 600 A continuous and are capable of closing into a 40,000-A momentary current. The 15-kV class power fuses associated with each selector switch have a 500-MVA interrupting rating. The magnetic air circuit breakers are rated for 1200 A continuous and 500-MVA interrupting capacity which is 25,000 A in the 12.47-kV system.

The 480-V unit substations consist of ventilated dry-type transformers, electrically operated drawout-type air circuit breakers and related control circuits. Unit substation 3A-3B is arranged to form a double-ended substation with a common aisle between control faces and an interconnecting overhead bus duct. The double-ended substation has, not only feeder air circuit breakers, but also a 4000-A main circuit breaker for each of the two transformers and a 3000-A tie circuit breaker. The main and tie circuit breakers provide a means of interchangeably using one or the other of the two transformers to feed the loads. Selection is available for manual or automatic operation. However, the loads must be compatible as to fluctuations, sensitivity to rapid changes, rectifier commutation transient voltages, and undesirable response to harmonic voltages. The single-ended unit substations do not have a main breaker and are, therefore, limited to not over six large power feeders per bus. Phase overcurrent protection is provided by series tripping devices attached to each circuit breaker. These series tripping devices prove to be inadequate on the 4000- and 3000-A main and tie circuit breakers. A satisfactory system of monitoring main bus and bus tie currents is the extremely inverse-type station relay operated from the unit substations current transformers. Ground fault and transformer neutral residual currents are satisfactorily monitored by a separate current transformer mounted in the connection between the transformer secondary neutral and the unit substation's neutral bus which is grounded at the substation. The series tripping devices mounted in the drawout-type feeder circuit breakers are adequate for monitoring feeder line currents for overload and short circuit. However, the tripping time vs current characteristics of drawout circuit breakers are not compatible with the tripping time vs current characteristics of large molded case circuit breakers.

The 4160-V unit substation consists of a ventilated dry-type transformer, six electrically operated rollout magnetic air circuit breakers, and related control circuits. A main circuit breaker is not provided. Phase current and ground fault current protection is obtained through the use of station relays operating from the unit substation current transformers and transformer neutral current transformer. The rollout indoor magnetic air circuit breakers are rated for 1200-A continuous and 75-MVA interrupting capacity, which is 10,500 A in the 4160-V circuit.

All transformer primary 12.47-kV windings are delta and the secondary windings are grounded Y. Distribution-type lightning arrestors protect the 12.47-kV coils and limit the surge voltages to which the 12.47-kV coils may be subjected to a safe value within the 50-kV basic insulation level.

The two single-ended 480-V unit substations, the one 4160-V unit substation, and the four 12.47-kV feeder circuit breakers can be selected to trip by underfrequency relays for purposes of interruptible power contract load shedding. Undervoltage tripping is provided to protect rectifier loads against single phase operation, which is damaging to silicon-controlled rectifier units.

Safety features for personnel in the end stations are provided. The 480-V (except house and emergency power), 4160-V, and 12.47-kV power circuits from the research area substation are arranged to allow selective tripping from either end station A or end station B. Access to the research area substation 12.47-kV fuse cubicles, the 4160-V and 12.47-kV circuit breaker roll-in ways, the electrical power vaults, the electrical utility tunnels, and the 12.47-kV manhole junction boxes is controlled by a key interlock system.

The initial loads served in the end station area are summarized in Table 25-5.

End station A and end station B house power is supplied from the research area substation at 480 V, three-phase, four-wire, 60 cycles/sec. Distribution of power throughout each end station building is made from a building service

Table 25-5 End station area electrical loads

Facility	*Permanent demand loads 480 V (kVA)*	*Present research operations maximum substation loads*		
		480 V (kVA)	*4160 V (kVA)*	*12.47 kV (kVA)*
End station A building, end station area facilities, and yard house power	800	—	—	—
82-in. bubble chamber house power	300	—	—	—
Counting house power	100	100	—	—
End station B building and adjacent facilities house power	300	—	—	—
Cryogenics facility	300	—	—	—
	1800	100		
End station A				
20-GeV spectrometer magnets 8-GeV spectrometer magnets 1.6-Gev spectrometer magnets	—	1000	4000	3700
2-Meter spark chamber magnet	—	—	—	7000
		1000	4000	10700
Central beam				
82-in. hydrogen bubble chamber magnet	—	—	—	3000
Beam transport magnets	—	2600	—	—
		2600		3000
End station B				
40-in. hydrogen bubble chamber magnet	—	—	—	4000
54-in. spark chamber magnet	—	—	—	3300
Beam transport magnets	—	6700	—	—
		6700		7300
Total: 37,200 kVA	1800	10400	4000	21000

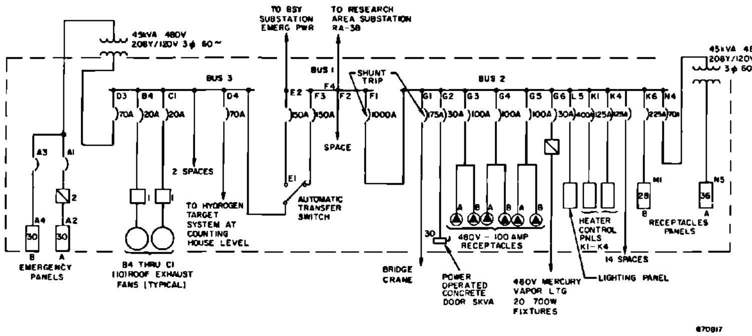


Figure 25-17 One-line diagram of end station A house power.

power center shown in Figs. 25-17 and 25-18. Power at 480 V, three-phase, is provided by this means for the high bay mercury vapor lighting, the 480-V receptacles, the bridge crane service, the motor-operated concrete doors, and the service to the roof ventilation fans. Several 45-kVA, 480-208Y/120-V transformers supply power for incandescent lighting and for the 120-V receptacles. The mercury vapor lighting is turned off as a warning that research operations are to begin. In addition, a major proportion of the incandescent lighting in the high bay and in the utility housings under the building are cycled between dim and bright as a final warning. The four 75-kW heaters in end station A are supplied from the building service power center.

End station A facilities, including the end station A Power Supply Building, the 2-meter spark chamber building, east yard buildings, and the beam dump at the east end of the A-beam line are supplied from the facilities power panel in utility vault A. This panel is supplied from the end station A building service power center.

Power for the end station area is distributed from the research area substation by cables run from the substation down a chase in the retaining wall

Figure 25-18 One-line diagram of end station B house power.

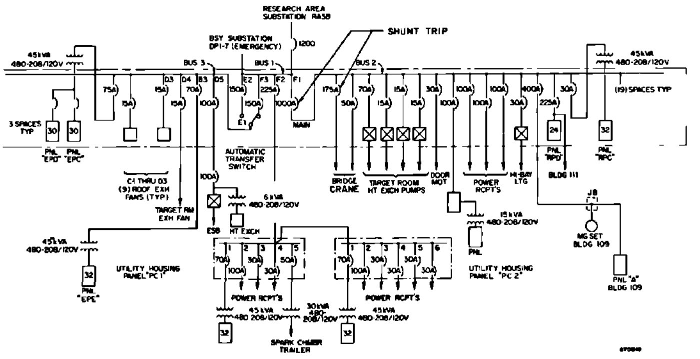


Table 25-6 Distribution capacity, end station area

	Installed cable and terminal bus capacity			
Facility	*480-V cables (kVA)*	*4160-V cables (kVA)*	*12.47-kV cables (kVA)*	*Total kVA*
End station A				
Building and end station area facilities and yard house power	830	—	—	—
Spectrometer magnets	2600	6667	14200	—
2-Meter spark chamber	—	—	7100	—
	3430	6667	21300	31,397
Central beam				
82-in. bubble chamber house power and magnet power	250	—	4000	—
Beam transport magnets	1330	—	—	—
	1580		4000	5,580
End station B				
Building and adjacent facilities house power	830	—	—	—
40-in. bubble chamber magnet and spark chamber magnet	—	—	7100	—
Beam transport magnets	6700	—	—	—
	7530		7100	14,630

to the electrical power cable vault adjacent to the wall footings. A 12.47-kV cable to the north staging area, H frame substation provides 300 kVA of transformation to 480 V. This serves the adjacent building facilities and lighting.

The installed distribution for the end stations is shown in Fig. 251-6 and Table 25-6. Electrical utility housings are located as per Fig. 25-15. These are the underground cableways connecting the electrical power vault with utility vaults A and B (see Fig. 25-19). These cableway housings are corrugated metal off-round culverts having a nominal cross-sectional dimension of 6 ft wide × 8 ft high. The arrangement of the hangers and oiled maple clamps permits forty triplexed or quadruplexed power cables or bundles of control cable. The housing-type cableway is used to minimize the end station yard area underlaid by the cableway as well as to minimize the trench width required. Yard area is at a premium because some research installations require deep borings and foundations that are not compatible with duct banks and housings. The 6-ft below-grade cover over duct banks or the crown of the housings is required by the surface mechanical loading specification

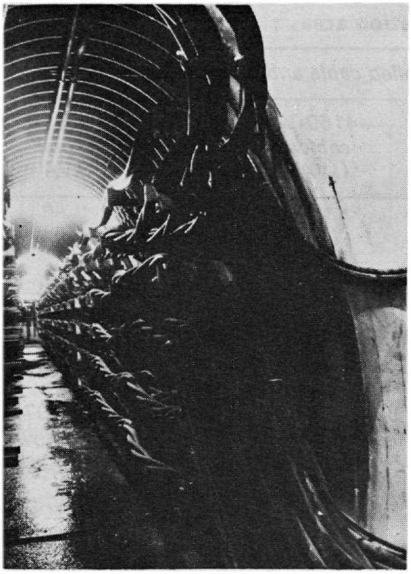


Figure 25-19 View from outgoing end of electrical utility housing serving utility vault.

for the concrete pad. The housing uses a 7-ft wide trench, 14 ft deep as compared with the less expensive equivalent duct bank which requires a more costly trench, 36 ft wide × $9\frac{1}{2}$ ft deep to accommodate four ten-duct banks.

The utility housing from the electrical power vault to vault A has 52% of available rack space filled with cables. These cables serve the end station A building, the 82-in. bubble chamber magnet, the 2-meter spark chamber magnet, and the area facilities and yard power. The spare rack space available and the thermal capacity of the housing permits an additional 6500 kVA of 480-V services.

The power and control cables installed in the utility tunnel to vault A are listed in Table 25-7.

The utility housing from the electrical power vault to vault B has 73% of available rack space filled with cables. These cables serve end station B, the 40-in. bubble chamber magnet, the spark chamber magnet, the end station B transport magnets, the central beam transport magnets, and the area facilities power. The spare rack space available and the thermal capacity of the housing permits an additional 4000 kVA of 480-V services.

The cables installed in the utility tunnel to vault B are listed in Table 25-8, However, the cable chase in the retaining wall below the research area substation does not have sufficient additional space to allow both 20% more cables in the housing to vault B and 40% more cables in the housing to vault A.

Table 25-7 Capacity of cables in utility tunnel to vault A

Quantity	*Service*	*Total installed cable capacity (kVA)*
1	125-V dc service	—
1	Controls, four-cable bundle	—
3	480-V services: three 750-MCM triplexed or quadruplexed, 90°C Hypalon-insulated, per service	3,430
6	4160-V services: one No. 4/0-triplexed 5-kV, concentric shielded, polyethylene-insulated, per service	6,667
3	12.47-kV services: one 350-MCM triplexed 15-kV, concentric shielded, polyethylene insulated, per service	21,300
1	12.47-kV service: one 350-MCM triplexed 15-kV, metal tape shielded, ethylene propylene insulated, per service	4,000
		35,397

Campus facilities

All conventional unit substations furnished for campus building power and lighting are 12.47 kV to 480Y/277 V. All unit substations are sized for present and planned loads plus 25% capacity for unforeseen load growth. The building power requirements are up to 50% higher than for industrial buildings of the same gross area. This is normal in scientific research buildings where power is often required at greater load density than in most manufacturing processes.

The cable and wire used for 480- and 120-V house power distribution are general, conventional, building wire and conduit systems. These systems

Table 25-8 Capacity of cables in utility tunnel to vault B

Quantity	*Service*	*Total installed cable capacity (kVA)*
1	125-V dc service	—
1	Control, four-cable bundle	—
7	480-V services: three 750-MCM copper triplexed or quadruplexed, 90°C Hypalon-insulated, per service	7,530
1	480-V service: twelve 1000-MCM aluminum, 75°C USE-insulated, per service	1,330
1	12.47-kV service: one 350-MCM triplexed 15-kV, concentric-shielded, polyethylene-insulated, per service	7,100
		15,960

are used in areas such as the Test Laboratory Building, Electronics Building, Heavy Assembly Building, and the Central Laboratory Building. Four hundred and eighty-volt plug-in bus duct at 480 V and 120-V busways are installed for flexibility and field additions.

The electrical control for mechanical equipment has undervoltage protection. In case there is a loss of voltage, the electrical control device drops out and has to be manually reset to allow the mechanical equipment to operate again. This is true for most of the mechanical equipment which does not have automatic control.

Lighting intensity levels were investigated during the conventional facilities design for special areas, office, and laboratory use. After detailed study, the following was established as a minimum standard for the project:

Office areas: 50 ft-c
Laboratories: 50 ft-c
Other areas: 25 ft-c

There are two 12.47-kV air circuit breakers and their associated feeder cables, 350-MCM, 15-kV class, PILC, which originate from the master substations for Campus Building electrical facilities:

C.8 (12.47-kV feeder)
Fabrication Building (1000–1333 kVA), Heavy Assembly Building 5B-W (750–1000 kVA), Test Laboratory B-E (2000–2667 kVA), and Central Laboratory 4B-E (750–1000 kVA)

C.7 (12.47-kV feeder)
Heavy Assembly Building 5A-E (750–1000 kVA), Test Laboratory 1A-W (2000–2667 kVA), Central Laboratory A-W (750–1000 kVA), Construction Office Building (250 kVA), and crafts shop (500 kVA)

25-4 Fire alarm system (CBJ)

The criteria established for the fire alarm system calls for an automatic detection system to protect personnel and to minimize the possibility of loss of equipment. The fire detection system is provided with detection devices at specific points. The master control located in the Fire Station Building has four coded fire-monitoring circuits. The four circuits are as follows: (1) the klystron gallery loop, (2) campus area loop, (3) research area loop, and (4) spare.

There are twenty-nine street-type master fire alarm boxes, strategically located throughout the site. Each one of the boxes is connected to one of three fire-monitoring supervised circuits. Each fire alarm box, when activated by a fire alarm, transmits a pulse-coded signal to the Fire Station master monitoring console. The signals are audibly indicated, recorded, and automatically retransmitted to the Stanford University Fire Department via leased telephone wires. The coded signal directs Fire Department personnel to the particular box originating the alarm and the annunciator used in conjunction with the master box gives further instruction as to the exact location.

Associated with each master fire alarm box there is a fire alarm subsystem which covers a specific area or building, which, in turn, is normally subdivided into several fire zones. The subsystems are provided with local audible alarms and ventilation fan interlocks when needed.

Each zone is equipped with either heat detector, smoke detector, sprinkler flow switch, manual switch, or combination thereof.

An alarm received at the Fire Station identifies the master fire box, and the fire box, in turn, annunciates the zone in trouble.

All fire alarm systems are equipped with emergency standby power. In addition, all alarm circuits are continually monitored for circuit faults.

In conjunction with the automatic fire detection system, a water sprinkler system was installed in all buildings except in areas where water could cause severe damage to electronic equipment In these areas, portable fire-extinguishing equipment suitable for electronic equipment is provided. Automatic water flow switches are provided to actuate the fire alarm system.

25-5 Grounding (AAT)

The grounding system installed in the project is a unified system combining both high-frequency short rise time pulse and 60-cycle power requirements. Grounding facilities are provided for (1) ac power system equipment grounding, (2) instrument and control requirements, and (3) electrolysis and corrosion damage control. Certain features of each of these three facilities are in conflict as to desirable criteria. However, the system provided herein includes compromises to accomplish the following overall purposes listed in order of importance: (1) personnel safety; (2) reduction of system deterioration resulting from electrolysis; (3) reduction of interference in the instrumentation and control system.

The klystron galley grounding design is intended to furnish a 60-cycle impedance of less than 0.03-ohm resistance and 0.03-ohm reactance and also to present a high-frequency characteristic impedance not greater than 5 ohms. Connections at the klystron tube flange and modulator ground leads are designed to have an impedance not greater than 0.2 ohm at 200 kHz. Normally, the dc current is less than 1 mA.

The grounding scheme is composed of (1) the major ground bus which forms the backbone of the system and runs the full length of the klystron gallery; (2) lateral runs of the same size bus that connect the thirty instrumentation and control alcoves and the accelerator control building; and (3) ac power system equipment grounding (control center, vacuum pump stations, etc.).

The following is a physical description of the above items.

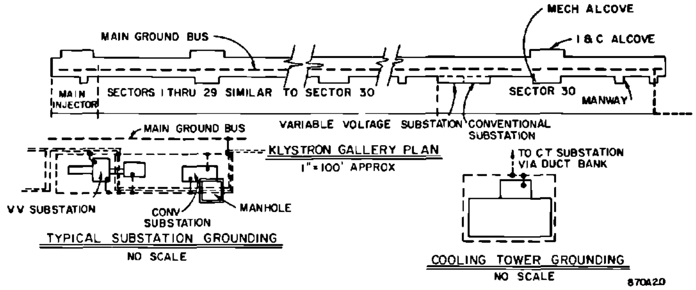
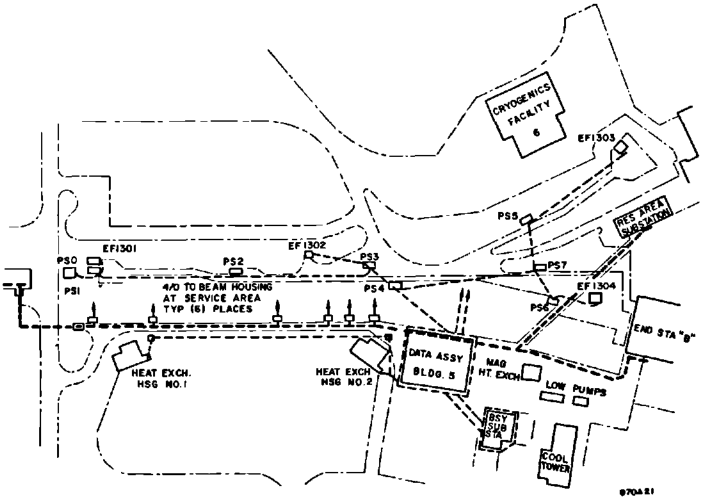


Figure 25-20 Grounding plan of accelerator.

1. The *major ground bus* consists of a copper bus $\frac{3}{16} \times 14$ in. in cross section running the full length of the klystron gallery and extending into the main injector station. Joints between lengths of the bus are thermal fusion butt-welds made by the Cadweld process. Expansion joints of flexible copper strap are made between sectors at the building steel expansion joint locations. The bus is secured to the building steel only at the midpoint of each sector, which allows expansion in both directions as required. Each roof beam is connected to the bus by a flexible copper strip. The main ground bus of each sector is connected to the sector substation grounding system with insulated cable. All connections to the main bus are bolted using silicon bronze lugs and hardware. The same ground bus extends all the way to the BSY and near end station areas as shown on Figs. 25-20 through 25-22.

2. The *lateral ground bus runs* are made from the major ground bus to each instrumentation and control alcove, and each ac power substation

Figure 25-21 Grounding plan of beam switchyard.



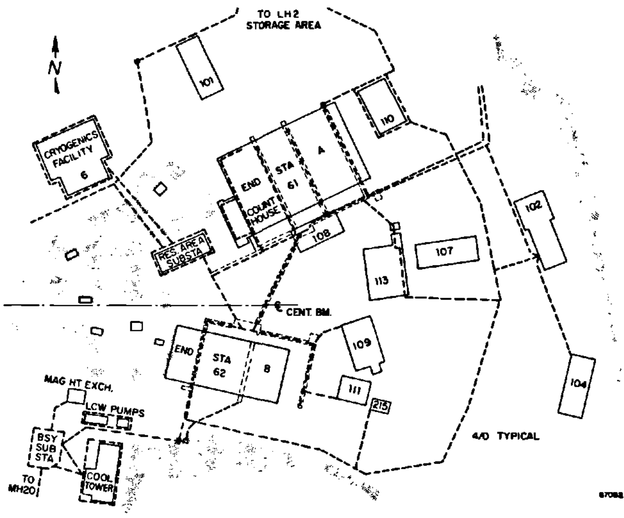


Figure 25-22 Grounding plan of end station.

480-V transformer neutral. They also are made to the monitoring and instrumentation ac power supply transformer shields, the accelerator control building, the receiving substation ground mat, the modulator dc facility ground mat, and the injector. In a depression in the floor, $\frac{3}{16} \times 14$ in. copper sheets are installed.

3. The *ac and dc power system equipment ground* is connected to the 13-kV distribution system cable sheath. The major element of the 12-kV power system ground is No. 4/0 copper cable, bare where the run is in concrete, TW-insulated where the run is in soil. Building columns are connected to the main ground bus by No. 1/0 TW cable run below grade.

Typical grounding and bonding criteria for the project substation and various buildings are as follows:

SUBSTATIONS. Each substation is furnished with a firm peripheral ground loop of not less than No. 4/0 stranded bare copper wire, located not less than 18 in. below grade. Ground rods in wells are set periodically in this loop and connected to the loop by removable pressure clamps. All transformer and switchgear equipment is connected to the loop. The loop is connected to the ground bus by No. 4/0 green "THW" stranded copper cable. The substation neutral is white "THW," insulated, run in wood mold where exposed. A pressure connector fastens the neutral to the ground bus. Each service run from a substation into the service area is routed at the point the service enters the building through not less than 20 ft of rigid, galvanized steel conduit, coated to resist corrosion. At the point where each steel conduit enters the building, the conduit is bonded once only to the ground bus.

BUILDING. The gallery structural steel frame is grounded to the floor slab reinforcement at each column. The floor slab reinforcement material is electrowelded mesh. Grounding connection points on columns are exposed. At each penetration pipe the klystron gallery floor reinforcements are connected to the pipe by a single exposed pigtail. Connections between steel and copper are mastic coated (or epoxy painted) except at the klystron gallery ground bus. Doors are metal or metal encased, not bonded to frame or columns. Each metallic utility service is bonded to the nearest building column at the point of entry.

120/208-V TRANSFORMER NEUTRALS. Each transformer neutral is bolted to the case and the shield at the transformer.

EQUIPMENT GROUNDING. A bare copper bus is run from each transformer housing to the grounding bus. The bus is bolted to the main bus and to transformer neutral, housing, and shielding. A green insulated wire equal in size to the service conductors, but no larger than No. 4/0, accompanies the service conductors in conduit from the transformer to the distribution panel and is connected to the "equipment ground bus" provided in the panel. The equipment ground bus in each panel is a $\frac{1}{4}$-in. thick × 2-in. wide copper bus grounded to the panel structure and equipped with mechanical connectors of the proper number to accommodate all ground wires terminating in the panel. A green insulated wire is carried in the conduit with service to each item and screwed or bolted to the item served. Wires are sized as follows:

No. 4/0.	To each item of electrical equipment with a capacity over 600 A
No. 2.	To each item of electrical equipment with a capacity between 200 and 600 A
No. 6.	To each item of electrical equipment with a capacity between 50 and 200 A
No. 12.	To all other items of electrical equipment in the building.

GENERAL GROUNDING AND BONDING. Reinforcing steel bars where required to be bonded are double-welded. Buried connections are thermal-welded.

All connections to ground rods are made with silicon bronze pressure connectors. Equipment connections to the ground bus are made with silicon bronze connectors in such a way as to be removable.

The overall project grounding system is shown in Figs. 25-20 through 25-22.

25-6 Emergency power (CBJ)

Early concepts of reliability called for parallel power services, distribution and transformation, and, in addition, numerous local standby emergency generator plants. The emergency generators were to be located at each substation along the klystron gallery. After careful analysis, the multiple standby generator concept was reduced to providing facilities for connecting portable generators.

It is difficult to predict the degree of reliability of each of the various areas and components of the power system, such as the 220-kV transmission line, the master substation, the distribution system, the unit substations, and the low-voltage distribution to the utilization devices. Rough cost estimates were made for doubling the transmission, distribution, and transformation system. Judgments on what these costs meant in improved reliability were made. The final choice was to use two Diesel-driven generators to serve the critical loads as outlined below. These generators start automatically upon failure of conventional power. Loads are transferred as soon as the generator voltage is at the correct value, usually about 6 sec from normal power failure. The generators carry their loads until 2 min after restoration of normal power.

One 75-kW generator located in the Central Utility Building supplies selected circuits in the Test Laboratory, Administration and Engineering Building, Control Utility Building, and Permanent Fire House. Minimum lighting is covered in all these buildings as well as telephone, radio, and fire alarm circuits. Vacuum pumps and control circuits associated with klystron processing stations in the Test Laboratory are also protected from power failure. The Diesel prime mover is supplied with fuel from a 10,000-gal tank which also serves two building heating boilers in case of natural gas failure. This tank is kept full, so that it has adequate reserve capacity for 8 hours of operation in case of simultaneous failure of gas and electricity.

The other Diesel generator is rated for continuous duty at 125-kW, 156.5-kVA, 0.8 power factor and is located in the BSY substation building and supplies selected circuits in the BSY, DAB, end stations A and B. Ventilation of end stations A and B and the target room are on emergency power to take care of the escape of hydrogen due to lack of refrigeration during a power outage. Fire alarm circuits and a few lights in end stations A and B and the DAB are protected. A 75-hp air compressor in the BSY substation can be switched to the generator circuit for periodic maintenance loading and checking of the Diesel engine. The Diesel prime mover is supplied with fuel from a 500-gal tank which is kept filled to at least 250 gal, enough for 5 days of operation.

A nonautomatic-start Diesel-driven generator of 50-kW rating supplied power through a manual transfer switch to the Temporary Fire House.

Portable generators of 50-, 25- and 10-kW ratings are available for emergency use in case of equipment failure or of scheduled maintenance outages.

In the klystron gallery, a small amount of emergency power can be obtained in any sector from an adjacent sector which is served from a different substation. Manual transfer switches for this purpose are adequate as the vacuum pumps served by these circuits can be off for an hour without serious deterioration of vacuum.

25-7 Operational experience (CBJ, AAT)

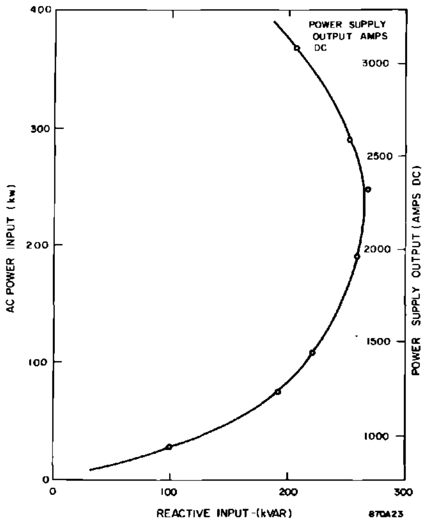
The master substation was designed to carry part of the loads on the 12-kV bus supplied from 220-kV and the remaining loads on the 12-kV bus supplied from 60 kV. Then, in the event of failure of either source, the loads affected are transferred automatically to the other source. This system worked many times when acceptance tests were made and a few times when sources were actually in trouble. However, on one occasion, the automatic transfer was not completed and the loads were energized only after manual switching. Because of this and because the 60-kV line is subject to more voltage dips due to mechanical damage to poles, all loads are presently fed from the 220-kV source.

The 12-kV manually operated load-break-disconnect switches turned out to be of a mechanically poor design. About half of them failed at least once in twenty operations. After two redesigns and the replacement of several operating parts, the sixty switches now work fairly well.

Some of the 12-kV switching (which disclosed the above design troubles) was required to allow work on 12-kV potheads which had been made up incorrectly in spite of detailed instructions. About sixty potheads had to have stress-cone construction corrected and then be repotted.

The 12- and 4-kV circuit breakers in the research area substation were not designed for frequent operation. The loads on their circuits need

Figure 25-23 Typical operating characteristics, 360-kW current regulated power supply, silicon-controlled rectifier, 3000 A, 120 V dc.

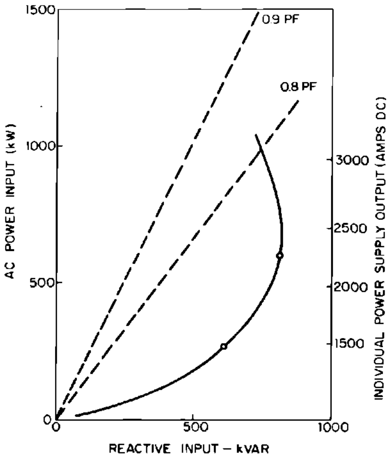


switching more frequently than had been anticipated, sometimes as often as 40 times per week. Electrically operated, vacuum-enclosed, load-break switches are being added to these circuits.

Typical power load characteristics are illustrated in Figs. 25-23 and 25-24 for operation of the end station B beam-transport system power supplies. Nine 360-kW current regulated power supplies are served from one 480-V, 2500/3333-kVA unit substation by feeders B4, B5, and B6 (see Fig. 25-16). These power supplies are silicon controlled solid-state rectifiers supplying the bending and quadrupole magnets in the beam transport line. Current regulation is accomplished by controlling the phase of triggering of the rectifier. Figure 25-23 demonstrates the operation of one of the power supplies which draws not only power but also a wattless reactive load from the ac power system. The reactive load and, hence, the power factor, $kW/(kW^2 + kVAR^2)^{1/2}$, varies as the rectifier ouput is adjusted to different output dc currents. The power demand is proportional to the power load of the magnet plus the small losses in the rectifier. A group of three power supplies served from one of the feeders (B4) shows the same semicircular characteristic (Fig. 25-24). The typical semicircular characteristic results from the process of phase-back control. The 3000-kW load level is the result of operating all the beam transport magnets for 16-GeV particles.

The voltage drop in the 480-V circuits from the research area substation has been too high in some cases. Better operational conditions would have been obtained had an additional substation been placed closer to the loads.

Figure 25-24 Typical group operating characteristics on feeder, three 360-kW current regulated power supplies, silicon-controlled rectifiers, each 3000 A, 120 V dc.



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This would have cost more and servicing would have been inconvenient at times due to high radioactivity in this area.

The 480-V circuits are protected from ground fault only at the larger breakers which have a relatively sluggish breaker mechanism. Molded case breakers have no ground current protection. The result is that a small ground fault can trip a larger breaker which needlessly disconnects some loads. Future additions and changes to the wiring will use overcurrent relays for ground current protection in all locations.

Most of the voltage-adjusting motor contactors in the variable-voltage substations have operated as often as one million times in a year. This excessive operation has been reduced by adding a small time delay to the circuit.

Power contracts, energy consumption, and cost (AAT)

There are two power contracts governing the supply of ac power from either 220- or 60-kV lines to the SLAC project.

1. Contract No. AT(04-3)-526, between the U.S. Atomic Energy Commission and the U.S. Bureau of Reclamation, June 16, 1965, calls for the supply of firm power starting at 6 MW for temporary power connections. The firm power supplied under this contract was later increased to 12 MW, then to 18 MW, and, most recently, to 25 MW. The pertinent data, extracted from Schedule R2-F2 of the above contract, are as follows:

Monthly rate: The demand charge is $0.75 per kilowatt of billing demand. The energy charge is 4 mils/kW-hour for the first 130 kW-hours/kW of billing demand; 3 mils/kW-hour for the next 130 kW-hours/kW of billing demand; and 2 mils/kW-hour for all over 260 kW-hours/kW of billing demand.

Minimum bill: $1.00 per month per kilowatt of contract rate of delivery.

Billing demand: The billing demand will be the highest 30-min integrated demand measured during the month.

Adjustments: If delivery is made at transmission voltage so that the Bureau of Reclamation is relieved of substation costs, 5% discount will be allowed on the demand and energy charges. If delivery is made at transmission voltage but metered at the low-voltage side of the receiving substation, the meter readings will be increased 2% to compensate for transformer losses. There are no adjustments for power factor; SLAC will normally be required to maintain a power factor at the point of delivery of not less than 90% lagging.

2. Contract AT(04-3)-466, which consists of firm or interruptible power procured from PG & E are from the same line as mentioned above. The rates and charges on this contract, as outlined in PG & E Schedule A-13, are as follows:

Firm service: Firm service energy charge is shown in Table 25-9. The minimum charge per month is $150.00 but is not to be less than 90 cents/kW of billing demand.

Table 25-9 Firm service energy charge

Energy	*Cents*
First 6000 kW-hour per meter per month	2.64 per kW-hour
For all excess over 6000 kW-hour per month	
First 50 kW-hour kW of billing demand	2.22 per kW-hour
Next 150 kW-hour per kW of billing demand:	
First 100,000 kW-hour	1.28 per kW-hour
Balance	0.91 per kW-hour
Next 100 kW-hour per kW of billing demand	0.91 per kW-hour
All excess	0.65 per kW-hour

Interruptible service: Interruptible on-peak demand is billed at $0.6832/kW per month; interruptible off-peak demand is billed at $0.1577/kW per month; the sum of these two shall not be less than a minimum monthly demand charge of $7000 per month. Interruptible energy is billed at $0.0062/kW-hour added to the demand charge. The total charge, except the minimum monthly demand charge for any month as computed on the above rates, shall be decreased or increased, respectively, by 0.1 % for each 1 % that the average power factor is greater or less than 85 %, such average power factor to be computed (to the nearest whole percent) from the ratio of lagging kilovolt-ampere hours to kilowatt-hours consumed in the month, provided, however, that no power factor correction charge will be made for any month when the interruptible on-peak demand was less than 10 % of the highest such demand in the preceding 11 months.

It is realized that operating costs can be reduced if research experimental loads can be scheduled to minimize short, infrequent, high-power demands each month. Furthermore, by proper negotiation of the firm power and interruptible power allocation of the above power contracts, the power costs can be further reduced. Meters to indicate the project's total megawatt load have been placed in three locations so that operators who control blocks of power can view the instantaneous power consumption and stagger the demands whenever possible.

Typical loads based on various operating conditions (July 1967) are shown in Table 25-10.

Power costs, load factors, and mils per kilowatt-hour for the fiscal years of 1965, 1966, and 1967 are shown in Table 25-11.

Power factor correction

Because of the use of large solid-state rectifiers in the end station power supplies as outlined above, the present average monthly power factor is approximately 86 %. It is expected that even lower power factors will result due to added magnet power supply loads and longer operating time of power supply equipment as the SLAC research program is expanded. SLAC is

Table 25-10 Typical loads based on various operating conditions (July 1967)

Facility	*Minimum (MW)*	*Average (MW)*	*Maximum (MW)*
Campus load including conventional substation for klystron gallery	8	9	10
Variable-voltage substations for accelerator operation	2	15	22
End station A	1	7	13
End station B	1	3	8
	12	34	53

obligated to maintain 0.9 power factor or better at the point of delivery as stipulated in Contract AT(04-3)-526, as noted above. The present load characteristics require power factor correction in order to maintain 0.9 power factor or better. Power factor correction devices supplying 3726 kVAR are currently needed to meet the contractual requirements under the present conditions of loading. This amount of correction provides a small margin for the immediate future.

The planned installation of power factor correction apparatus must have a harmonic current control feature. The harmonic current control is essential in operating power factor correction apparatus on feeders serving the silicon-controlled rectifier power supplies. This control prevents excessive heating in existing electrical equipment and unacceptable distortion in the project's line voltage. It also reduces line harmonics to levels acceptable under the power service contract.

SLAC is in the process of procuring a power factor correction device to improve average power factor to 0.9 or better.[4] Negotiations are under way to procure a large, government-surplus, synchronous condenser which will be connected to a 12-kV bus at the master substation.

Acknowledgments

In addition to the authors noted under the chapter heading many other people made significant contributions to the design of electrical systems. T. Turner investigated the possibility of dc distribution to modulators. K. Wilson promulgated a number of project electrical standards and made a number of studies of project power costs and system load growth forecasts. W. K. H. Panofsky, R. B. Neal, G. Loew, J. V. Lebacqz, C. Kruse, K. Mallory, and C. Olson were invaluable in advising on design details and overall system criteria. H. Halperin consulted on transmission and distribution problems. L. Stone consulted on RF interference as did members of the staff

Table 25-11 Power usage and cost experience

Month	Billing demand (kW)	Average P.F.	Billing energy (kW-hour)	Total charge	Load factor	Average cost (mils/kW-hour)
			Fiscal year 1965			
Jul 64	2,654	—[a]	1,258,584	$ 5,267.76	0.644	4.20
Aug 64	2,656	—	1,267,783	5,285.24	0.658	4.15
Sep 64	2,962	—	1,444,057	5,951.55	0.66	4.12
Oct 64	3,635	0.860	1,696,464	7,159.99	0.63	4.21
Nov 64	4,125	0.873	1,837,860	7,959.31	0.61	4.30
Dec 64	4,015	0.875	2,052,526	8,248.04	0.687	4.10
Jan 65	4,125	0.861	2,176,737	8,603.17	0.708	3.94
Feb 65	4,663	0.860	2,198,194	9,226.60	0.70	4.19
Mar 65	5,753	0.877	2,788,969	11,529.54	0.65	4.14
Apr 65	5,985	0.885	3,103,636	12,378.66	0.72	3.99
May 65[b]	6,524	0.870	3,163,563	13,076.27	0.653	4.13
Jun 65	6,348	0.854	2,779,200	12,399.63	0.59	4.45
			25,767,573	$107,085.76		4.16
			Fiscal year 1966			
Jul 65	5.104	0.853	2,706,919	$ 11,400.00	0.69	4.21
Aug 65	5,569	0.866	2,913,138	11,566.19	0.703	3.98
Sep 65	7,430	0.865	3,350,474	14,412.59	0.626	4.30
Oct 65	8,482	0.849	3,893,140	16,582.97	0.617	4.26
Nov 65	8,433	0.875	3,962,186	16,615.44	0.656	4.20
Dec 65	9,486	0.867	4,896,955	19,577.55	0.694	4.00
Jan 66	10,086	—	4,422,758	19,326.38	0.59	4.37
Feb 66[c]	10,404	—	4,835,718	20,455.40	0.69	4.24
Mar 66	12,240	0.852	5,650,841	23,992.52	0.531	4.25
Apr 66	13,709	—	5,802,813	25,872.20	0.588	4.46
May 66	18,482	—	7,776,011	34,790.42	0.566	4.48
Jun 66	18,360	—	7,415,298	33,972.95	0.564	4.57
			57,626,251	$248,564.61		4.31
			Fiscal year 1967			
Jul 66	17,258	—	7,579,069	$ 33,090.65	0.614	4.38
Aug 66	15,178	—	6,885,122	29,519.50	0.610	4.28
Sep 66	20,318	—	6,870,374	35,058.11	0.470	5.11
Oct 66	24,480	—	7,139,408	40,076.72	0.406	5.60
Nov 66	25,826	0.85	8,592,546	45,731.46	0.460	5.34
Dec 66[d]	29,131	0.85	9,343,955	52,142.26	0.432	5.65
Jan 67	28,519	0.85	9,887,717	53,111.37	0.466	5.30
Feb 67	26,561	0.86	8,346,823	43,160.05	0.435	5.15[e]
Mar 67	30,233	0.86	12,885,599	53,537.01	0.575	4.15[e]
Apr 67	30,845	0.87	13,358,685	56,085.74	0.603	4.20[e]
May 67	33,660	0.87	15,039,288	62,627.55	0.600	4.18[e]
Jun 67	33,415	0.85	14,237,262	61,314.34	0.592	4.30[e]
			120,373,398	$565,454.76		4.70

[a] Data not available.

[b] Firm power delivery changes from 6 to 12 MW.

[c] Firm power delivery changes from 12 to 18 MW.

[d] Firm power delivery changes from 18 to 25 MW.

[e] Including $11,685.00 credit to SLAC from PG & E on 220-kV transmission lines.

of the Stanford Radio Sciences Laboratory. U. Lamm consulted on system power factor correction equipment design. M. Grushkin was responsible for overall project communications and developed audio–visual systems for the auditorium. V. Smith and J. Kuypers consulted on physical requirements for the instrumentation and control cable plant and racks for supporting electronic equipment. E. Mortenson, C. Hale, R. Ardnt, and W. Farley were principal contributors to the preparation of drawings and specifications for the cable plant and racks. J. Smith prepared a number of early construction cost studies. E. Keyser and D. Pike expedited the electrical installation work. J. Fish and R. Laughead were responsible for preparation of working drawings for the electrical systems. K. Johnson participated in the design of the test stands power system and electrical distribution systems for the beam switchyard and end stations. R. Robbers was invaluable in working out field construction problems. W. Lusebrink and M. Buenrostro were very helpful in putting systems into operation and developing maintenance programs. Chief J. Marston of the Stanford Fire Department consulted on development of fire alarm system criteria. R. Mizrahi prepared a report on ac distribution to modulators and then collaborated with C. Olson *et al.* on the design of the high-voltage rectifiers for the modulators. J. Casati was very helpful in the design of the variable-voltage substation control equipment and other electrical systems for the accelerator.

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26

SHIELDING AND RADIATION

H. DeStaebler, T. M. Jenkins, Coeditor,
and W. R. Nelson, Coeditor

The purpose of this chapter is to present a simplified logic useful in understanding the shielding around a high-energy electron accelerator. This should be useful in cases where a shield is to be designed for radiation worker tolerance and in cases where a shield already exists and some knowledge of the radiation penetrating that shield is required.

Certain basic assumptions are made which should be discussed here. First, the energy spectrum of radiation penetrating a shield is assumed to be known, or to be approximated in such a way that a flux-to-dose conversion may be made. Second, the problem of distant boundaries is assumed to be secondary to that of the radiation worker in close proximity to the shield, so that to a first-order approximation, skyshine, etc., may be ignored.

Shielding calculations are done in distinct steps:

1. First, one must determine the radiation tolerances. At SLAC this value is 0.75 mrem/hour (steady occupancy). To be conservative, one should design shielding to produce about one-tenth of the steady occupancy value.
2. The amount of average electron beam power stopped within the shield must be estimated.
3. One must derive some information on the development of the electromagnetic cascade.
4. One must determine the production of penetrating particles by the cascade.
5. Finally, the attenuation of these penetrating particles in the shield has to be calculated.

This chapter is concerned with items (3), (4), and (5) above. First, the electromagnetic cascade and the production of penetrating particles by that