Chapter 6
Generator-Voltage System

6-1. General

The generator-voltage system described in this chapter includes the leads and associated equipment between the generator terminals and the low-voltage terminals of the GSU transformers, and between the neutral leads of the generator and the power plant grounding system. The equipment generally associated with the generator-voltage system includes switchgear; instrument transformers for metering, relaying, and generator excitation systems; neutral grounding equipment; and surge protection equipment. The equipment is classified as medium-voltage equipment.

6-2. Generator Leads

a. General. The term “generator leads” applies to the circuits between the generator terminals and the low-voltage terminals of the GSU transformers. The equipment selected depends upon the distance between the generator and transformer, the capacity of the generator, the type of generator breakers employed, and the economics of the installation. There are two general classes of generator leads: those consisting of metal-enclosed buses and those consisting of medium-voltage cables. The two classes, their advantages, disadvantages, and selection criteria are discussed in the following subparagraphs.

b. Metal-enclosed buses. There are three categories of metal-enclosed bus: nonsegregated-phase, segregated-phase, and isolated-phase. Each type has specific applications dependent mainly on current rating and type of circuit breaker employed with the bus.

(1) Nonsegregated-phase buses. All phase conductors are enclosed in a common metal enclosure without barriers, with phase conductors insulated with molded material and supported on molded material or porcelain insulators. This bus arrangement is normally used with metal-clad switchgear and is available in ratings up to 4,000 A (6,000 A in 15-*kV* applications) in medium-voltage switchgear applications.

(2) Segregated-phase buses. All phase conductors are enclosed in a common enclosure, but are segregated by metal barriers between phases. Conductor supports usually are of porcelain. This bus arrangement is available in the same voltage and current ratings as nonsegregated-phase bus, but finds application where space limitations prevent the use of isolated-phase bus or where higher momentary current ratings than those provided by the nonsegregated phase are required.

(3) Isolated-phase buses. Each phase conductor is enclosed by an individual metal housing, which is separated from adjacent conductor housings by an air space. Conductor supports are usually of porcelain. Bus systems are available in both continuous and noncontinuous housing design. Continuous designs provide an electrically continuous housing, thereby controlling external magnetic flux. Noncontinuous designs provide external magnetic flux control by insulating adjacent sections, providing grounding at one point only for each section of the bus, and by providing shorting bands on external supporting steel structures. Noncontinuous designs can be considered if installation of the bus will be at a location where competent field welders are not available. However, continuous housing bus is recommended because of the difficulty in maintaining insulation integrity of the noncontinuous housing design during its service life. Isolated-phase bus is available in ratings through 24,000 A and is associated with installations using station cubicle switchgear (see discussion in paragraph 6-7*b*).

c. Metal-enclosed bus application criteria.

(1) For most main unit applications, the metal-enclosed form of generator leads is usually preferred, with preference for the isolated-phase type for ratings above 3,000 A. Enclosed buses that pass through walls or floors should be arranged so as to permit the removal of housings to inspect or replace insulators.

(2) On isolated-phase bus runs (termed “delta bus”) from the generators to a bank of single-phase GSU transformers, layouts should be arranged to use the most economical combination of bus ratings and lengths of single-phase bus runs. The runs (“risers”) to the single-phase transformers should be sized to carry the current corresponding to the maximum *kVA* rating of the transformer.

(3) Metal-enclosed bus connections to the GSU transformer that must be supported at the point of connection to the transformer should have accommodations permitting the bus to be easily disconnected should the transformer be removed from service. The bus design should incorporate weather-tight closures at the point of disconnection to prevent moisture from entering the interior of the bus housing.

(4) On all enclosed bus runs, requirements for enclosing the connections between the bus and the low-voltage bushings of the GSU transformer should be coordinated and responsibilities for scopes of supply clearly defined between transformer supplier and bus supplier. Details of the proposed design of the connector between the GSU transformer bushing terminals and the bus terminal should be evaluated to ensure probability of reliable service life of the connection system.

d. Insulated cables.

(1) Cables may be appropriate for some small generators or in installations where the GSU transformer is located in the plant's switchyard. In the latter situation, economic and technical evaluations should be made to determine the most practical and cost-effective method to make the interconnection. Cables, if used, should have copper conductors. Acceptable cable types include:

(a) Single conductor, ethylene-propylene-rubber (EPR) insulated, with non-PVC jacket.

(b) Multi-conductor, ethylene-propylene-rubber (EPR) insulated cables, with aluminum or steel sheath, and non-PVC jacket, in multiple if necessary to obtain capacity.

(c) Oil-pipe cable systems.

(2) Oil-filled cable terminations with cables terminated with a conductor lug and a stress cone should be used for terminating oil-pipe cable systems. Cold shrink termination kits should be used for terminating single and multi-conductor EPR cables. Termination devices and kits should meet the requirements of IEEE 48 for Class I terminations.

(3) When cables of any type are run in a tunnel, the effect of cable losses should be investigated to determine the safe current-carrying capacity of the cable and the extent of tunnel ventilation required to dissipate the heat generated by these losses. Locations where hot spots may occur, such as risers from the tunnel to equipment or conduit exposed to the sun, should be given full consideration.

6-3. Neutral Grounding Equipment

Equipment between the generator neutral and ground should, insofar as practicable, be procured along with the generator main leads and switchgear. The conductor may be either metal-enclosed bus or insulated cable in non-magnetic conduit. Generator characteristics and system requirements determine whether the machine is to be solidly grounded through a circuit breaker (usually not possible), through a circuit breaker and reactor (or resistor), or through a disconnecting switch and a distribution type of transformer (See Chapter 3.) Solidly grounded systems do not find wide application because resulting fault currents initiated by a stator to ground fault are much higher than currents produced by alternative neutral grounding systems. Higher ground fault currents lead to higher probability of damage to the stator laminations of the connected generator. If a circuit breaker is used in the grounding scheme, it can be either a single-pole or a standard 3-pole air circuit breaker with poles paralleled to form a single-pole unit. Suitable metal enclosures should be provided for the reactors, resistors, or grounding transformers used in the grounding system.

6-4. Instrument Transformers

a. General. The instrument transformers required for the unit control and protective relaying are included in procurements for metal-clad switchgear breakers that are to be employed for generator switching. The instrument transformers are mounted in the switchgear line-up with potential transformers mounted in draw-out compartments for maintenance and service. Current transformers for the GSU transformer zone differential relay are also mounted in the metal-clad switchgear cubicles. In isolated-phase bus installations, the instrument transformers are included in procurement for the isolated-phase bus. The current transformers, including those for generator differential and transformer differential protection, are mounted "in-line" in the bus with terminations in external terminal compartments. Required potential transformers are mounted in dedicated compartments tapped off the main bus leads. The dedicated compartments also contain the generator surge protection equipment (see Chapter 3, "Generators"). Specified accuracy classes for instrument transformers for either type of procurement should be coordinated with the requirements of the control, protective relaying, and metering systems. Instrument transformers for the generator excitation system should be included in the appropriate procurement.

b. Current transformers. Current transformers of the multiple secondary type are usually required and are mounted in the isolated-phase bus or in the metal-clad switchgear to obtain the necessary secondary circuits within a reasonable space. Current transformers in the neutral end of the generator windings are usually mounted in the generator air housing. Accessibility for short-circuiting the secondary circuits should be considered in the equipment layout. The current transformers should be designed to withstand the momentary currents and short-circuit stresses for which the bus or switchgear is rated.

c. Potential transformers. The potential transformers for metering and for excitation system service are housed in separate compartments of the metal-clad switchgear. If station cubicle breakers or isolated-phase bus are involved, a special cubicle for potential transformers and surge protection equipment is provided in a variety of arrangements to simplify generator lead connections. Potential transformers should be protected by current-limiting resistors and fuses. Draw-out type mountings are standard equipment in metal-clad switchgear. Similar arrangements are provided in cubicles associated with isolated-phase bus. Cubicles with the isolated-phase buses also provide phase isolation for transformers.

6-5. Single Unit and Small Power Plant Considerations

When metal-clad switchgear is used for generators in small plants (having typically one or two generators of approximately 40,000 *kW* or less) the switchgear may be equipped with indicating instruments, control switches, and other unit control equipment (e.g., annunciators and recorders) mounted on the switchgear cell doors. This arrangement can take the place of a large portion of the conventional control switchboard. The switchgear may be located in a control room, or the control room omitted entirely, depending upon the layout of the plant. Current philosophy is to make the smaller plants suitable for unmanned operation, and remote or automatic control. This scheme eliminates the need for a control room. Arrangements for control equipment with this type of scheme are described in more detail in Chapter 8, “Control System.”

6-6. Excitation System Power Potential Transformer

The power potential transformer (PPT) is fed from the generator leads as described in paragraph 3-6*e*(2), Chapter 3, “Generators.” The PPT is procured as part of the excitation system equipment. The PPT should be a three-phase, 60-Hz, self-cooled, ventilated dry type transformer. The PPT is generally tapped at the generator bus with primary current limiting fuses, designed for floor mounting, and with a low-voltage terminal chamber with provisions for terminating the bus or cable from the excitation system power conversion equipment.

6-7. Circuit Breakers

a. General. The particular switching scheme selected from those described in Chapter 2, “Basic Switching Provisions,” the generator voltage and capacity rating, and results from fault studies will determine the type of generator breaker used for switching, together with its continuous current rating and short-circuit current rating. If a “unit” switching scheme is chosen with switching on the high side of the GSU transformer, then criteria regarding high-voltage power circuit breakers as described in Chapter 5, “High-Voltage System” are used to select an appropriate breaker. If a generator-voltage switching scheme is selected, then criteria outlined in this paragraph should be used for breaker selection.

b. Generator-voltage circuit breaker types.

(1) When generator-voltage circuit breakers are required, they are furnished in factory-built steel enclosures in one of three types. Each type of circuit breaker has specific applications dependent on current ratings and short-circuit current ratings. In general, Table 6-1 provides a broad overview of each breaker type and its range of application for generator switching. The three types are as follows:

(a) Metal-clad switchgear. Metal-clad switchgear breakers can be used for generator switching on units of up to 45 *MVA* at 13.8 *kV*, depending on interrupting duty requirements. Details of construction are covered in Guide Specification for Civil Works Construction CWGS-16345. Either vacuum interrupters or SF_6 interrupting mediums are permitted by the guide specification.

(b) Station-type cubicle switchgear. Station-type breakers can be used in generator switching applications on units of approximately 140 *MVA*. Details of construction are covered in IEEE C37.20.2. For SF_6 circuit breakers, the insulating and arc-extinguishing medium is the gas. For indoor equipment, in areas not allowed to reach temperatures at or near freezing, the gas will probably not require heating provisions. However, special care and handling is needed for SF_6 gas.

(c) In-line isolated-phase bus breakers. For high-current, medium-voltage, generator breaker applications, i.e., 15 *kV*, 6,000 Amp or higher, in-line breakers mounted in the isolated-phase bus system have been employed on high-capacity systems. These breakers

Table 6-1
Generator Breaker Application Table, 13.8-*kV* Application

Upper Limit Generator Application MVA	Continuous Current Rating, kA	Short-Circuit Current Rating @ 13.8 *kV*	Breaker Type	Interrupting Medium
45	3.0	40 kA	Draw Out	SF_6 or vacuum
143	6.0	63 kA	Station Cubicle	SF_6
*478	20.0 or greater	100 kA OR GREATER	In-line isolated-phase bus	SF_6 or air blast

* 478 *MVA* @ 20 kA

employ either SF_6 or compressed air insulating and arc extinguishing systems and can incorporate breaker isolating switches in the breaker compartment. This type of breaker requires less space than a station type cubicle breaker but has higher initial cost. It should receive consideration where powerhouse space is at a premium. Technical operating parameters and performance are covered in IEEE C37.013.

(2) The essential features of draw-out metal-clad switchgear and station type cubicle switchgear are covered in IEEE C37.20.2. Essential features of in-line isolated-phase bus-type circuit breakers are covered in IEEE C37.013 and C37.23. Specific current and interrupting ratings available at other voltages are summarized in Tables 6-2 and 6-3.

Table 6-2
Indoor Metal-Clad Switchgear, Removable Breaker Nominal Ratings

Phase protection is by insulated buses

Voltage (*kV*)	Voltage Rating Factor K	Current (kA)	Short-Circuit Rating (kA)	Inter-rupting Rating (kA)	Closing Mechanism
4.76	1.36	1.2	8.8	12	Stored
4.76	1.24	1.2, 2	29	36	Energy
4.76	1.19	1.2,2,3	41	49	"
8.25	1.25	1.2, 2	33	41	"
15.0	1.3	1.2, 2	18	23	"
15.0	1.3	1.2, 2	28	36	"
15.0	1.3	1.2,2,3	37	48	"
38.0	1.65	1.2,2,3	21	35	"
38.0	1.00	1.2, 3	40	40	"

Note: The voltage range factor, K, is the ratio of maximum voltage to the lower limit of the range of operating voltage in which the required symmetrical and asymmetrical current interrupting capabilities vary in inverse proportion to the operating voltage. See ANSI C37.06.

Table 6-3
Indoor Metal-Enclosed Switchgear, Fixed Breaker Preferred Ratings For Generator Circuit Breakers 4/

Phase protection is by steel barriers

Voltage (*kV*)	Voltage Rating Factor K	Current (kA)	Short-Circuit Rating (kA)	Inter-rupting Rating (kA)	Closing Mechanism
15.8	1	1/	2/	3/	Stored
27.5	1	1/	2/	3/	Energy

1/ Typical values, in kA: 6.3, 8.0, 10.0, 12.0, 16.0, 20.0, 25.0, 30.0 and 40.0.

2/ Typical values in kA: 63, 80, 100, 120, 160, 200, 250, 275.

3/ Symmetrical interrupting capability for polyphase faults shall not exceed the short-circuit rating. Single-phase-to-ground fault interrupting capability shall not exceed 50A.

4/ IEEE C37.013.