APPLICATION AND INSTALLATION GUIDE

GENERATOR PARALLELING SWITCHGEAR

Contents

Foreword

This section of the Application and Installation Guide generally describes wide-ranging requirements and options for Switchgear with a focus on Generator Paralleling Switchgear. Additional engine and generator systems, components, and dynamics are covered in other sections of this Guide.

Systems and components described in this guide may not be available or applicable for all Switchgear. While much of the content of this guide is applicable to all switchgear the primary focus of this guide is on the North American generator paralleling switchgear market.

1 SWITCHGEAR

Electric Power Generation systems provide primary and backup electrical power in installations around the world. Generator Paralleling Switchgear is an integral component in many of these installations to ensure optimal power generation and electrical distribution system performance.

The term switchgear refers to the combination of electrical disconnects, fuses, and/or circuit breakers used to isolate electric equipment and distribute electrical power. The primary functions of Generator Paralleling Switchgear are:

- Switching power source to the load.
- Protecting the generator set.
- Metering output.
- Providing paralleling and load sharing capability.
- Operating the generator set.

1.1 Codes, Standards, and Terms

Within the United States, several organizations are responsible for creating codes and standards regarding switchgear construction. The main organizations are

- American National Standards Institute (ANSI).
- Institute of Electrical and Electronic Engineers (IEEE).
- Underwriters Laboratory (UL).
- National Fire Protection Association (NFPA) – also sponsors the National Electrical Code (NEC).
- National Electrical Manufacturers Association (NEMA).
- American Bureau of Shipping (ABS).

Switchgear installations in countries other than the US are typically subject to requirements of the International Electro-Technical Commission (IEC) or Underwriters Laboratory (UL) as well as the national agencies of the country involved.

Marine installations in the US are subject to and generally require approval of various marine regulatory bodies such as the United States Coast Guard and the American Bureau of Shipping (ABS).

Marine applications often require switchboard and complete shipboard electrical systems to be furnished and installed according to IEEE Standard 45 (IEEE Recommended Practice for Electric Installations on Shipboard).

International marine applications must comply with other regulatory bodies such as Lloyd’s, Bureau of Veritas, Det Nork Veritas, and coast guard requirements of other countries.

1.1.1 IEEE1547

IEEE1547 is a standard that establishes criteria and requirements for interconnection of distributed resources with electric power systems (EPS).

This document provides a uniform standard for interconnection of distributed resources with EPS. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection.

2 VOLTAGE CLASSIFICATIONS

Switchgear systems are generally classified by voltage. Typical ranges of paralleling switchgear voltages are from 480V to 15kV and match the voltage ranges of the generators. Assemblies are also rated at specific voltages (i.e. 5kV, 15kV, 27kV, 38kV, etc.).

Figure 1 illustrates the most common voltage ranges for switchgear.

Caterpillar Inc. denotes 15kV generators as high voltage. The focus of this documentation will be on the low and medium voltage ranges.

Voltage Class	Nominal System Voltage	
	3-Wire	4-Wire
Low Voltage (LV)	240/120 240 480 600	208Y/120 240/120 480Y/277 -
Medium Voltage (MV)	2400 4160 4800 6900 13200 13800 14400	4160Y/2400 8320Y/4800 12000Y/6930 12470Y/7200 13200Y/7620 13800Y/7970

Figure 1 – Standard Nominal System Voltages and Voltage Ranges (IEEE Standard 141-1993)

3 SWITCHGEAR TYPES

Three types of switchgear are available: metal-enclosed, metal-clad, and arc resistant. Metal-enclosed switchgear is primarily used for low voltage applications while metal-clad and arc resistant switchgear are most often used for medium voltage switchgear.

While uncommon in North America, it is possible to find requirements for medium voltage metal-enclosed switchgear.

3.1 Metal-Enclosed

Metal-enclosed switchgear is commonly used in low voltage applications.

Rated Maximum Voltage (V rms)	Impulse Withstand (kV)
254	2.2
508	2.2
635	2.2

Figure 2 – LV AC Metal-Enclosed Switchgear Voltage and Insulation Levels (IEE C37.20.1 –2002)

Metal-enclosed switchgear typically includes:

- Low voltage molded case or power circuit breakers (fused or unfused) in accordance with ANSI/IEEE C37.13.
- Bare bus bars and connections.
- Instrument, control voltage, and current transformers.
- Instruments and meters.
- Relays, digital automation processors, and other logic devices.

- Control wiring, fuses, and terminal blocks.
- Speed and voltage control components for the specific generator set.
- Feeder circuit breakers and power cable connections.
- Speed control components.
- Voltage control components.

Low voltage molded case or power circuit breakers are contained in metal compartments. These circuit breakers can be manually operated or electrically operated by local or remote system controls. The circuit breakers may be stationary or removable, plug-in for molded case type, and draw-out for power type circuit breakers.

Indoor Switchgear:

Metal-enclosed switchgear is enclosed on all sides, including the top, with sheet metal. Ventilating openings and inspection windows are not covered. The enclosure contains the power switching or interrupting devices with buses and connections, controls, instrumentation, metering, and other auxiliary devices. Doors and/or removable covers provide access to the interior of the enclosure.

Outdoor Switchgear:

Outdoor metal-enclosed switchgear is similar to indoor switchgear except it is also weatherproof. A walk-in outdoor enclosed switchgear assembly with an aisle in front of the circuit breaker and instrument sections to protect workers and equipment from weather during maintenance and system operation can be provided.

3.2 Metal-Clad

Metal–clad switchgear is most commonly used in medium voltage applications. Figure 3 shows the values for rated maximum voltage and impulse withstand for metal-clad switchgear.

Rated Maximum Voltage (kV rms)	Impulse Withstand (kV)
4.76	60
8.25	95
15.0	95

Figure 3 – MV AC Metal-Clad Switchgear Voltage and Insulation Levels (ANSI/IEEE C37.20.2-1999)

Medium voltage metal-clad switchgear construction differs from metal-enclosed switchgear in several ways. The features that characterize metal-clad switchgear are summarized in the following paragraphs.

- The main switching and interrupting device is of the removable (draw-out) type arranged with a mechanism for moving it physically between connected and disconnected positions. It is also equipped with self-aligning and self-coupling primary disconnecting devices and control wiring connections capable of being disconnected.
- Major parts of the primary circuit, such as the circuit switching or interrupting devices, buses, voltage transformers, and control power transformers, are completely enclosed by grounded metal barriers that have no intentional openings between compartments. Specifically included is a metal barrier in

front of or a part of the circuit interrupting device to insure that, when in connected position, no primary circuit components are exposed by the opening of a door.

- All live parts are enclosed within grounded metal compartments.
- Automatic shutters cover primary circuit elements when the removable element is in the disconnected, test, or removed position.
- Primary bus conductors and connections are covered with insulating material throughout.
- Mechanical or electrical interlocks are provided for proper operating sequence under normal operating conditions.
- With the exception of short lengths of wire such as at instrument transformer terminals, instruments, meters, relays, secondary control devices, and their wiring are isolated from all primary circuit elements by grounded metal barriers.
- The door through which the circuit-interrupting device is inserted into the housing may serve as an instrument or relay panel and may also provide access to a secondary or control compartment within the housing.

3.3 Arc Resistant

Conventional medium voltage metal-clad switchgear is not designed to withstand high arc energy faults. Faults due to defective insulating materials, improper bus joints, poor maintenance, incorrect protective or safety devices, human error, ingress of moisture, abnormal service conditions, etc. could quickly develop into a 3-phase fault. High arc energy faults cause rapid temperature increases of the surrounding air and rapid increases of pressure inside the enclosure.

Arc resistant switchgear is designed to provide protection against internal arcing faults. The following safety benefits can be gained by using arc resistant switchgear:

- Each compartment door and barrier plate is designed to withstand pressure surges due to internal arcing.
- Hot gases and molten particles escape through a specially designed pressure relieve vent located on the roof of the enclosure away from operating personnel.
- Closed door racking of circuit breaker provides added safety.
- Viewing windows allow personnel to observe the status of the circuit breaker without opening the door.
- The low voltage compartment is completely segregated to avoid pressure buildup.
- Arc resistant switchgear design should contain the damage within the faulty compartment, reducing down time.

3.4 Enclosure Ratings

The National Electric Manufacturers Association (NEMA) provides standards for enclosures to ensure safe operation under various conditions. Two major categories of classification are for switchgear in non-hazardous locations and those in hazardous locations.

3.4.1 Non-Hazardous Locations

In non-hazardous locations the specific enclosure types, their applications, and the environmental conditions they are designed to protect against, when completely and properly installed, are as follows (see Figure 4 and Figure 5):

Type 1 Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt).

Type 1A is similar to Type 1, but also includes gasketing material. Type 1A is not officially recognized but is often included in specifications.

Type 2 Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt); and to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (dripping and light splashing).

Type 3 Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt and windblown dust); to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (rain, sleet, snow); and to remain undamaged by the external formation of ice on the enclosure.

Type 3R Identical to Type 3 except Type 3R does not protect against ingress of solid foreign objects and may be ventilated.

Type 3S Identical to Type 3 with additional protection against sleet, ensuring the external mechanism(s) remain operable when ice laden.

Type 3X Identical to Type 3 with an additional level of protection against corrosion and against the external formation of ice on the enclosure.

Type 3RX Identical to Type 3 except Type 3RX does not protect against ingress of solid foreign objects, may be ventilated, and provides an additional level of protection against corrosion and against the external formation of ice on the enclosure.

Type 3SX Identical to Type 3 but also provides additional protection against corrosion and sleet, ensuring the external mechanism(s) remain operable when ice laden.

Type 4 Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt and windblown dust); to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (rain, sleet, snow, splashing water, and hose directed water); and to remain undamaged by the external formation of ice on the enclosure.

Type 4X Identical to Type 4 but also provides an additional level of protection against corrosion (usually by incorporating stainless steel or nonmetallic composites) and against the external formation of ice on the enclosure.

Type 5 Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt and settling airborne dust, lint, fibers, and flyings); and to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (dripping and light splashing).

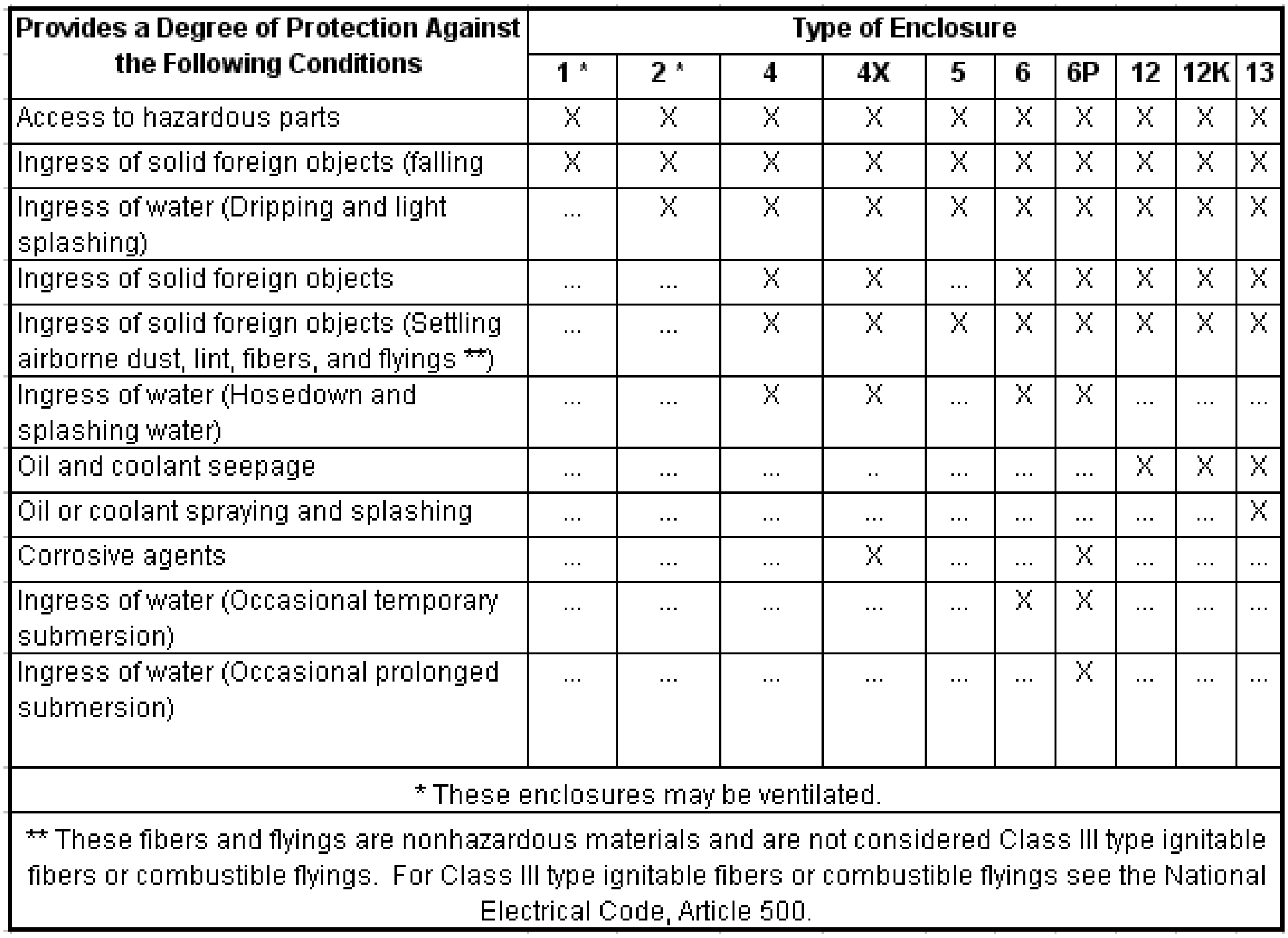
Type 6 Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protect-tion to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt); to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (hose-directed water and the entry of water during occasional temporary submersion at a limited depth); and to remain undamaged by the external formation of ice on the enclosure.

Type 6P Identical to Type 6 but also provides an additional level of protection against corrosion, ingress of water (occasional prolonged submersion), and protection against the external formation of ice on the enclosure.

Type 12 Enclosures constructed without knockouts for indoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt and circulating dust, lint, fibers, and flyings); and to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (dripping and light splashing).

Type 12K Identical to Type 12 but with the addition of being constructed with knockouts.

Type 13 Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts; to provide a degree of protection to the equipment inside the enclosure against ingress of solid foreign objects (falling dirt and circulating dust, lint, fibers, and flyings); to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (dripping and light splashing); and to provide a degree of protection against the spraying, splashing, and seepage of oil and non-corrosive coolants.

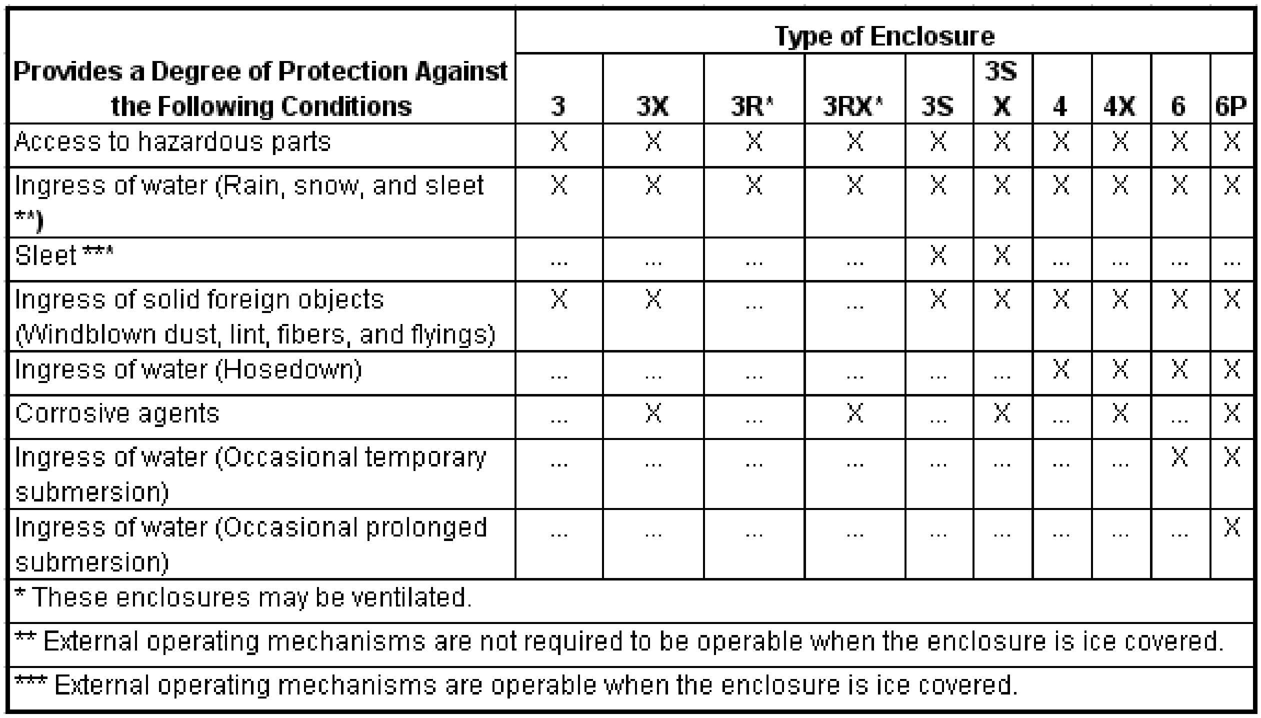


Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	1 *	2 *	4	4X	5	6	6P	12	12K	13
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of solid foreign objects (falling	X	X	X	X	X	X	X	X	X	X
Ingress of water (Dripping and light splashing)	...	X	X	X	X	X	X	X	X	X
Ingress of solid foreign objects	...	...	X	X	...	X	X	X	X	X
Ingress of solid foreign objects (Settling airborne dust, lint, fibers, and flyings **)	...	...	X	X	X	X	X	X	X	X
Ingress of water (Hosedown and splashing water)	...	...	X	X	...	X	X	...	...	...
Oil and coolant seepage	...	...	...	..	...	...	...	X	X	X
Oil or coolant spraying and splashing	...	...	...	...	...	...	...	...	...	X
Corrosive agents	...	...	...	X	...	...	X	...	...	...
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	X	X	...	...	...
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	X	...	...	...

* These enclosures may be ventilated.

** These fibers and flyings are nonhazardous materials and are not considered Class III type ignitable fibers or combustible flyings. For Class III type ignitable fibers or combustible flyings see the National Electrical Code, Article 500.

Figure 4 – Comparison of Specific Applications of Enclosures for Indoor Non-Hazardous Locations (NEMA 250-2003)



Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	3	3X	3R*	3RX*	3S	3S X	4	4X	6	6P
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of water (Rain, snow, and sleet **)	X	X	X	X	X	X	X	X	X	X
Sleet ***	...	...	...	...	X	X	...	...	...	...
Ingress of solid foreign objects (Windblown dust, lint, fibers, and flyings)	X	X	...	...	X	X	X	X	X	X
Ingress of water (Hosedown)	...	...	...	...	...	...	X	X	X	X
Corrosive agents	...	X	...	X	...	X	...	X	...	X
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	...	...	...	X	X
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	...	...	...	X
* These enclosures may be ventilated.										
** External operating mechanisms are not required to be operable when the enclosure is ice covered.										
*** External operating mechanisms are operable when the enclosure is ice covered.										

Figure 5 – Comparison of Specific Applications of Enclosures for Outdoor Non-Hazardous Locations (NEMA 250-2003)

3.4.2 Hazardous Locations

Manufacturers who specialize in hazardous location equipment should be used for consultation when selecting equipment for hazardous locations.

In hazardous locations, when completely and properly installed and maintained, Type 7 and 10 enclosures are designed to contain an internal explosion without causing an external hazard. Type 8 enclosures are designed to prevent combustion through the use of oil-immersed equipment. Type 9 enclosures are designed to prevent the ignition of combustible dust.

Type 7 Enclosures constructed for indoor use in hazardous (classified) locations classified as Class I, Division 1, Groups A, B, C, or D as defined in NFPA 70.

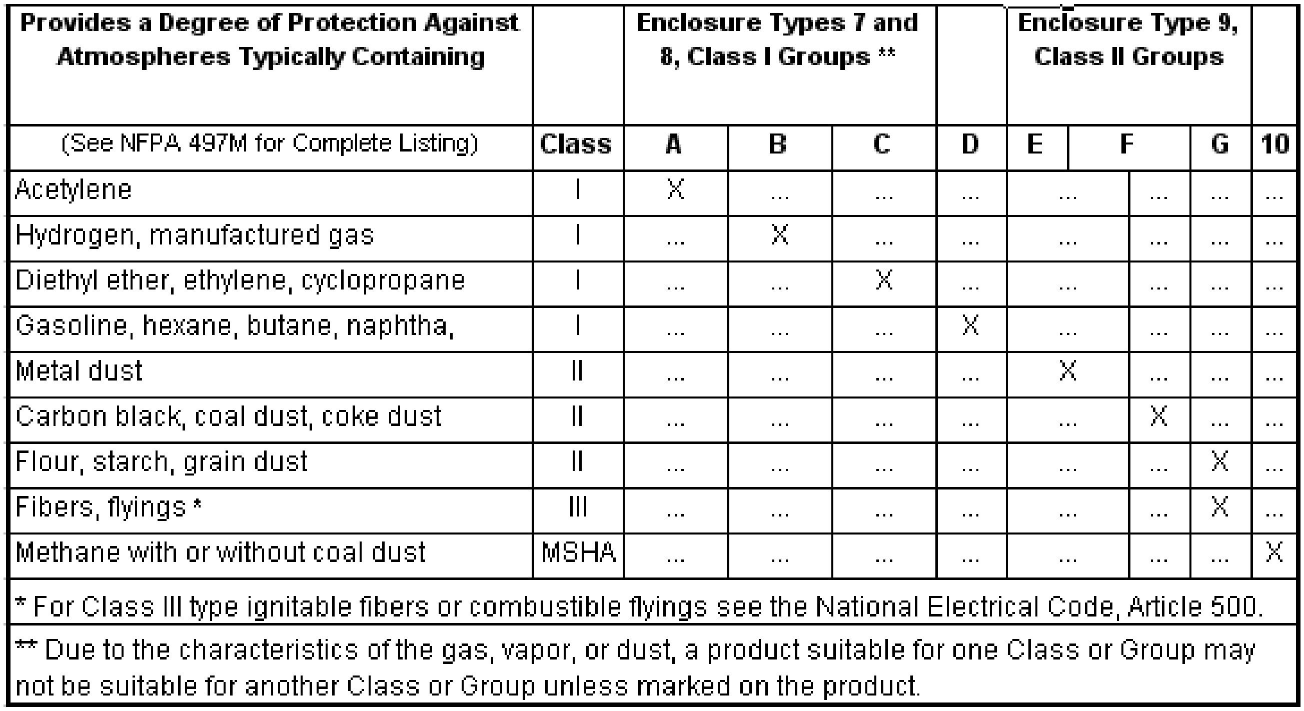
Type 8 Enclosures constructed for either indoor or outdoor use in hazardous (classified) locations that is classified as Class I, Division 1, Groups A, B, C, and D as defined in NFPA 70.

Type 9 Enclosures constructed for indoor use in hazardous (classified) locations classified as Class II, Division 1, Groups E, F, or G as defined in NFPA 70.

Type 10 Enclosures constructed to meet the requirements of the Mine Safety and Health Administration, 30 CFR, Part 18.

Figure 6 summarizes the requirements for enclosures in hazardous locations.

If the enclosure in a hazardous location is to be outdoors or additional protection is needed from Figure 4 or Figure 5, a combination-type enclosure is needed.



Provides a Degree of Protection Against Atmospheres Typically Containing		Enclosure Types 7 and 8, Class I Groups **				Enclosure Type 9, Class II Groups			
(See NFPA 497M for Complete Listing)	Class	A	B	C	D	E	F	G	10
Acetylene	I	X	...	...	...	...	...	...	...
Hydrogen, manufactured gas	I	...	X	...	...	...	...	...	...
Diethyl ether, ethylene, cyclopropane	I	...	...	X	...	...	...	...	...
Gasoline, hexane, butane, naphtha,	I	...	...	...	X	...	...	...	...
Metal dust	II	...	...	...	...	X	...	...	...
Carbon black, coal dust, coke dust	II	...	...	...	...	...	X	...	...
Flour, starch, grain dust	II	...	...	...	...	...	...	X	...
Fibers, flyings *	III	...	...	...	...	...	...	X	...
Methane with or without coal dust	MSHA	...	...	...	...	...	...	...	X
* For Class III type ignitable fibers or combustible flyings see the National Electrical Code, Article 500.									
** Due to the characteristics of the gas, vapor, or dust, a product suitable for one Class or Group may not be suitable for another Class or Group unless marked on the product.									

Figure 6 – Comparison of Specific Applications of Enclosures for Indoor Hazardous Locations (*NEMA 250-2003*)

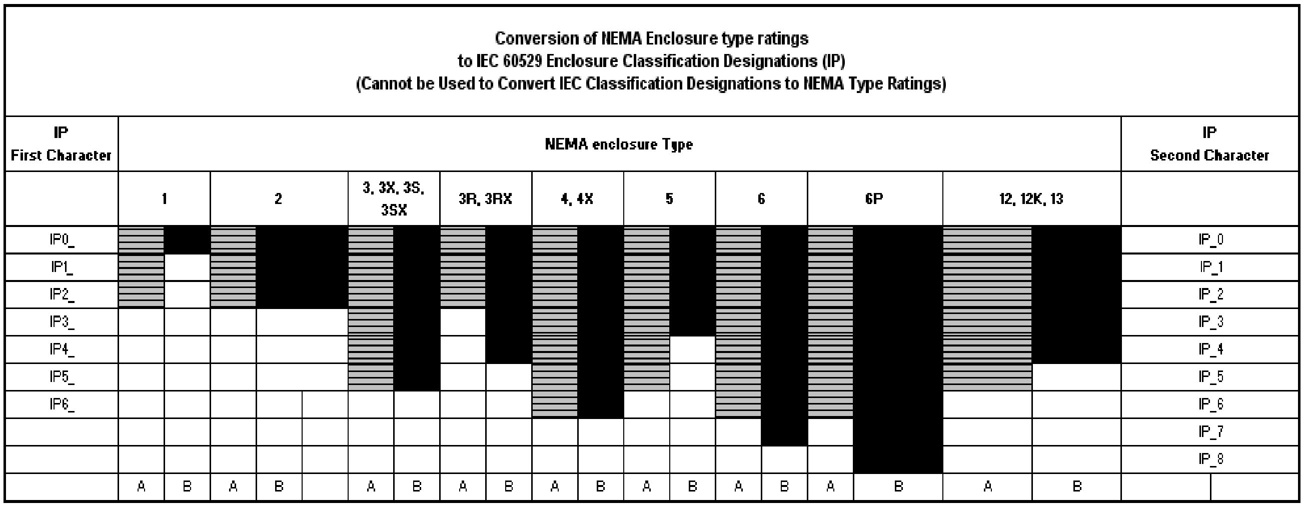
3.4.3 NEMA Enclosure Type Numbers vs. IEC Enclosure Classification Designations

IEC Publication 60529, "*Classification of Degrees of Protection Provided by Enclosures,*" provides a system for specifying the enclosures of electrical equipment on the basis of the degree of protection provided by the enclosure.

IEC 60529 does not specify degrees of protection against mechanical damage of equipment, risk of explosions, or conditions such as moisture, corrosive vapors, fungus, or vermin. The NEMA Standard for Enclosures for Electrical Equipment does test for environmental conditions such as corrosion, rust, icing, oil, and coolants. For this reason and because the test and evaluations for other characteristics are not identical, the IEC enclosure classification designations cannot be exactly equated with the enclosure Type numbers in this standard.

The IEC designation consists of the letters IP followed by two numerals. The first numeral indicates the degree of protection provided by the enclosure with respect to persons and solid foreign objects entering the enclosure. The second numeral indicates the degree of protection provided by the enclosure with respect to the harmful ingress of water.

Figure 7 provides an equivalent conversion from the enclosure Type numbers in this standard to the IEC enclosure classification designations. The enclosure type numbers meet or exceed the test requirements for the associated IEC Classification; for this reason Figure 7 cannot be used to convert from IEC classifications to enclosure Type numbers.



Conversion of NEMA Enclosure type ratings
to IEC 60529 Enclosure Classification Designations (IP)
(Cannot be Used to Convert IEC Classification Designations to NEMA Type Ratings)

IP First Character	NEMA enclosure Type																		IP Second Character
	1		2			3, 3X, 3S, 3SX		3R, 3RX		4, 4X		5		6		6P		12, 12K, 13		
IP0_	▤	■	▤	■	■	▤	■	▤	■	▤	■	▤	■	▤	■	▤	■	▤	■	IP_0
IP1_	▤		▤	■	■	▤	■	▤	■	▤	■	▤	■	▤	■	▤	■	▤	■	IP_1
IP2_	▤		▤	■	■	▤	■	▤	■	▤	■	▤	■	▤	■	▤	■	▤	■	IP_2
IP3_						▤	■		■	▤	■	▤	■	▤	■	▤	■	▤	■	IP_3
IP4_						▤	■		■	▤	■	▤		▤	■	▤	■	▤	■	IP_4
IP5_						▤	■			▤	■	▤		▤	■	▤	■	▤		IP_5
IP6_										▤	■			▤	■	▤	■			IP_6
															■		■			IP_7
																	■			IP_8
	A	B	A	B		A	B	A	B	A	B	A	B	A	B	A	B	A	B	

Figure 7 – IEC Enclosure Classification

A shaded block in the “A” column indicates that the NEMA enclosure type exceeds the requirements for the respective IEC 60529 IP first character designation. The IP first character designation is the protection against access to hazardous parts and solid foreign objects.

A shaded block in the “B” column indicates that the NEMA enclosure type exceeds the requirements for the respective IEC 60529 IP second character designation. The IP second character designation is the protection against the ingress of water.

4 POWER ASSEMBLY

4.1 Switchgear vs. Switchboard

The terms switchgear and switchboard are often used interchangeably when referring to low voltage circuit breaker distribution equipment. However, there are significant differences in components, standards, applications, configurations, selection criteria, and reliability between these two types of power distribution equipment.

The major differences between switchgear and switchboard are the types of circuit breakers used. A more detailed discussion of circuit breakers can be found in Section 5.

Molded case circuit breakers are the most common, used in all types of low voltage switchboards and panel boards. The ratings for these breakers range from 15A to 3,000A.

Insulated case breakers typically range from 400A to 5,000A. These breakers are available as options for switchboards and can be designed as fixed or drawout systems.

Power circuit breakers typically range from 800A to 5,000A. They are connected to the bus in a drawout.

Switchgear is larger than switchboards and requires front and rear access. Drawout breakers in switchgear will require more clearance in the front.

Front accessible switchboards have the smallest space requirements.

Further details about circuit breakers, switchboard, and switchgear standards can be found in Figure 9.

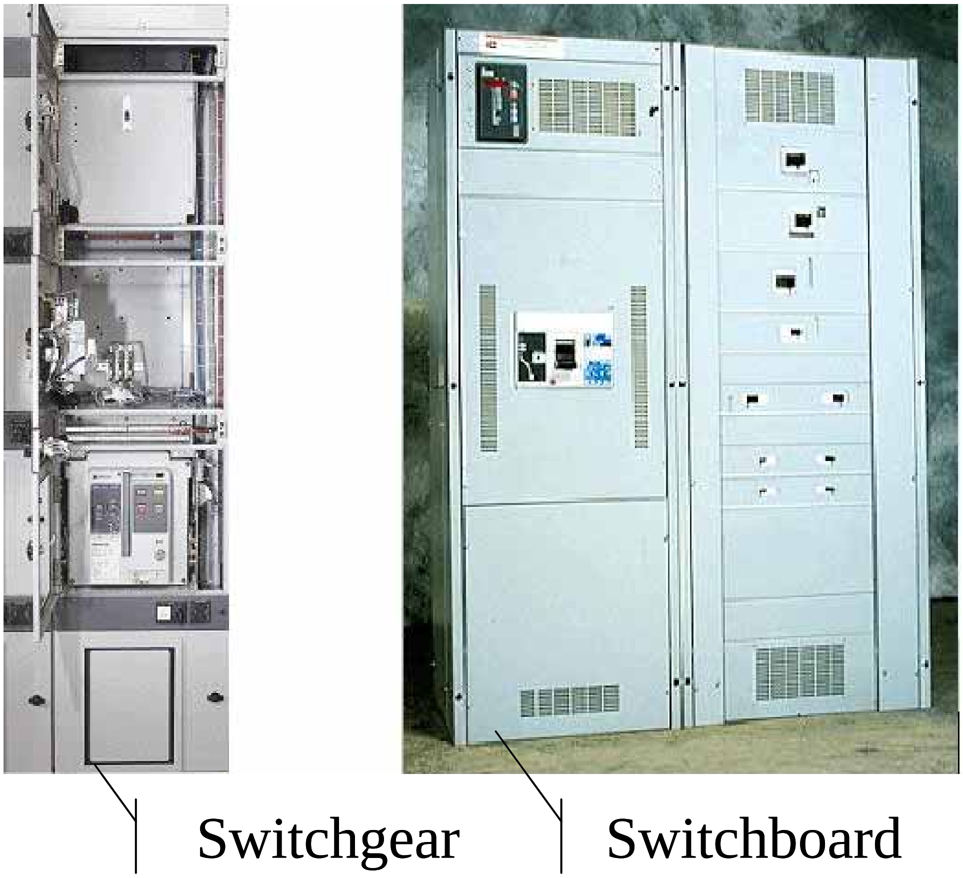


Figure 8 – Switchgear and Switchboard

4.2 Switchgear Standards

The two main standards for low voltage switchgear are UL 1558 and UL 891; a comparison of the standards is shown in Figure 9 and photos of the switchboard and switchgear are shown in Figure 8.

Category	UL 1558	UL891
Name	Switchgear	Switchboards
ANSI Reference	Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear	No ANSI Standard Reference
Access	Front and Rear Access	Front Access or Front and Rear Access
Application Standards	NEMA SG3, SG5, ANSI C37.20.1	NEMA PB2
Circuit Breakers	Power Circuit Breakers	Molded Case or Insulated Case Circuit Breakers
Mounting	Usually Draw-Out Mounted	Fixed Mounted (Some Mains May be Draw-Out)
	Individually Mounted	Group Mounted (can be Individually Mounted in some cases)
Service Conditions	Ambient Air Temperatures and Altitude Specified	Service conditions not addressed
Short Circuit Ratings	Determined by testing at 635V for 4 cycles at 60 Hz	Determined by testing at 600V for 3 cycles at 60 Hz
Short Circuit Bus Testing	Requires phase to neutral and phase to ground	Phase to neutral only required under certain conditions and phase to ground not required
Enclosure Finish	Requires finish to pass 200 hour salt spray test	Requires indoor finish to pass 24 hour salt spray test. Outdoor finish must pass 600 hour test
Barriers	Requires barriers between breakers and bus and between breakers	Does not require internal barriers
Service Entrance	Requires barriers isolating service entrance bus from serviceable load connections	requires barriers for "Line of Sight" contact
Means of Trip	Requires Mechanical means to trip E.O. Breakers	Does not require mechanical tripping of E.O. breakers
Production Tests	Requires 7 production tests	Requires 3 Production tests

Figure 9 – UL 1558 and UL 891 Comparisons

4.3 Switchgear Dimensions

4.3.1 Metal-Enclosed

For switchgear located indoors, the room should be designed to allow ample space for the switchgear and provide adequate ventilation. To estimate space requirements, manufacturer catalogs usually provide information used to plan the layout. Breakers up to 3200A frame size will be in units of 18 or 22 inches wide and can typically be stacked four units high. Usually only two 3200A breakers are permissible in a unit, although in some cases three may be furnished. Also with one 3200A breaker, two or three smaller breakers may be supplied in the vertical section.

Breakers with frame sizes of 4000 or 6000A require units 36 to 44 inches wide, depending on the manufacturer. Usually, only one of these breakers can be furnished with a unit.

Fused breakers in 225, 600, and 1600A frame sizes are supplied in units of the same width as unused breakers of the same frame size. When fuses are used in series with 3000A and above breakers, they are occasionally in a separate compartment directly above or directly below the breaker. However, at least one manufacturer can offer 3000 and 4000A breakers with integrally mounted fuses and no increase in space requirements.

Depth of indoor switchgear ranges from 54 to 90 inches, depending on the manufacturer. However, this depth may not allow enough space for outgoing cables, so it may be necessary in some cases to add a section on the rear of one or more units to provide sufficient space. If overhead breaker lifting devices and ventilation is excluded, the height of the indoor switchgear will be approximately 90 inches.

Depth of outdoor switchgear is approximately 72 to 94 inches; the height of outdoor gear is 112 inches. All dimensions given here are to be used for preliminary estimates only.

4.3.2 Metal-Clad

In medium voltage metal-clad switchgear, breakers are not stacked as they are in low voltage switchgear. Each breaker unit will contain only one or two breakers.

Indoor 5kV metal-clad switchgear units for 1200 to 2000A breakers are 26 to 36 inches wide with height varying from 72 to 95 inches, depending on supplier; depth varies from 56 to 96 inches. Aisled or Aisless units may be used. For aisled units an unobstructed work space (aisle) is required on the breaker drawout side wide enough to permit removal of the breaker and may be from 28 to 50 inches wide, an aisle is also required on the rear of the switchgear for use in maintenance; a 36 inch wide aisle is usually recommended. NEC working clearance dictates width.

Auxiliary units are commonly the same size as breaker units except in special situations, such as power company metering units. When such cubicles are required, they should be constructed to the power company's specifications and drawings of the units should be approved by the power company before manufacture.

Outdoor switchgear units are the same width as the indoor units of the same rating and they will be somewhat taller, since a sloping roof is usually supplied. The depth of the outdoor unit will depend on the width of the sheltered aisle (if any) and whether standard aisle or common aisle type of construction is used. Aisle spaces usually range from 70 to 110 inches wide.

4.4 Switchgear Layout

The size of a switchgear group will vary slightly with the manufacturer. When outdoor switchgear is used, space is not often the most critical consideration, so the product of any manufacturer can be used. However, the pad should not be poured until certified drawings have been received from the manufacturer to be sure that it will be the proper size and shape.

4.5 Busbar

When several control panels are located adjacent to one another in a floor-standing assembly, a set of common conductors is used on the load side of the circuit breaker. These conductors consolidate the output of all the operating generators and conduct the total output to the distribution system. The bus may be cables joining the respective terminal lugs or it may be rigid, bare bars of aluminum or copper suitably insulated from the structure of the switchboard.

The size of the busbar is important in determining the maximum amount of current that can be safely carried. Busbars are typically either flat strips or hollow tubes as these shapes allow heat to dissipate more efficiently due to a high surface area to cross-sectional area ratio. The skin effect (see section 4.5.1) makes alternating electric current (AC) busbars more than ½” thick inefficient, so hollow or flat shapes are prevalent in high current applications. A hollow section is stiffer than a solid rod which allows for a greater span between busbar supports.

A busbar may either be supported on insulators or insulation may completely surround it. Busbars are protected from accidental contact by a metal enclosure or by elevation out of normal reach. Phase busbars may be insulated while ground busbars are typically bolted directly onto a metal chassis of the enclosure.

Busbar insulation is a requirement of metal-clad switchgear and is provided to minimize the possibility of communicating faults and to prevent development of bus faults which would result if foreign objects momentarily contacted the bare bus. Further information on busbar insulation can be found in ANSI Standard Z244.1.

Busbars may be connected to each other and to electrical apparatus by bolted or clamped connections. Often joints between high-current bus sections have matching silver-plated surfaces to reduce the contact resistance; a conductive joint compound may also be used to increase conductivity and reduce thermal stress at the joint.

Low voltage switchgear is not typically required to have insulated busbars. If insulation is required, additional cost will be incurred.

Splice plates allow for field inter-connection of the main bus of two adjacent floor-standing panels. In low voltage applications these are typically used when additional structures are added to an existing switchgear lineup or to limit main bus sections to a practical length to accommodate shipping splits. Metal-clad medium voltage switchgear structures are manufactured with modular main bus sections and normally require splice plates between each adjacent section.

4.5.1 Skin Effect

Skin effect is the tendency of an alternating electric current (AC) to distribute itself within a conductor so the current density at the surface of the conductor is greater than at its core. Thus, the electric current tends to flow along the “skin” of the conductor.

Silver plating on buswork is used to mitigate skin effects and provide more even conductivity.

4.5.2 Metal Selection

Copper is preferred over aluminum, except where corrosive atmospheres may have an adverse affect on the copper. Copper has a higher conductivity than aluminum, it is more easily plated, and bolted joints are made more easily. The melting point of copper is higher than aluminum so less damage is done to copper busses in case of an arcing fault.

In most cases, copper is a more expensive metal. If aluminum is used, joints may be welded, making field changes difficult. Copper joints must be silver-plated; aluminum bolted joints may be silver-plated or tin-plated. Where bolted joints are necessary, as at shipping splits, aluminum may be welded to copper. Bolted joints should be made to minimize the tendency to cold flow (permanently deform due to constant stress) and to maintain a tight clamp in the case of some cold flow or stretching of the bolt over a period of time.

4.6 Wiring

When determining wiring, applicable standards must be used to determine the following:

- Size of wire.
- Insulation material.
- Terminal types.
- Terminal insulation.

A detailed wiring diagram is required to show the relative location of terminals on various devices and terminal blocks. Referring to this diagram can identify when trouble-shooting or making changes to wiring.

Secondary wiring in metal-clad switchgear must be enclosed in metal channels or in conduit to isolate it from the primary circuits. The wire should not be smaller than 16 AWG if stranded wire is used. Flexible wire must be used for wiring across a hinge to a panel.

The insulation on the wire must meet the requirements for Type TA, TBS, or SIS as described in the National Electrical Code.

4.7 Transformers

A transformer is a device that transfers electrical energy from one circuit to another through a shared magnetic field. A changing current in the primary circuit creates a changing magnetic field, which induces a voltage in the secondary circuit. The secondary circuit mimics the primary circuit but with different current and voltage.

4.7.1 Current Transformers

Current transformers (CTs) are designed to provide a current in its secondary conductor proportional to the current flowing in its primary conductor. Current transformers can safely isolate measurement and control circuitry from high voltages and currents present in the circuit while giving an accurate measurement of the primary current. Figure 10 shows a picture of current transformers.

Figure 10 – Current Transformers

The current transformer ratio is generally selected so the maximum load current will read about 70% full scale on a standard 5A coil ammeter. Therefore, the current transformer primary rating should be 140-150% of the maximum load current.

4.7.2 Voltage/Potential Transformers

Voltage transformers (VT's) or potential transformers (PTs) are used between the phase voltage of the generator and the various instruments and apparatus to reduce the voltage to standard 120V instrument voltage. A picture of a voltage transformer is shown in Figure 11.

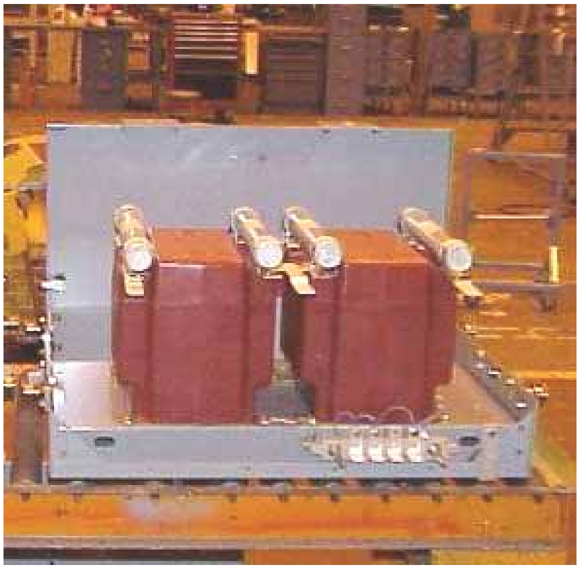


Figure 11 – Medium Voltage Switchgear Voltage Transformer

Voltage transformers are designed to present negligible load to the supply being measured and to have a precise voltage ratio to accurately step down high voltages so metering and protective relay equipment can be operated at a lower potential.

Selection of the ratio for the voltage transformer is seldom a question since the primary rating should be equal to or higher than the system line-to-line voltage. The type of system and the relaying determines the number of potential transformers per set and the connection and metering required.

A 3-phase, 3-wire system with 2 element watt-hour meters requires a set of two line-to-line voltage transformers. If line-to-ground potential is also required for a directional ground relay, a set of three line-to-ground voltage transformers can be used to provide both line-to-line potential for the 2 element watt-hour meter and line-to-ground potential for the ground relay.

A 3-phase, 4-wire solidly grounded system usually requires three line-to-ground voltage transformers for 2-1/2 or 3 element metering

Where synchronizing of generators or systems is necessary, it is recommended that only line-to-line potential be used.

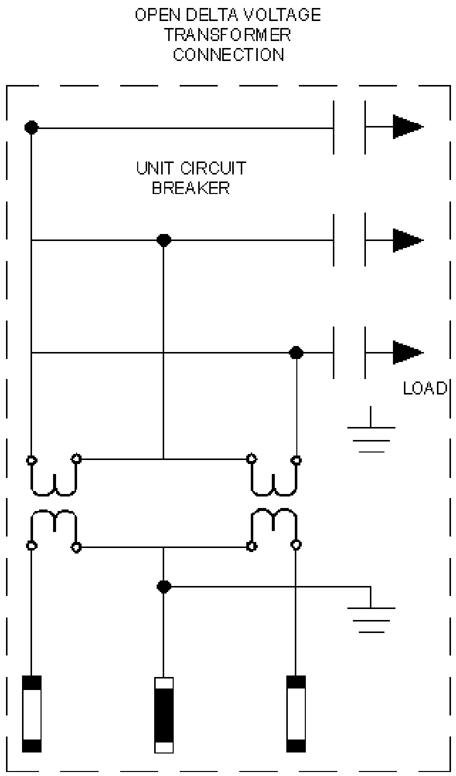


Figure 12 – Open Delta Voltage Transformer Diagram

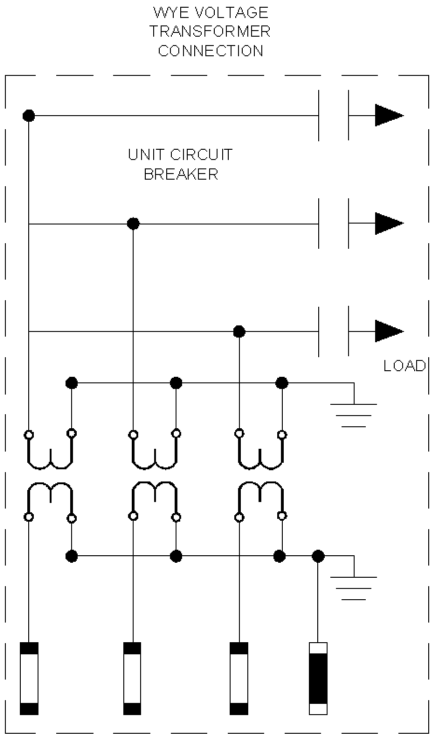


Figure 13 – Wye Voltage Transformer Connection

4.7.3 Control Power Transformers

Control power transformers (CPTs) are used for auxiliary power to space heaters, lights, and receptacles and control of electrically operated breakers when external auxiliary power sources are unavailable. CPTs, when used for control of electrically operated breakers, should be connected on the source side of the main breaker so the control power is available to close the main breaker. Some of the main features of CPTs are listed below:

- Step the primary voltage down to 120/240VAC.
- Provide 120/240VAC power for heaters, lights, and breaker control.
- Mounted in a drawout auxiliary drawer up to 15kVA.
- Fix mounted in the rear of the structure and provided with a drawout primary fuse drawer above 15kVA.

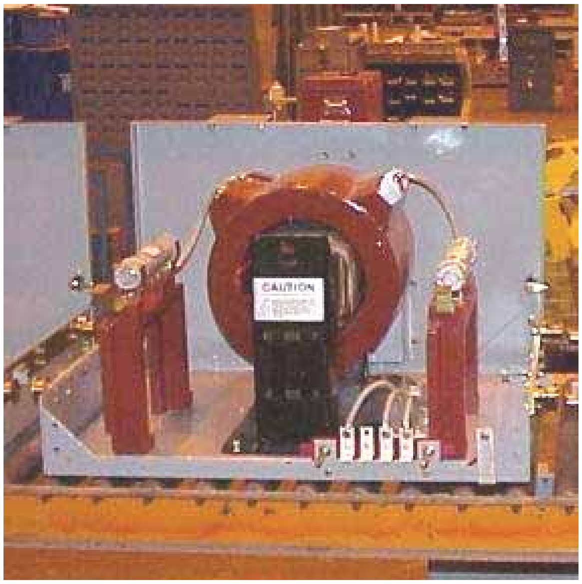


Figure 14 – Medium Voltage CPT

5 CIRCUIT BREAKERS

The circuit breaker is an integral component in switchgear, opening and closing a circuit by non-automatic means and opening the circuit automatically on a predetermined over-current level without damage. Circuit breakers are located between the power source and the load and play a crucial role in two of the main functions of switchgear:

- Switching the load to and from the generator.
- Protecting the generator from short circuits and overloads.

All circuit breakers have the following common design and functional characteristics:

- Frame.
- Contacts and operating mechanisms.
- Trip units.
- Arc extinguishing methods.
- Mounting methods.
- For low voltage CBs. application/circuit specific standards must meet the requirements of UL 1066 (used in UL 1558 switchgear) or UL 489 (used in UL 891 switch-gear). For a comparison of UL 1066 and UL 489 see.
- For medium voltage CBs, compliance to application/circuit specific standards does not apply. Medium voltage CBs can be rated using the ANSI C37.06 rating structure.

Required Ratings	UL 1066	UL 489
Name	Typically used with LV Switchgear	Typically used for LV Switchboards
Rated (Maximum) Voltage	254V, 508V, 635V or 600V for integrally fused CB's	120, 120/240, 240, 277, 347, 480Y/277, 480 600Y/347 or 600 Vac
Rated Frequency	dc, 60 Hz/ 50 Hz.	dc, 50 or 60 Hz or 400 Hz
Rated Continuous Current	Frame sizes: 800-6000A, other ratings are available from combinations of sensors and trip units	Frame sizes: 15-6000A
Rated Short - Time Current	Carry for (2) 0.5 sec. periods (1 second withstand)	Not specified
Short-Circuit Operating Duty	O -15 sec. - CO	O - (2 to 60 min.) - CO
Mechanical Endurance	500 Drawout Operations e.g. 800A Frame – 12,500 open/close operations with maintenance every 1,750 operations	e.g. 4000A frame – 1,500 open/close operations 800A frame – 3,500 open/close operations No maintenance possible
Electrical Endurance	4000A frame 400 open/close operations under load 800A frame 2,800 open/close operations under load	4000A frame – 400 open/close operations under load 800A frame 500 open/close operations under load

Continuous - Current Test Requirements	UL 1066		UL 489	
Enclosure	Required		Optional	
Current Level	Must carry 100% of continuous current within enclosure (100% rated)		100% of continuous current in air. 80% of continuous current in enclosure. (Optionally can be 100% rated)	
Allowable Temperature Limits	Temp. Rise	Total Temp	Temp. Rise	Total Temp
Internal Circuit Breaker Contacts	85ºC	125ºC	Limit = Insulating Materials Capability	
Connections	85ºC	125ºC	Limit = Insulating Materials Capability	
At Terminal Connection	55ºC	95ºC	50ºC	90ºC
Insulating Materials	C37.13, Table 2		Table 7.1.4.1.1	

Figure 15 – Low Voltage Circuit Breaker Standards Comparison

5.1 80% vs. 100% Rating

All circuit breakers are tested to carry their full current rating indefinitely. However, the NEC requires that circuit breakers and circuit conductors be sized at 125% of their applied, continuous loads. The purpose of this requirement is to build a "safety factor" into installations.

Standard (80%) rated circuit breakers are tested in open air at 40°C ambient and required to carry their rated current without tripping within specific operating temperature guidelines. However, in actual installations, circuit breakers are often installed in equipment with little or no ventilation. If the breaker carries its full current rating, the temperature inside the equipment (at the breaker, and on the conductors) could be higher than rated limits. By restricting the amount of current flowing in each device, the NEC limits the heat to safe levels.

Both the NEC and UL489 (Molded Case Circuit Breaker Test Standard) allow for testing and usage at 100% current rating if the breaker, conductors and enclosure are tested and certified to make sure that the temperature inside the enclosure will not exceed limits. The test is conducted with the Circuit breaker installed in the smallest enclosure they could be used in and the breaker must carry 100% rated current until maximum temperatures are reached. The circuit breaker cannot trip and the temperature rise at the customer connection cannot exceed 60° C above ambient. If the temperature rise exceeds 50°C, the breaker must be labeled with special wiring and installation.

5.1.1 NEC Requirements

With regards to the issue of over-current protection, Section 210.20 of the NEC states:

"Branch-circuit conductors and equipment shall be protected by over-current protective devices that have a rating or setting that complies with 210.20(A) through (D). (A) Continuous [loads lasting longer than 3 hours] and Non-continuous Loads. Where a branch circuit supplies continuous loads, or any combination of continuous and non-continuous loads, the rating of the over-current device shall not be less than the non-continuous load plus 125 percent of the continuous load. Exception: Where the assembly, including the over-current devices protecting the branch circuit(s), is listed for operation at
100% of its rating, the ampere rating of the over-current device shall be permitted to be not less than the sum of the continuous load plus the non-continuous load."

It is important to note that installing a 100% rated breaker in an assembly does not necessarily mean that the entire assembly is 100% rated. An assembly may only be listed for 100% operation after it has successfully passed separate testing by UL, as an assembly, per UL requirements.

5.2 Types of Circuit Breakers

5.2.1 Low Voltage Circuit Breakers

Low voltage circuit breakers are available in molded-case, insulated case, and power type. When specifying circuit breakers, the required frame size and desired trip rating must be determined. The choice must be made between draw-out and stationary, and manually operated or electrically operated. A comparison of low voltage circuit breaker types are shown below:

	Power Circuit Breaker	Insulated Case Circuit Breaker	Molded Case Circuit Breaker
Maintainability	Fully Replaceable: - arc chutes - contacts - springs	Arc chutes may be replaceable depending on the manufacturer	No internal maintenance Circuit breakers are sealed
Certification	ANSI C37.16 UL1066	UL 489 (or UL1066)	UL 489
Mounting	Drawout	Drawout or Fixed	Fixed
Operation	Two-Step Stored Energy Electrically Operated or Mechanically Operated	Two-Step Stored Energy Electrically Operated or Mechanically Operated	Toggle Typically Mechanically Operated Only
Trip Unit Type	Electronic	Electronic	Thermal Magnetic or Electronic
100% Rated	Yes	Yes	Typicallly 80% rated 100% optional with electronic trip unit
Instantaneous Override Trip	Optional	Yes ~ 13 times rating	Yes ~ 10 times rating
30-Cycle Withstand	Yes Up to Full Interrupt Rating	Yes Less than Full Interrupt Rating	No

Figure 16 – Low Voltage Circuit Breaker Comparison

5.2.1.1 Low Voltage Molded Case

Molded case circuit breakers are a fixed mount, completely sealed design, primarily intended for wire protection. Molded case circuit breakers can be bolt-on or plug-in mounted.

Molded case circuit breakers typically have a maximum voltage limit of 600V and feature the following main components:

- Molded case - a housing of insulating materials.
- Operating mechanism - opens and closes the breaker.
- Contacts – carry current.
- Arc extinguishers – confine and extinguish the arc which will be drawn between contacts each time they interrupt current.
- Trip elements – monitor current and trip the operating mechanism and open the contacts in the event of a fault condition.
- Terminal connectors - connect the circuit breakers to the power source and the load.

Short time current ratings on molded case circuit breakers are much lower than their interrupting ratings. Selective tripping is available over a small range well below kAIC ratings. They are typically operated via a mechanical over-center toggle; add-on motor operators are available. Low voltage molded case circuit breakers exhibit the following characteristics:

- Must be certified to the UL 489 standard.
- No internal maintenance required due to circuit breaker being sealed.
- Can be thermal-magnetically tripped or electronically tripped.
- 10X instantaneous override trip.
- Voltage limit of 600V.

Figure 17 – Molded Case Circuit Breakers

5.2.1.2 Low Voltage Insulated Case

Insulated case circuit breakers exhibit the following characteristics:

- Must be certified to the UL 489 standard.
- Can be fixed-mounted or drawout-mounted.
- Electronically tripped.
- 13X Instantaneous override trip.
- 30-cycle withstand less than full interrupt rating.

Figure 18 – Insulated Case Circuit Breaker

5.2.2 Low Voltage Power Breakers

Power circuit breakers are designed to be connected to busbars in switchgear. They may be manually operated or electrically operated. They have fully replaceable (field maintainable) arc-chutes, contacts, and springs. Low voltage power breakers exhibit the following characteristics:

- Must be certified to UL 1066 standards.
- Must be drawout mounted.
- Electronically tripped.
- 30-cycle withstand up to full interrupt rating.
- Perform fast re-closure to maintain high continuity of service.
- Trip unit is integrally mounted on the circuit breaker.

Some of the advantages of power circuit breakers are

- High interrupting ratings.
- High short time ratings.
- Speed of operations:
  - ❖ Remote open/close operation.
  - ❖ Fast re-closing.

    - ❖ Transfer loads while maintaining continuity of service:
        - o Used for paralleling switch gear.
        - o Used in main-tie-main transfer schemes.
- Coordination/selectivity.
- Maintainability.

Figure 19 – Power Circuit Breakers

5.2.3 Medium Voltage Circuit Breakers

Two types of medium voltage circuit breakers are typically used: vacuum circuit breakers and SF_6 circuit breakers. In North America vacuum circuit breakers are typically used; internationally SF_6 circuit breakers are commonly found.

5.2.3.1 Vacuum Circuit Breakers

The vacuum interrupter (Figure 20) is a pair of separable contacts enclosed in a vacuum-tight envelope. The envelope itself is a ceramic material with a metal end plate brazed to each end. The metal plates seal the ends and provide support for the parts inside.

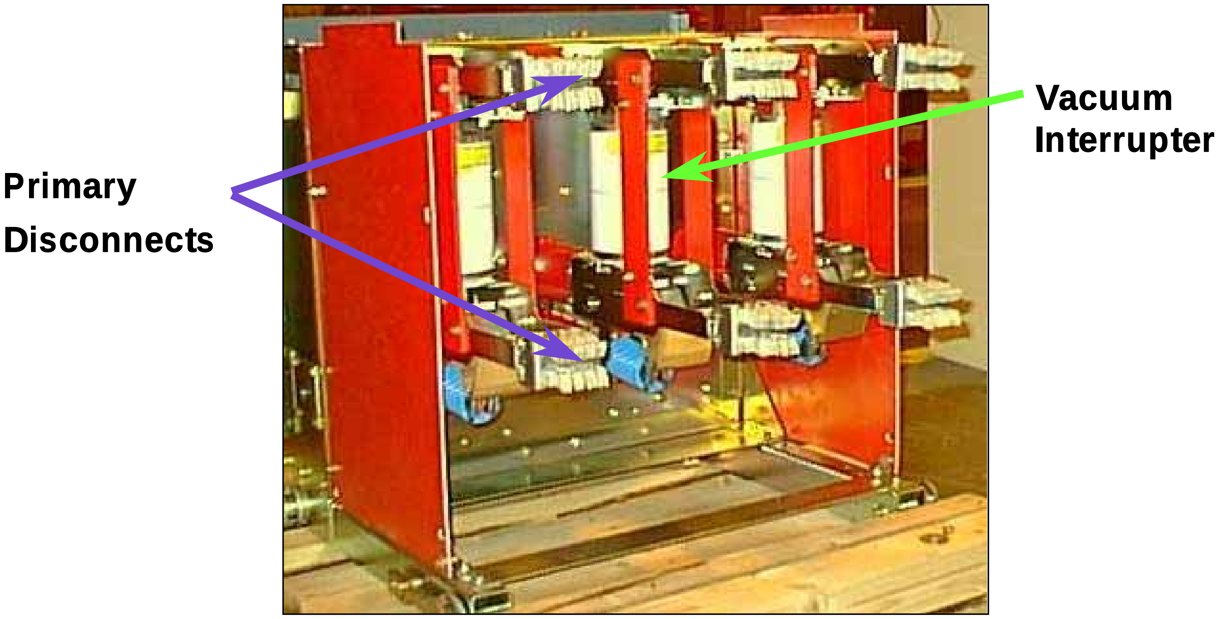


Figure 20 – Vacuum Breaker Rear View

Of the two contacts inside, one is fixed and the other is movable through a bellows type connection.

Various shields inside the envelope provide different types of protection to interrupter parts.

When the circuit breaker is closed, the contacts within the interrupter touch, allowing current to flow.

When a fault occurs and interruption is required, the contacts are quickly separated and an arc forms. An arc is formed because the voltage tries to keep the current moving.

Figure 21 – Interrupter Cut Away View

The arc burns in the metal vapor evaporated from hot spots on the contact surfaces. This metal vapor continuously leaves the contact region and re-condenses on the contact surfaces and surrounding metal shield which protects the ceramic envelope.

At current zero the arc extinguishes, contact vapor production stops, and the original vacuum condition is restored. Current zero is a point in the AC current sine wave where the value is zero.

The vacuum in the envelope is considered a dielectric. The dielectric strength is the maximum voltage the dielectric can withstand without breaking down. The transient recovery voltage is the most severe wave form the interrupter will have to withstand. This is why the speed of the dielectric recovery and the strength of the dielectric inside the interrupter are critical issues for successful circuit interruption. If the dielectric does not reach sufficient strength fast enough, the arc will re-ignite.

Vacuum interrupters for circuit breaker duty must be capable of interrupting currents of 12-50kA and up at voltages up to 38kV.

Figure 22 – Vacuum Circuit Breaker

5.2.3.2 SF$_6$ Circuit Breakers

Popular outside of the United States is SF$_6$ technology. It is specifically associated with European manufacturers of medium and higher voltage circuit breakers.

In an SF_6 circuit breaker the main contacts are enclosed in a chamber of SF_6 gas, a good dielectric. The arc interruption technology results in arc energy being used and absorbed while the arc is simultaneously cooled.

There are several types of SF_6 interrupter designs; the two most common types are:

- Puffer.
- Rotary arc.

Puffer:

The puffer-type interrupter is more complicated than the rotary arc-type. During current interruption a piston compresses the SF_6 gas in a cylinder, all of which is contained in an epoxy-type enclosure. After the main current-carrying contacts separate the current transfers to the arcing contacts. Once the arcing contacts separate the SF_6 gas in the compression chamber blasts the arc through the nozzle. The heat created by the arc breaks the SF_6 molecules into fluorine and sulfur. Arc energy is absorbed and the arc is cooled.

As current zero is approached the heat energy subsides as more SF_6 gas flows through the nozzle and extinguishes the arc.

Rotary Arc:

The rotary arc technology is less complicated than the puffer type; however, it is not effective over as wide a range of short circuit currents and voltages as the SF_6 puffer or vacuum CBs.

As the contacts separate the arc transfers from the main contacts to an annular contact; this causes the current to switch into the coil behind it. The coil's magnetic field, produced by the load current, causes the arc to rotate rapidly. The arc is cooled by moving through the SF_6 gas.

The SF_6 gas is normally at rest inside the interrupter. The arc's movement acts like a mixer, mixing hotter and cooler gas to help cool the arc. Contact erosion is also reduced due to the rapid arc movement.

At current zero, the arc is cooled and extinguished.

5.3 Trip Units

Trip units are most commonly found on low voltage applications. The trip units serve as the logic control for the breaker. There are two types of trip units:

- Thermal magnetic.
- Electronic.

Thermal magnetic units offer a delay in the event of overload while responding quickly to excessive current. Magnetic-only units are mainly used to protect motors and fire pumps in a high-heat application.

Electronic trip units provide more sophisticated protection and monitoring by measuring and comparing actual current with a reference table of values to determine the appropriate response. A variety of settings make it possible to adapt the breaker to the precise characteristics of the protected circuit.

In addition, electronic trip units offer communication and monitoring capabilities. Current demand and ground fault current can be monitored as well as breaker status, settings of protection functions, and trip history.

Residual current devices that provide earth leakage protection are also available, as well as a broad range of accessories.

Four trip unit protective functions exist:

1. Long Delay (L).
2. Short Delay (S).
3. Instantaneous (I).
4. Ground Fault (G).

In applications, the trip functions afforded by the trip unit of the breaker are abbreviated in the form of L, S, I, and G. i.e. a trip unit with long delay, short delay, and instantaneous functions would be abbreviated as LSI.

5.3.1 Solid State Circuitry

Conventional breakers are available with either fixed or interchangeable electromechanical trip units depending on the breaker and frame size. Although trip units can be changed, failure to correctly tighten the electrical connections is a frequent cause of circuit breaker problems in the field.

Most manufacturers offer molded case breakers with current transformers and solid-state circuitry in place of the conventional thermal magnetic trip units. This offers advantages including:

- Quickly modified overload protection rating by changing a rating plug (versus changing the entire trip unit).
- Adjustable instantaneous or short circuit trip rating capability to selectively trip other breakers in the system through incorporation of a time delay in the instantaneous or short circuit trip.

5.3.2 Long Delay (L)

Long delay pickup determines the continuous ampere rating of the breaker. It also determines the amount of time the breaker will carry a low level overload before tripping.

There are two types of responses in long delay pickup:

1. I^2t response
   a. I^2t in: for coordination with other circuit breakers with electronic trip devices and for coordination with thermal magnetic circuit breakers.
2. I^4t response
   a. I^4t out: for coordination with fuses and upstream transformer damage curves.

5.3.3 Short Delay (S)

Short delay pickups determine or set the level of fault current at which the short time trip delay countdown is actuated. Short delay sets the amount of time the breaker will carry both low level and high fault currents before tripping.

There are two types of short delay responses:

1. Flat response
   a. I^2t out: for coordination with other circuit breakers with electronic trip devices.
2. I^2t response
   a. I^2t in: for coordination with fuses and thermal magnetic breakers.

5.3.4 Ground Fault (G)

Ground fault is defined as an unintentional electric path between a source of current and a grounded surface. Ground faults occur when current is leaking and electricity is escaping into the ground.

Ground faults may be divided into three classes:

1. A bolted fault.
2. Faults resulting from insulation depreciation starting as what may be considered a leakage from 10 to 250mA. Such a breakdown may be observed in equipment such as motors and transformers.
3. Faults resulting from immediate insulation breakdown producing an arc.

The NEC creates specific standards for ground fault protection which should be used when designing a system.

The rating of the service disconnect is considered to be the rating of the largest fuse that can be installed or the highest continuous current trip setting for which the actual overcurrent device installed in a circuit breaker is rated or can be adjusted.

Ground fault trip units can be preselected to either trip the main contacts or to leave the main contacts closed and annunciate the ground fault condition.

The zero-sequence current transformer (CT) is used for sensitive ground fault relaying or self-balancing primary current type machine differential protection. In a zero-sequence CT, the three-core cable or three single cores of a three phase system pass through the inner diameter of the CT. When the system is fault free, no current flows in the secondary of the zero-sequence CT. When there is a fault, the residual current of the system flows through the secondary of the zero-sequence CT which operates the relay.

The minimum number of current transformers for circuit relaying and instruments is three current transformers, one for each phase or 2-phase connected current transformers and one zero-sequence current transformer. Separate sets of current transformers are required for differential relays.

The minimum pickup of a ground relay in the residual of 3-phase connected current transformers is primarily determined by the current transformer ratio. Adding one residual connected auxiliary current transformer can reduce the relay pickup. This connection is desirable on main incoming and tie circuits of low resistance grounded circuits.

5.3.5 Anti-Pump

An anti-pump is a device that prevents a circuit breaker from repeatedly opening and closing with both open and closed signals applied simultaneously.

Without the anti-pump the breaker would be destroyed; as soon as the breaker trips the motor operator recloses the breaker, the breaker immediately trips again, and the cycle of tripping and re-closing continues.

5.4 Components

5.4.1 Shunt Trip

A shunt trip is a solenoid device used to trip a breaker from a remote location.

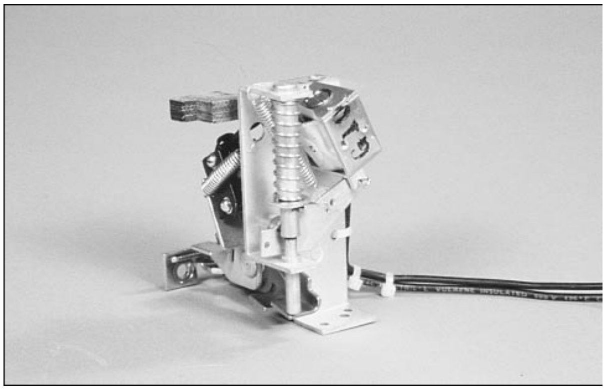


Figure 23– Shunt Trip

5.4.2 Under-Voltage Device

An under-voltage device will trip the breaker when the voltage falls below a predetermined level. Usually mounted in place of the shunt trip, these units include a spring and solenoid.

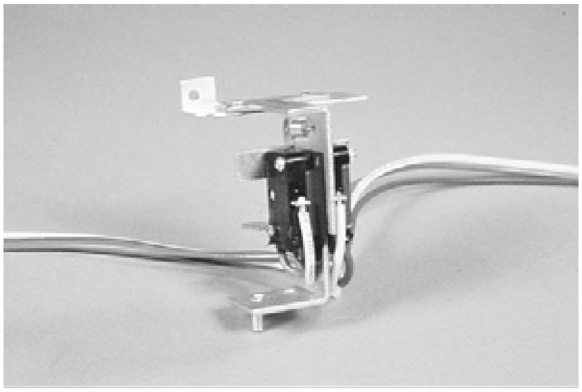


Figure 24 – Under-Voltage Device

5.4.3 Auxiliary Contacts

An auxiliary switch controls normally open and/or normally closed contacts which open and close with the breaker. It can be used with indicating lights to show breaker status.

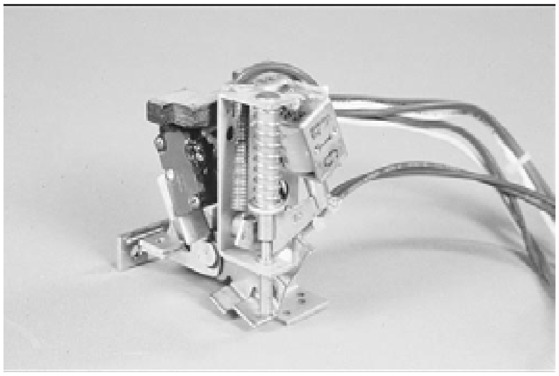


Figure 25 - Aux Contact

5.4.4 Motor Operator

A motor operator allows remote opening and closing of the breaker. It consists of an actuating motor with an operating arm and attaches to the breaker operating mechanism. When the motor operator is energized from a remote location, the operating arm moves the breaker handle to the on or off position as required.

It is not recommended that motor operators be used for paralleling operations. Electrically operated breakers with closing speeds of approximately 5 cycles or less are preferred for paralleling operations.

Figure 26 – Motor Operator

Functions of the motor operator are:

- Switching the load to and from the generator.
- Protecting the generator from short circuits and overloads.

5.4.5 Medium Voltage Circuit Breaker Components

The primary components of a medium voltage breaker pan assembly (Figure 27) are:

- Code Plates
    - Prevent insertion of a lower rated breaker into a higher rated cell.
- Ground Bar
    - Keeps the breaker grounded at all times.
- Levering Mechanism
    - Used to rack the breaker in and out.
- Mechanism Operated Cell (MOC) Switch.
    - Auxiliary contacts that operate when the breaker opens or closes.
- Truck Operated Cell (TOC) Switch.
    - Auxiliary contacts that operate when the breaker is levered into or out of the cell.

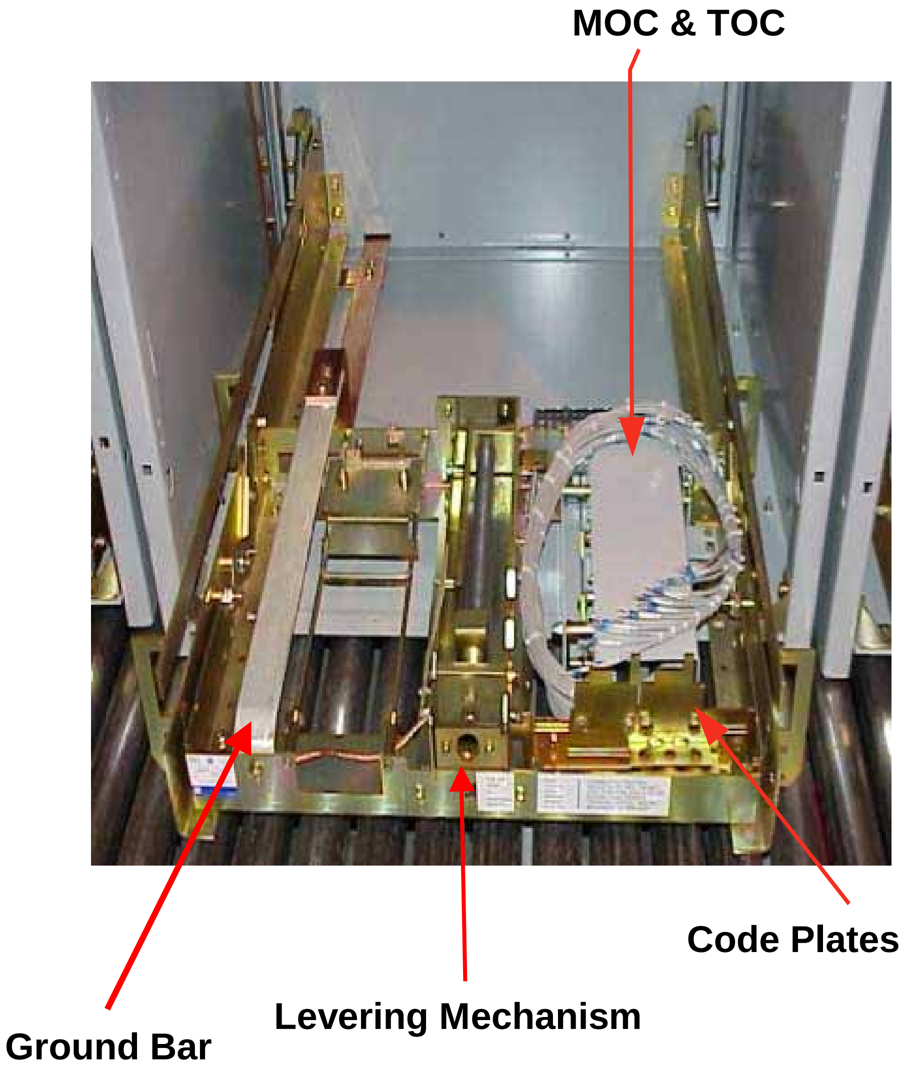


Figure 27 – Medium Voltage Breaker Pan Assembly

5.5 Sizing Circuit Breakers

A circuit breaker is required to connect or disconnect the electrical load to and from the generator. To size the circuit breaker and switchgear the following formula should be used:

Breaker Size (in amperes)

$$= \frac{\text{kW x 1000}}{\text{1.732 x volts x 0.9 x pf}}$$

Where:

kW = net rating of the generator set

Volts = system voltage, phase-to-phase or line-to-line

pf = power factor of the system load

Constants:

1000 – to convert kW to watts

1.732 – for three-phase system

0.9 – temperature compensation and overload margin for the circuit breaker

This formula can be simplified to read:

Breaker Size (in amperes)

$$= \frac{\text{kW x 642}}{\text{volts x power factor}}$$

5.6 Overload Protection

Though circuit breakers are designed to protect against overloads, they should not trip open instantaneously when current limits are exceeded; this would result in nuisance tripping. Breakers should trip before the cable insulation is damaged.

In an overload condition, heating in a cable is a function of the current level and time. Time delay on tripping should be quite long for slight overloads but Ohm's Law states that the heating effect varies with the square of the current, so the delay must be reduced rapidly as the overload increases.

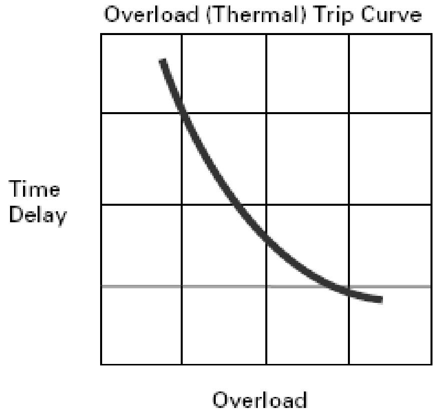


Figure 28 – Overload Trip Curve

Using a bimetal element heated by the load current provides overload or thermal protection. A bimetal element is made of two strips of metal (each with a different rate of thermal expansion) banded together. Heat due to excessive current will cause the bimetal to bend or deflect; the amount of deflection is dependent on the amount of heat, which is a function of current and time.

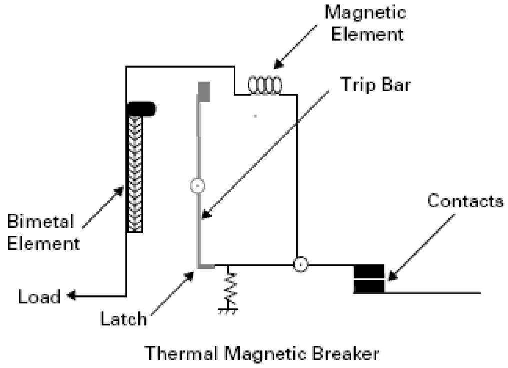


Figure 29 – Thermal Magnetic Breaker

On sustained overload, the deflected bimetal element will cause the operating mechanism to trip.

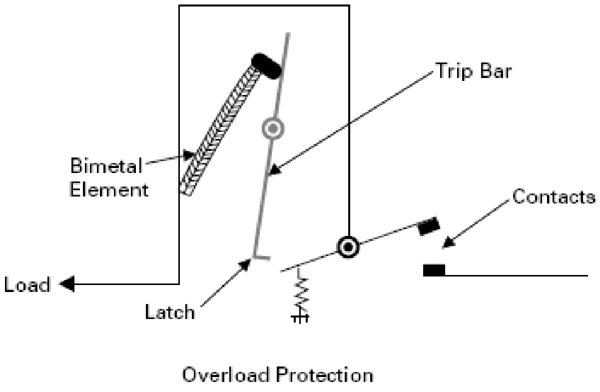


Figure 30 – Overload Protection/ Tripped

A 100A breaker might trip in 30 minutes when carrying 135% of its rated current, but might trip in ten seconds when carrying 500% of its rating. Using these values, a thermal trip curve can be constructed as shown in Figure 31.

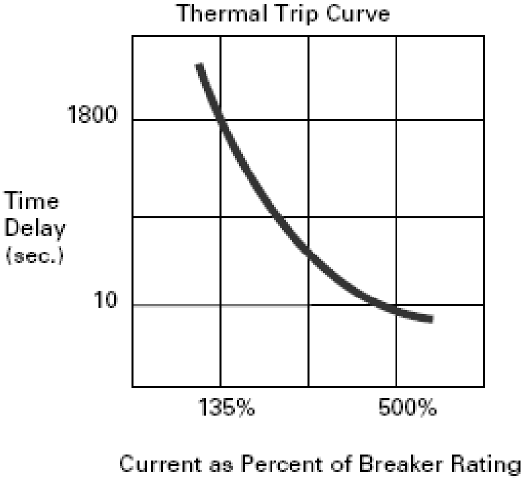


Figure 31– Thermal Trip Curve

5.7 Short Circuit Protection

A short circuit is an accidental or unplanned connection of low resistance between two points that are normally separated by a high resistance. It results in an immediate flow of current at abnormally high levels. The heat generated by this condition can cause severe damage to wiring and other components in a short period of time.

In a short circuit condition, the system cannot wait for an element to heat up before the breaker opens; the breaker must open as quickly as possible. This is achieved by using an electromagnet in series with the load current.

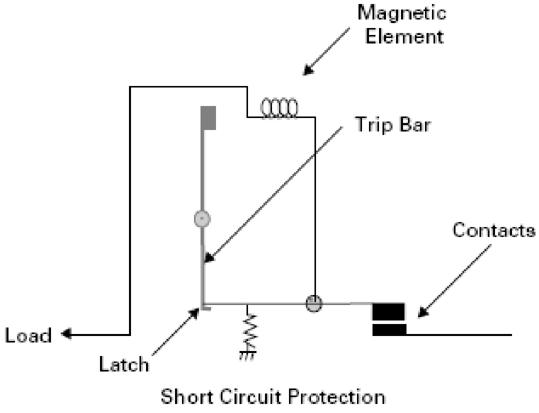


Figure 32 – Short Circuit Protection/Closed Breaker

When a short circuit occurs, the fault current passing through the circuit energizes the electromagnet and causes the trip to open the breaker. The only delay in this action is time required for the breaker contacts to open and extinguish the arc, which takes place in less than one cycle (0.016 seconds for 60Hz, 0.02 seconds for 50Hz).

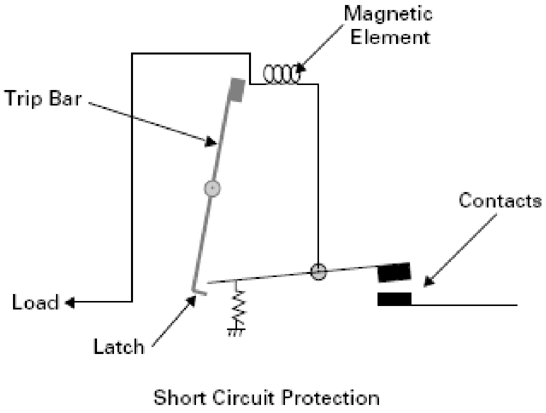


Figure 33 – Short Circuit Protection / Open Breaker

This instantaneous tripping is illustrated in a typical magnetic trip curve, shown in Figure 34.

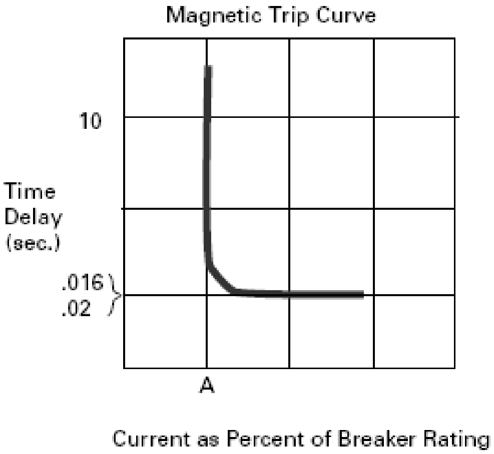


Figure 34 – Magnetic Trip Curve

The breaker will trip as soon as the fault current exceeds value A. The magnetic trip element is often adjustable to allow for varying the fault current level at which the breakers will trip instantaneously; this allows for varying motor starting inrush current levels.

Combining the features of the thermal overload protection and the magnetic short circuit protection, a typical thermal magnetic circuit breaker can be constructed. The thermal and magnetic trip curves can then be combined.

In this typical example, if there were an overload of 250% of the rated current, the breaker will trip in 60 seconds due to thermal action.

If instead of the overload there were a short circuit of 40 times the breaker rating, the breaker would trip in approximately one cycle. So the thermal magnetic trip will not trip immediately if the overload is not dangerous, but will trip on heavy short circuit current.

5.8 Control Power

5.8.1 Batteries

Circuit breaker control power may be derived from a combination of a station battery and engine cranking batteries (24 VDC) connected together through a best battery diode circuit. AC power derived from utility and/or generator source may also be used for circuit breaker control power.

The best battery diode circuit is necessary to avoid connecting starting batteries directly in parallel and prevents cranking the engines with the station battery.

When designing a best battery diode circuit:

- Size diodes to allow proper forward current and to prevent reverse current.
- Peak inverse voltage must be considered.

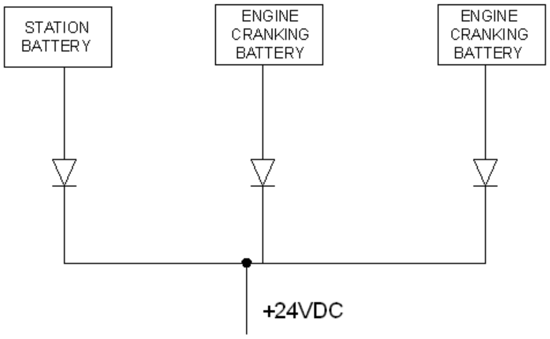


Figure 35 – Best Battery Diode Circuit

5.8.2 Battery Chargers

Utility power is typically used to recharge the batteries using battery chargers. Input power to the battery charger is typically 120 VAC single phase.

6 CONTROLS

6.1 Components

6.1.1 Control Relay

A control relay is an electromechanical device consisting of a coil and sets of contacts used for a number of functions including:

- Closing or tripping circuit breakers.
- Discrete status of devices
- Turning on or off other control devices.

Control relays have only two possible operating states: on and off. A control relay is essentially a switch; control relays use one or more pairs of contacts to make or break circuits. Multiple control relays can be grouped together in a ladder logic configuration to accomplish more complex functions.

Programmable logic controllers and digital automation processors have for the most part replaced control relays in more complex circuitry due to improvements on space savings, flexibility, and speed.

Control relays are still a necessary device due to higher current ratings of their contacts. In these instances, the control relay will be acting as a pilot relay to switch higher voltage and/or current to a particular device. See Figure 36.

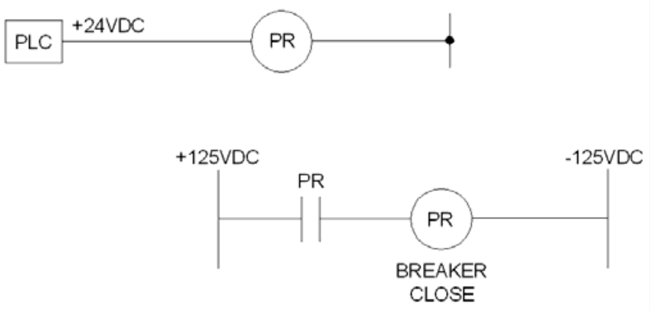


Figure 36 – PLC/Control Relay

6.1.2 Programmable Logic Controller

A programmable logic controller (PLC) is a microprocessor-based electronic device used for automation. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory system. A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result.

6.1.3 Transducer

A transducer is a device that converts one form of energy to another. Transducers typically convert:

- Voltage.
- Current.
- Power.
- Frequency.
- Fuel Levels.
- Temperature.
- Pressure.

Transducers will convert these parameters into signal level information which can be used by a PLC or other control device for processing.

6.1.4 Operator Interface

The operator interface allows the operator of a machine to monitor and control devices in the system. The operator can view and adjust the following system parameters:

- Electrical metering.
- Engine metering.
- Protective relay settings.
- Annunciators.
- Synchronize and parallel.
- Set modes of operations.
- Voltage and frequency adjustments.

6.2 Communications

6.2.1 Modbus

Modbus is a serial communications protocol published by Modicon for use with its programmable logic controllers. This protocol allows for communication between multiple devices connected to the same network and is often used to connect a supervisory computer with a remote terminal unit (RTU) in supervisory control and data acquisition (SCADA) systems.

Versions of the Modbus protocol exist for serial port (e.g. Modbus RTU) and Ethernet (e.g. Modbus TCP). Every Modbus network consists of one master device and at least one slave device. All devices on the network are daisy-chained using a twisted pair cable, with each slave device assigned a factory default unique address for each Modbus card; this address enables the master to distinguish between the various slaves on the network. It also allows the master device to send a query command to the addressed slave. When the addressed slave receives this command it will send back an appropriate response to the master.

6.2.2 Ethernet

Ethernet is a large, diverse family of frame-based computer networking technologies that operates at many speeds for local area networks (LANs). For switchgear it provides a way for individuals to remotely monitor and/or control the switchgear with a computer.

6.2.3 Remote Monitoring and Control

The system/group monitoring systems most commonly used are the Building Management System (BMS), Building Automation System (BAS), and Supervisory Control and Data Acquisition (SCADA).

Implementing monitoring systems with devices that are equipped with Ethernet or Modbus communication abilities enables integration of the electric power system controls with the building equipment controls for a single application to control all systems within a building.

6.2.3.1 Building Management/ Automation System

A Building Management System (BMS) or Building Automation System (BAS) is a computer software program used to control, monitor, and manage all the equipment installed in the building. Customers frequently integrate the monitoring and control of the emergency power system components with the BMS/BAS. The BMS can also be used to incorporate electrical, HVAC, fire safety, elevator/escalator, etc. into one system.

To accomplish this integration, a means by which to communicate electric power systems (EPS) parameters to their system is required. Typically a dedicated PLC on the switchgear master controls is used for integrating with the BMS.

6.2.3.2 SCADA

Supervisory Control and Data Acquisition (SCADA) systems are typically used to perform data collection and control at the supervisory level. The supervisory control system is a system that is placed on top of a real time control system to control a process external to the SCADA system.

The SCADA system can utilize either the Modbus connection or the Ethernet connection to monitor and control the switchgear and automatic transfer switch.

6.2.4 Human Machine Interface

Human machine interface (HMI) refers to a touch-screen used by the operator for interfacing with the paralleling generator system. The system provides the user a means of:

- Input: Allowing the users to manipulate the system.
- Output: Allowing the system to display the effects of the users' manipulation.

6.2.5 Reporting and Trending

Trending is the capability of reporting a set of given data over a period of time.

Switchgear controls may contain functions which will allow reporting and trending of data such as:

- Frequency.
- Voltage.
- Current.
- Temperatures.
- Fuel Consumption.
- Pressures.
- Typically, engine and generator set information communicated to the switchgear can be trended with reported time and a date data

6.3 Master Controls

Master controls contain system level functionality not specific to any individual generator set. Typically, integration with other building systems will occur at the master controls.

They could contain additional controls for paralleling with utility grid or other systems across a point of common coupling (PCC). Examples of master controls functionality are:

- Load sense/demand.
- Load shed/add.
- Dead bus arbitration.
- Integration with BMS.
- System level testing.
- Reporting, trending, and alarming.
- System level metering and protective relaying.

6.3.1 Load Sense/Demand

Load sense/demand, also referred to as "generator demand priority control," "bus optimization," "generator load based sequencing," or "load demand sensing" is a feature whereby the optimum number of generators is paralleled, serving facility loads to maintain peak fuel efficiency with adequate reserve available.

Load sense/demand typically will have user selected set points to set the level for spinning reserve.

Spinning reserve is the amount of total additional generator unused capacity available on the load bus.

Upon entrance into a load sense/demand mode of operation all generators will be started and paralleled to the bus. After a given time delay generators are removed from the bus as a function of a generator loading percentage set point. Generators should be removed from the bus in descending priority.

Should the generator loading percentage increase to a pre-selected generator add limit, the next priority generator will be started, synchronized, and paralleled to the bus. Generators should be added to the bus in ascending priority order.

6.3.2 Load Prioritization

Prioritization is the process by which the customer identifies what electrical loads are needed and in what priority.

The highest priority loads are powered first; the first generator set ready to accept the load takes the first priority loads. As capacity becomes available, the next highest prioritized load is powered. This process repeats until all loads are applied.

Smaller load steps equate to smaller transients, which result in smoother transitions. For example, a medical center might prioritize lifesaving equipment as the number one need.

That equipment (or special outlets for that equipment) is the first supplied with electricity from the first available generator set. Lights may be identified as the second most important need and handled by the second load step.

When starting generator sets without a preferred load order it is suggested that the largest loads are started first.

The largest transient will occur before the system is heavily loaded. These large loads will have the least effect on the rest of the system.

6.3.3 Load Shed/Add

When speaking of load shedding/ adding this document is referring to local loads served by the switchgear and generator power system. The utility industry uses the term load shedding to mean disconnecting their service to users as a means to manage capacity.

Power systems are designed and operated so that for any normal system condition, including a defined set of contingency conditions, there are adequate generating and transmission capacities to meet load requirements. However, there are economic limits on the excess capacity designed into a system and the contingency outages under which a system may be designed to operate satisfactorily.

For those conditions where the systems capability is exceeded, processes must be in place to automatically monitor power systems loading levels and reduce loading when required. A load-shed system automatically senses overload conditions and sheds enough load to relieve the overloaded generator sets before there is loss of generation, line tripping, equipment damage, or a chaotic random shutdown of the system.

For example, in a factory all welding equipment and other machines may be operated at capacity at the same time between 10 am and 12 noon and then again between 1 pm and 3 pm. During these times the load to lights in the lunchroom and parking lot would be shed because they are less of a priority.

Conversely, load-add circuits serve to bring loads online based on available capacity of the power system. Prioritization will dictate the order the loads come online.

6.3.4 Dead Bus Arbitration

When multiple generators are simultaneously started, their outputs are not synchronized when they reach rated speed and voltage. If more than one generator is allowed to simultaneously close to the de-energized (dead) bus, an out of phase paralleling situation occurs. Therefore, one generator must be selected to close to the dead bus prior to the other generators initiating synchronization.

Failure of the control system to allow only one generator to exclusively close to the dead bus could result in extensive damage to the generator sets.

Automatic circuit breaker closure is inhibited to all units except one. The one that is selected is typically the first generator to reach rated speed and voltage.

6.3.5 System Level Testing

Certain emergency power systems are required to be tested periodically. It may be necessary to perform these tests automatically. The master control may be configured with an automatic or manual test switch to initiate various system level function tests with or without load. In addition to an overall system level test, the generator sets may be exercised periodically to maintain proper fluid circulation.

6.3.6 System Level Protective Relaying and Metering

Protective relaying is a system of relays used to protect service from interruption or to prevent or limit damage to apparatus.

System level metering may include:

- Totalized kW metering from the load bus.
- kW-hr metering for purposes of revenue metering.
- Utility grade metering.

6.4 Generator Controls

6.4.1 Voltage Control

6.4.1.1 Voltage Regulators

A voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level. The voltage regulator may use an electromechanical mechanism or passive/active electronic components; it may be used to regulate one or more AC or DC voltages.

Voltage regulators (with the exception of shunt regulators) operate by comparing actual output voltage to an internal fixed reference voltage. Any difference between the voltages is amplified and used to control the regulation element.

6.4.2 Speed Control

Speed is controlled to adjust the frequency and load level of the generator set. Speed must also be controlled for proper synchronization. Speed is controlled by adjusting fuel throttle position. For additional information on speed control, see the Governor Section of Engine A&I Guide.

6.4.3 Communication

Communication is the means by which switchgear communicates with the engine generation set. This could include discrete outputs from the generator set indicating common alarm, common shutdown, etc. It also could include data from the engine generator set such as engine temperatures, pressures, fuel consumption, etc.

6.5 Protective Devices

The application of switchgear and/or synchronous generators into any installation requires at least a minimum amount of protection to protect the generator and prime mover against faults and abnormal operating conditions. The customer needs to balance the expense of applying a particular protective device (relay, surge arrestor, etc...) against the consequences of losing a generator or prime mover. When considering what protective devices to use, the potential loss of a generator or prime as well as the impact of loss of service needs to be considered. The extent of the protection system design will depend on the size and relative value of the generating unit. There is no standard solution based on the generator set power rating, however large critical units tend to have extensive protection systems with redundancy while smaller less critical units may have a subset of the primary protection provided for the larger unit with little if any backup protection. It is the responsibility of the customer to understand the site and application and to provide the appropriate amount of protection. This will require an evaluation of the potential risks, and a commercial evaluation of the cost for protection devices versus the cost of failed equipment.

There are a number of faults, which could have serious impacts on service reliability. To detect and reduce/eliminate the impacts of these faults, a variety of relay configurations and protective devices can be used. This section provides detailed descriptions of important protective devices. Also, possible faults are shown under the IEEE Device Numbering system in Appendix A.

Reference Material

The following information is provided as additional reference to subjects discussed in this section. You can also reference the bibliography at the end of this guide.

IEEE Std 142 - IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

IEEE C62.92 - IEEE guide for the application of neutral grounding in electrical utility systems. Part II -

grounding of synchronous generator systems

IEEE C62.92.1 - IEEE guide for the application of neutral grounding in electrical utility systems - Part 1: introduction

IEEE C62.92.2 - IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part II-Grounding of Synchronous Generator Systems

IEEE C62.92.3 - IEEE guide for the neutral grounding in electrical utility systems, Part III-Generator Auxiliary Systems

IEEE C62.92.4 - IEEE guide for the application of neutral grounding in electrical utility systems, part IV - distribution

IEEE C62.92.5 - Active - IEEE guide for the application of neutral grounding in electrical utility systems, part V - transmission systems and subtransmission systems

IEEE C37.101 - IEEE Guide for Generator Ground Protection

IEEE C37.102 - IEEE guide for AC generator protection

25 - The Synch Check (Synchronizing or Synchronism Check) Relay is a relay that functions when two AC circuits are within the desired limits of frequency, phase angle and voltage, to permit or to cause the paralleling of these two circuits. The Synch Check Relay is used to prevent out of phase closure when paralleling generators to each other or when paralleling generators to another source.

27 - The Under-Voltage Relay is a device that functions on a given value of under-voltage. This device protects equipment that would otherwise be damaged from operating at voltages less than what is specified. The device also protects the generator from operating at low voltage output which by Ohm’s Law would require a higher current output for the same power (kW) output.

32 - The Reverse (or Directional) Power Relay is a relay that functions on a desired value of power flow in a given direction. The Reverse Power Relay is used to prevent power flow in the reverse direction; this function protects the generator from becoming motorized and damaging the prime mover.

32RV - The Reverse Power (reactive/kVAR) Relay is a relay that functions on a desired value of reactive power flow in a given direction. 32RV is used to prevent reactive power flow in the reverse direction. This prevents reverse reactive power flow to the generator that would cause excessive heat build up and damage the machine.

38 - A Bearing Protective Device is a device that functions on excessive bearing temperature or other abnormal mechanical conditions associated with the bearing, such as undue wear which may eventually result in excessive bearing temperature or failure. Thermocouple or resistive temperature device sensors are used to detect this condition. When a pre-programmed temperature limit is reached, the relay energizes its output accordingly.

A resistive temperature device (RTD) supplies a constant current to a resistive element located on the bearing housing and senses the temperature of the bearing by measuring the voltage across the resistive element.

A thermocouple is a device in which the temperature difference between the ends of a pair of dissimilar metal wires is deduced from a measurement of the difference in the thermoelectric potentials developed along the wires.

40 - The Loss of Field Relay is a relay that functions on a given or abnormally low value or failure of machine field current, or on an excessive value of the reactive component of armature current in an ac machine indicating abnormally low field excitation. Loss of Field is used to prevent reverse reactive power flow to the generator that would cause excessive heat build up and damage the alternator windings.

A Loss of Field Relay that utilizes the mho function is recommended for paralleling applications to provide superior fast acting protection, without nuisance tripping. In addition to protecting the generator from reverse reactive power, the Loss of Field Relay is utilized to prevent a generator from operating at a leading power factor, whereas there is a weakening of magnetic coupling resulting in rotor pole slipping or generator falling out of synchronism due to the inability of the voltage regulator to effectively control the generator.

46 - Reverse Phase or Phase Balance Current Relay functions when the polyphase currents are of the reverse phase sequence, or when the polyphase currents are unbalanced or contain negative phase-sequence components above a given amount.

The 46 responds to the negative phase sequence current which flows during unbalance faults or loads on a power system; this will protect machines against excessive heating damage due to prolonged current unbalance.

47 - The Phase Sequence Voltage Relay functions upon a predetermined value of three-phase voltage in the desired phase sequence. This relay is used to detect under-voltage conditions and/or incorrect phase sequence of the incoming utility. When this relay operates it starts the process of causing the system to enter Emergency Mode.

49 - A Machine (Generator) or Transformer Thermal Relay is a relay that functions when the temperature of a machine armature winding (stator) or other load-carrying winding or element of a machine exceeds a predetermined value. Thermocouple or RTD sensors function as described in Type 38.

50 - The Instantaneous Over-Current Relay functions instantaneously on an excessive value of current or on an excessive rate of current rise, thus indicating a fault in the circuit or apparatus being protected.

51 - The Timed Over-Current Relay is a relay with either a definite or inverse time characteristic that functions when the current in a circuit exceeds a predetermined value.

This relay functions the same as the long time trip in a breaker trip unit.

This relay is commonly used in conjunction with a neutral grounding impedance to detect excessive ground current. In such cases it is referred to as device function 51G.

The type (resistive or inductive) and sizing (low or high) of neutral grounding impedance is dependent on application. The impedance is commonly sized to keep a neutral to ground fault current below the full load current rating of the generator.

The 51G and 87G protective relay functions, when set-up appropriately, are effective at minimizing damage to generator stator windings that could occur due to migration of shorted turns in a stator slot evolving to a catastrophic ground fault slot fail that could damage the stator iron.

52 - An AC Circuit Breaker is a device used to close and interrupt an AC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions. Further details can be found in Section 5.

59 - The Over-Voltage Relay is a relay that functions on a given value of over-voltage. This protects equipment from being damaged by long-term high voltage conditions and protects the generator windings and field from overheating and over excitation.

64S - 100% Stator Ground Protection by Low Frequency Signal Injection, used in conjunction with a neutral grounding transformer to provide superior protection in identifying stator insulation weakening, whether the generator is on line or off line.

67 - An AC Directional Over-Current Relay functions on a desired value of AC over-current flowing in a pre-determined direction. This is commonly used across the point of common coupling (PCC) such that no real current will be exported to the grid/utility.

81 - The Under/Over-Frequency Relay responds to the frequency of an electrical quantity, operating when the frequency or rate of change of frequency exceeds or is less than a predetermined value.

86 - The Lockout Relay is an electrically operated, hand or electrically reset, relay that functions to shutdown and holds equipment out of service on the occurrence of abnormal conditions.

87 - The Differential Relays have many applications in power systems. The basic principle is that the current flowing into the relay must equal the current flowing out of the relay. The three types of differential relays are described below.

87B - The Differential Bus Relay operates on the same principle as the Generator Differential Relay. The sum of all currents entering and leaving the bus must be equal to zero under normal conditions or if the fault is outside the protected zone. If there is a fault on the bus there will be a net flow of current to the bus and the differential relay will operate.

87T - The 87T is a Transformer Differential Relay designed as primary protection for power transformers against internal faults. This relay compares the currents entering and leaving the protected transformer.

If any imbalance is detected that is not attributable to other factors the relay provides a contract closure to isolate the power transformer and limit damage.

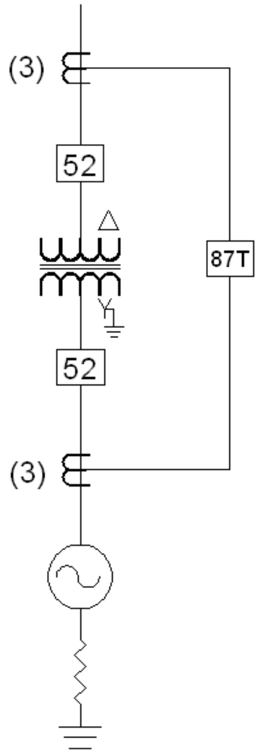


Figure 37 – 87T Protective Relay Scheme

87G - The 87G is a Variable Percentage Differential Relay designed to provide selective, high speed, differential protection for generators.

Differential relaying is the most selective form of fault protection that may be applied to the individual elements, or zones, of AC power systems. The selectivity of differential relaying is based on the ability of the relay to distinguish between an internal fault (within the protected zone) and an external fault. Under normal operating conditions the current into the protected zone equals the current out of the protected zone with a net operating current equal to zero. Internal faults upset this balance and result in a difference between the input and output currents. External faults have relatively little effect on the balance, because the current in still equals the current out of the protected zone. Therefore, by comparing the currents on both sides of the protected element or zone and detecting when these currents are not equal, a differential relay acts to isolate the element or zone from the system.

The 87G typically trips a lockout relay (Device number 86) which in turn trips the generator breaker. For the protective scheme in Figure 38, 6 current transformers are required. 3 CTs must be mounted on the generator leads in the generator housing and 3 CTs must be mounted on the load side of the switchgear generator circuit breaker. It is necessary for these CTs to be sized identically and recommended that they be sourced from the same manufacturer.

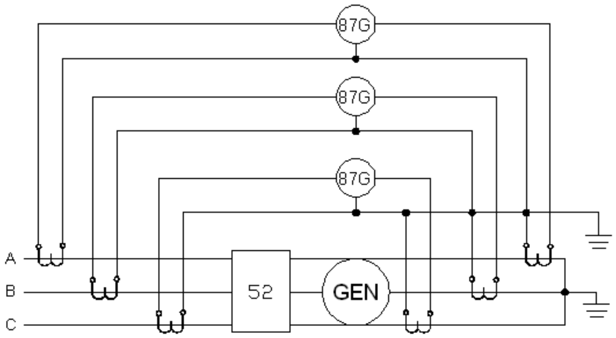


Figure 38 –Typical 87G Protective Relay Scheme

6.5.1 Utility Intertie Protective Relays

Utility Intertie Protective Relays are intended to protect the utility from having generators operating in an unintentional island mode while still connected to the utility grid at the PCC. This protection is accomplished by monitoring the intertie (PCC) to the utility for abnormal voltage, abnormal frequency, and excessive power import/export, which can indicate a loss of the utility supply.

The relay should also provide detection of phase and ground faults as well as current and voltage imbalance of the utility system. A sync check function may also be applied to supervise the closure of the intertie breaker.

See a typical example of a Utility Intertie Protective Relay scheme in Figure 39.

Either the utility or the authority having jurisdiction (AHJ) will specify the exact site requirements.

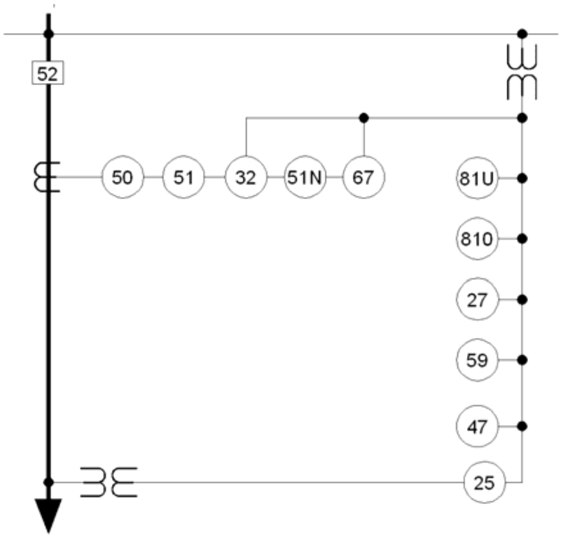


Figure 39 – Utility Intertie Protective Relay Scheme

6.5.1.1 Generator Protective Relays

Generator protective relaying schemes typically contain the following features:

- Over-voltage (59).
- Under-voltage (27).
- Reverse power (32).
- Voltage restrained time over current (51V).
- Under-frequency (81U).
- Over-frequency (81O).

An example of a Generator Protective Relay scheme is shown in Figure 40.

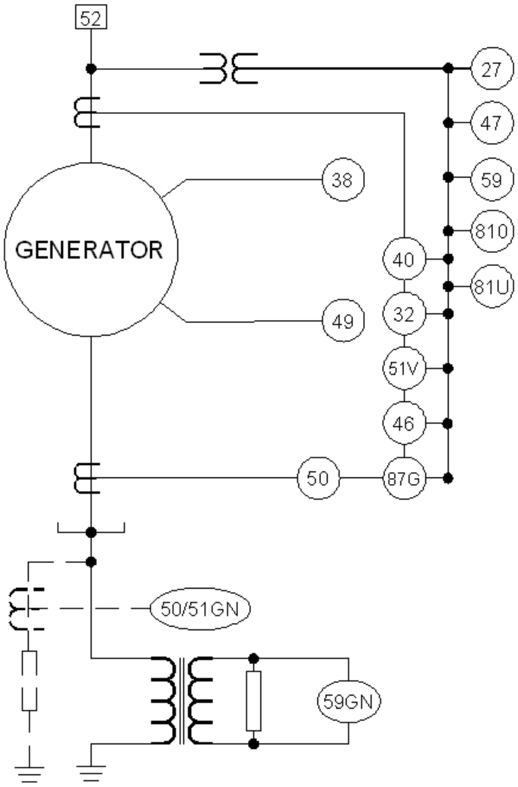


Figure 40 – Generator Protective Relay Scheme

6.5.2 Test Blocks

Test blocks are intended to simulate a fault condition so it can test the protective relay and its ability to operate. Test blocks are mounted on switchboard panels for use in conjunction with proper test equipment to facilitate testing of AC instruments, meters, and relays.

6.5.3 Surge Protection

6.5.3.1 Transient Low Voltage Surge Suppressor

A Transient Voltage Surge Suppressor (TVSS) is a device that attenuates (reduces in magnitude) random, high energy, short duration electrical power anomalies caused by utilities, atmospheric phenomena, or inductive loads. Such anomalies occur in the form of voltage and current spikes with durations of less than half an AC cycle. These high-energy power spikes can damage sensitive electronic equipment such as computers, instrumentation, and process controllers.

Surge suppressors are designed to divert high-energy power away from a load by providing a lower impedance path to common point ground. Surge suppressors used most often for panel-board protection have metal oxide varistors (MOVs) connected in parallel.

6.5.3.2 Surge Arrestors and Surge Capacitors

For medium voltage applications surge arrestors and capacitors are used for protection against system stresses that can be caused by conditions such as lightning surges, circuit breaker switching transients, arcing faults, inductive and/or capacitive load switching. Surge arrestors are used to limit the amplitude of the voltage rise (surge) and the surge capacitor is used to reduce the rate of rise of the voltage. With proper system design, the probability of these surges and their effects can be minimized or virtually eliminated. The method of reducing the risk of damage caused by transient over-voltages heavily depends upon the system and application.

A surge arrestor is used to prevent large surges (power inconsistencies, lightning, etc.) from reaching system components such generators, transformers, etc and ensure the safety of individuals nearby. Surge arrestors are devices that dissipate excess voltage by providing a short circuit to the ground only when over-voltage conditions exist. Surge arrestors use spark gaps or non-conductive materials to prevent regular electric flow from being grounded. If a surge occurs, the over-voltage is safely shunted to the ground and the electrical equipment downstream is protected.

Surge arrestors should be chosen with care. The three classes of surge arrestors that can be utilized are Distribution Class, Intermediate Class, and Station Class. There are multiple things that need to be considered when selecting what classification of arrestors to use and where they need to be located within the system (ie. cost, application, grounding method). Furthermore, the level of protection provided depends upon sizing, placement and the particular devices/equipment within the system.

Surge arrestors function best when located close to generator output leads.

Surge Capacitors can also be used for protection. Resistor-Capacitor pairs can be applied to limit the rate of rise of surge voltages in addition to limiting their magnitude. Surge capacitors are less effective against sheer voltage magnitude, but are more effective in slowing the rate of rise. In addition cable length can be extended to limit reflected waves. In choosing capacitors, it is important to realize that every circuit has a resonant frequency and adding capacitance will change this frequency.

7 METERING

It is essential that critical values be measured and displayed for reference and control purposes. For switchgear typical metering parameters are:

- Utility metering.
- Trip unit metering.
- Generator/generator set metering.
- System metering.
- Revenue metering.

7.1 Discrete Analog vs. Virtual Metering

Virtual metering has primarily taken the place of discrete analog metering. Instead of having numerous analog meters an operator can use the HMI to view a variety of meters on one interface.

- Analog metering devices are typically either ± 2% or ± 1%, while digital metering accuracies are ±1/2% or ±1/4%

7.2 Phase Selector Switch

The phase selector switch allows one meter to monitor all three phases of generator output. The phase selector switch can be set to voltmeter, ammeter, or a combination of the two.

7.3 Ammeter

The ammeter indicates the electrical current flowing through the phases where the CTs are located. With AC generators the ammeter usually has a 5A movement and must be used with a current transformer.

7.4 Voltmeter

Used to measure voltage, the voltmeter is often designed for 120V full-scale deflection and must be used with potential transformers (PTs). The voltmeter designed for wall-mounted switchgear can take the full voltage of the system up to and including 600V. On floor-standing switchgear, the voltmeter works on full voltage of 208V maximum. For voltage beyond 208V, PTs are used.

7.5 Frequency Meter

This monitors the frequency of the AC sine wave of the source or bus.

7.6 Wattmeter

The wattmeter indicates instantaneously the kilowatt load of the source, bus, or load.

7.7 Kilowatt-Hour Meter

Similar to the unit used by utility companies, this component maintains a running total of the power produced or consumed by the source or the load.

7.8 Power Factor Meter

This indicates the instantaneous ratio between true power in kilowatts (kW) to apparent power in kilovolt amperes (kVA).

7.9 Elapsed Time Meter

This is used to total the hours of equipment operation.

7.9.1 Discrete Analog vs. Virtual Metering:

Virtual metering has primarily taken the place of discrete analog metering. Instead of having numerous analog meters, an operator can use the HMI to view a variety of meters on one interface.

Analog metering devices are typically either ± 2% or ± 1% while digital metering accuracies are ±1/2% or ±1/4%.

8 ANNUNCIATION

Annunciation is the means by which a system notifies the user/operator of critical system operations and alarms when conditions are approached which could result in system failure.

In addition to audible alarming a variety of techniques are used for annunciation including the following:

- LED annunciation.
- Remote alarm annunciation.
- Lamp display annunciation.

Several standards exist that require annunciation to identify specified system conditions; the most commonly used are NFPA 99 and NFPA 110.

8.1 NFPA 99

NFPA 99 is the standard for heath care facilities. Health care facilities are defined as "buildings or portions of buildings in which medical, dental, psychiatric, nursing, obstetrical, or surgical care are provided." Due to the critical nature of the care being provided at these facilities and their increasing dependence on electrical equipment for preservation of life, health care facilities have special requirements for the design of their electrical distribution systems. These requirements are much more stringent than commercial or industrial facilities.

Health care electrical systems usually consist of two parts:

1. Non-essential or normal electrical systems.
2. Essential electrical systems.

All electrical power in a health care facility is important though some loads are not critical to the safe operation of the facility. Non-essential loads such as general lighting, general lab equipment, non-critical service equipment, etc. are not required to be fed from an alternate source of power.

NFPA 99 breaks health care facilities into three types:

- Type 1 - essential electrical systems.
- Type 2 and type 3 - type 1 requirements meet or exceed the requirements for type 2 and type 3 facilities.

Description	Definition	EES Type
Hospitals	NFPA 99 Chap. 13	Type 1
Nursing Homes	NFPA 99 Chap. 17	Type 2
Limited Care Facilities	NFPA 99 Chap. 18	Type 2
Ambulatory Surgical Facilities	NFPA 99 Chap. 14	Type 3 [1]
Other Health Care Facilities	NFPA 99 Chap. 14	Type 3 [1]
1) If electrical life support or critical care areas are present, then facility is classified as type 1.		

Figure 41 – NFPA 99 Health Care Facility Types

The NFPA 99 standard should be consulted for the most up to date requirements for system annunciation.

8.2 NFPA 110

NFPA 110 is the standard for emergency and standby power systems. This standard controls the assembly, installation, and performance of electrical power systems used to supply critical and essential needs during outages of the primary power source.

The NFPA 110 standard should be consulted for the most up to date requirements for system annunciation.

8.3 Site Specific Components

In addition to the standard requirements there are number of other components the customer may want to annunciate. This could include parameters of a fuel tank, generator temperature metering, remote circuit breaker positions, fire detection systems, and security systems.

9 PARALLEL OPERATION

Many situations can be optimally handled by operating two or more generators sets in parallel on a common bus instead of dispersed multiple single units or a central, larger, single unit. An existing distribution system itself may not lend itself to being split into several sections and handled by separate non-parallel units. Also, when loads are expected to increase substantially, provisions can be made to add more generator sets in parallel as the loads increase. The cost of switchgear for parallel operation of multiple generators is greater per generator than for single generators; however, a common master section that will accommodate additional parallel-operated generators can help keep the cost down for adding generators if they are initially planned.

The most important reason for paralleling in a standby system is increased reliability. When a part of the emergency load is deemed critical it may be desirable to have more than one generator capable of being connected to that load. When there is a normal source outage all generators in the system are started. The probability of having a generator set start and achieve nominal voltage and frequency is increased in proportion to the number of sets available. The first set ready to handle the essential load does so. As additional generators are running and connected to the bus, the remaining loads are connected in declining order of priority.

9.1 Isochronous

Isochronous means having an equal time difference or occurring simultaneously. For electric power generation isochronous is considered flat frequency or 0% generator droop.

9.2 Droop

Droop has many uses and applications in the control of engines. In non-isochronous speed control systems, engine-speed control would be unstable without some form of droop.

Droop is defined as a decrease in speed setting as the load increases.

Droop is expressed as a percentage of the original speed setting from no load to full load. The normal recommended percent of droop is 3% to 5%; a minimum of 2.5% is required to maintain stability in a speed-droop governor. Droop is calculated with the following formula:

$$\%Droop = \frac{No\_Load\_Speed - Full\_Load\_Rated}{Full\_Load\_Rated\_Speed} X100$$

If, instead of a decrease in speed setting an increase takes place, the governor shows negative droop. Negative droop will cause instability in a governor.

Simple hydro-mechanical governors have the droop function built in and always operate in droop. More complex governors include temporary droop which returns the speed setting to its original speed setting after the engine has recovered from a change in speed or load. The temporary droop is known as “compensation.”

Why Is Droop Necessary?

In a system without droop, a load increase will cause the engine to slow down.

The governor will respond by increasing the fuel until the engine speed has returned to the original speed.

Due to the combined properties of inertia and power lag, the engine speed will continue to increase beyond the original speed setting, causing an overshoot in speed. The governor again will respond to decrease speed to correct for the overshoot. It will over-correct the speed in the other direction causing undershoot. This overcorrection of speed in both directions (instability) will amplify until the engine shuts down on over-speed.

It is impossible to have stable parallel operation if two or more units are set for isochronous (zero speed droop) operation, except with an electric load-proportioning governor (see 9.5.4).

9.3 Synchronizing

Synchronization, as applied to the electric power generation, is the matching of the output voltage waveform of one alternating current electrical generator with the voltage waveform of another alternating current electrical system. For two systems to be synchronized, five conditions must be matched:

- The direction of rotation of these phases.
- The voltage amplitudes of the two systems.

- The frequencies of the two systems.
- The phase angle of the voltage of the two systems.

The first two conditions are determined when the equipment is specified, installed, and wired. A voltage regulator usually controls the output voltage of a generator automatically. The last two conditions, frequency matching and phase matching, must be accounted for each time the tie-breaker is closed, paralleling the generator sets or systems.

9.3.1 Rotation of Phases

Each generator set or system being paralleled must be connected so all phases rotate in the same direction. If the phase rotation is not the same, no more than one phase can be synchronized (see Figure 42).

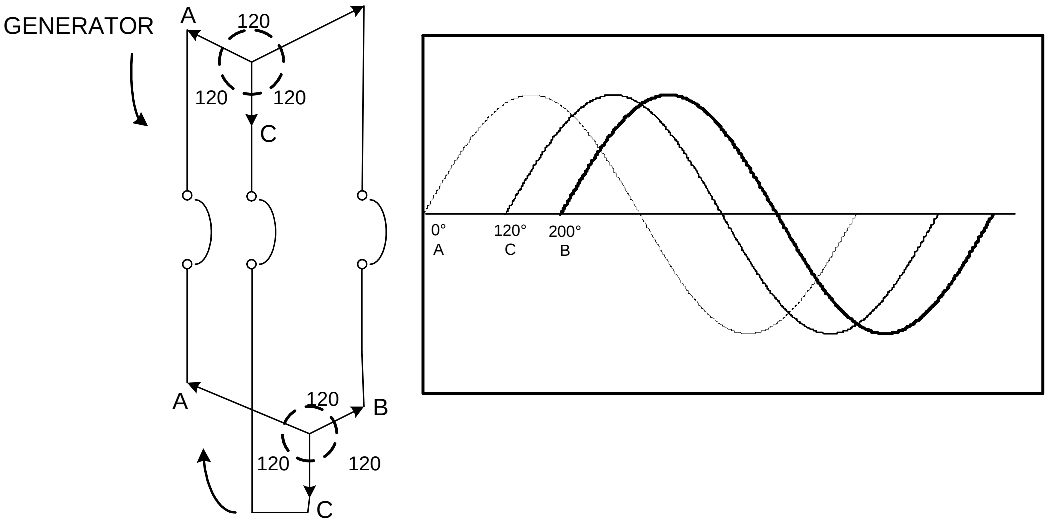


Figure 42 – Phase Rotation

9.3.2 Voltage Match

The voltages generated by generator sets or systems being paralleled must be within a small percentage of the same value, usually 1% to 5%. Changing the excitation voltage can control the output voltage of a synchronous generator (normally done by the voltage regulator.)

If two synchronous generators of unequal voltage are paralleled, the combined voltage will have a value different from the voltage generated by either of the generators. The difference in voltages results in reactive currents and lowered system efficiency (see Figure 43).

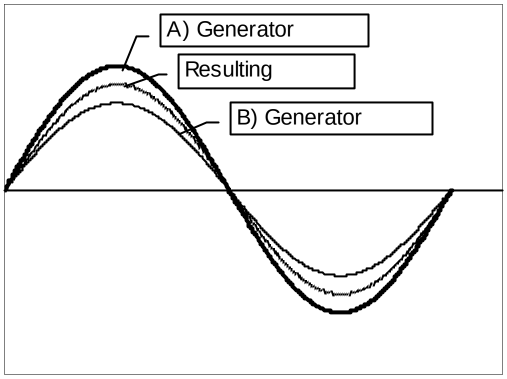


Figure 43 – Voltage Difference in Generator to Generator

If, on the other hand, a synchronous generator is paralleled to a larger system such as a utility, a difference in voltages before paralleling will not change the voltage of the bus (see Figure 44).

In this instance, the power factor of the generator will be changed. If the generator voltage is much lower than the bus voltage, the generator could be under excited causing generator stator heating. An induction generator needs no voltage regulator because its output voltage will automatically match the voltage of the system supplying its field voltage.

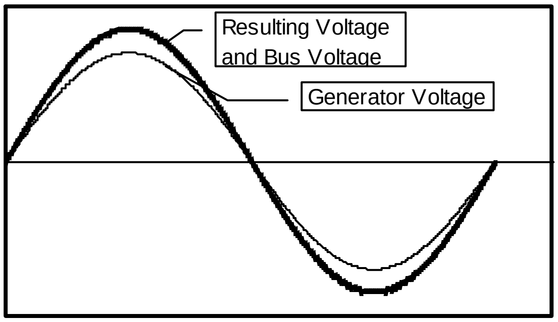


Figure 44 – Voltage Difference in Generator to Bus

9.3.3 Frequency Match

The frequency of the oncoming generator must be nearly identical to that of the system it is being paralleled with, usually within 0.2% (see Figure 45).

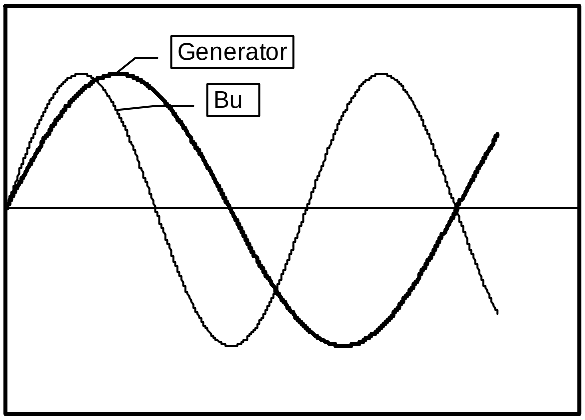


Figure 45 – Frequency Difference

If the oncoming generator is a synchronous type, this match is normally accomplished by controlling the speed of the prime mover driving the oncoming generator.

If the oncoming unit is an induction generator, frequency is determined automatically by the generator field voltage. Field voltage is supplied by the system to which the generator set is being paralleled; however, the field voltage is not applied to the generator until the generator breaker is closed. The generator must be kept close to synchronous speed prior to breaker closure. A speed below synchronous will cause the oncoming generator to act as a motor and a speed over 1.5% above synchronous will cause the induction machine to generate at full capacity.

9.3.4 Phase Angle Match

The phase relationship between the voltages of the systems to be paralleled must be very close prior to paralleling. This match usually is within plus or minus 10 degrees. If the oncoming generator is a synchronous type, phase matching, like frequency matching, is accomplished by controlling the speed of the oncoming generator's prime mover. If the machine to be paralleled with the system is an induction generator, the phase match will be automatic, since the system is supplying the generator field voltage

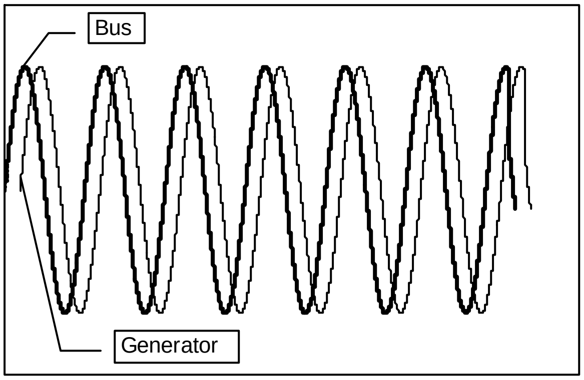


Figure 46 – Phase Angle Match

For the synchronous generator, voltage, speed/frequency, and phase must be matched each time before the paralleling breakers are closed.
If the oncoming generator is an induction-type with the armature rotating at synchronous speed, no difficulties will occur when the paralleling breakers are closed.

Currently, most installations use synchronous generators. The advantage of synchronous over induction generators is that synchronous systems allow independent operation without a utility or other AC power source. Induction generators cannot operate without an external AC source.

Why Is Synchronization Important?

When two or more electrical generating sets or systems are paralleled to the same power distribution system, the power sources must be synchronized properly. Without proper synchronization of the oncoming unit or system, power surges and mechanical or electrical stress will result when the paralleling breaker is closed. Under the worst conditions, the voltages between the two systems can be twice the peak operating voltage of one of the systems, or one system can place a dead short on the other. Extremely high currents can result from this, which put stress on both systems.

These stresses can result in bent drive shafts or broken couplings. Under some conditions, power surges can be started which will build on each other until both generating systems are disabled; these conditions are extreme. Stress and damage can occur in varying degrees. The degrading effects depend on the type of generator, the type of driver, the electrical load, and how poorly the systems are synchronized when the breakers are closed.

Modern systems often supply power to sophisticated and sensitive electronic equipment. Accurate synchronization is necessary to prevent expensive down time and replacement costs.

9.4 Methods of Paralleling

Where two generator sets are in parallel, they must have the same voltage, phase sequence frequencies, and their output voltages must be in phase. When paralleling is required and current will exceed 1200A, the floor-standing control panel is the proper switchgear choice. Four methods of paralleling are available for the floor-standing panel, ranging from completely manual to automatic.

9.4.1 Manual Paralleling

This system consists of a governor speed toggle switch (on units equipped with synchronizing motors), two synchronizing lamps, an on/off toggle switch, and reverse power relay.

As stated in the synchronization section for proper paralleling:

1. Phase sequence must be the same.
2. Frequencies must be the same.
3. Voltages must be the same.

Engine governors must have speed droop of which one can be isochronous. The exception to this is electronic load sharing governors.

4. Generators must have voltage droop or cross-current compensation.

The condition of the units being correctly phased or operating with voltages in phase means that the individual sine waves appear in sequence. Voltages must be capable of being superimposed so instantaneous voltage differences do not exist in the same phase of units being paralleled.

To meet the second and fourth conditions the engine governors must be adjusted to give similar frequency under conditions of proportionate load sharing. If one set is trying to operate at a lower frequency than the others the active or kW load will not be proportionately shared and motoring current will flow to the lower frequency machine to make it run at synchronous speed.

There are many manual-paralleling methods in use; a common method of manual paralleling is through the use of synchronizing lamps.

To parallel a generator set with one or more generator sets already on the line, the first three conditions must first be met. If there is a difference between the frequencies or voltages of the generators being paralleled there will be an undesirable line voltage disturbance when the incoming generator circuit breaker is closed. Extensive damage may result if generators are paralleled while the voltages are out of phase. In order to manually parallel generator sets, it is necessary to use one of two methods: (1) synchronizing lamps or (2) a synchroscope.

Example – Synchronizing Lamps:

The dark lamp method is most commonly used as the indicator of when to close the incoming circuit breaker. This method lights the synchronizing lamps when there is a potential between the phases of the incoming and the online generators. This means that when all the lamps are dark the generators are synchronized. Steps for synchronizing an offline unit with an online generator are shown below.

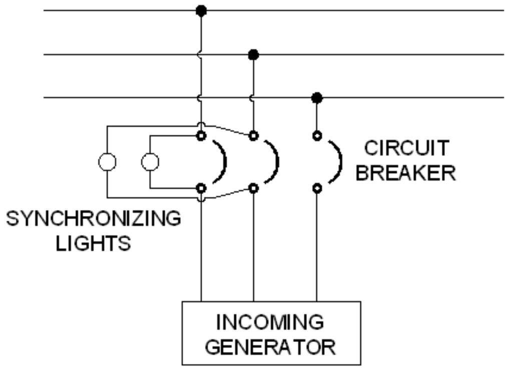


Figure 47 – Synchronizing Lights

1. The online circuit breaker should be closed and the offline (incoming) circuit breaker should be open.

2. With the incoming unit governor control lever in the full-governed speed position, turn on the synchronizing lamps switch and observe the lamps for the frequency at which they flash. By means of the governor control vary the incoming engine speed until the synchronizing lamps come on and fade out about six to ten times a minute. Always have the incoming generator initially slightly higher in frequency; doing this will assure that the incoming generator set will absorb a small amount of load instead of consuming power when initially connected to the bus.
3. To put the generator set online and in-sync with the online source wait until the lamps are dark and then very quickly, while the lamps are still dark, close the circuit breaker. The incoming generator is now in parallel with the bus and online generator.

9.4.2 Permissive Paralleling

This option includes manual paralleling, a synchronizing check relay, an under-voltage trip on the breaker (instead of a shunt trip), and a ready-to-close indicating lamp.

This attachment allows inexperienced operators to parallel generator sets only when the incoming generator and the live bus are within predetermined limits. The incoming generator set is started by an operator and brought up to operating frequency and voltage as determined by the panel meters.

The operator then places the synchronizing switch in its on position, energizing the synchronizing relay and the synchronizing lamps. The synchronizing relay compares voltage, frequency, and the phase angle of the incoming generator set with the live bus. It also provides a signal to illuminate the ready-to-close lamp and energize the circuit breaker under-voltage device to prevent the circuit breaker from tripping open.

9.4.3 Semiautomatic Paralleling

This group includes all the equipment found in the manual paralleling option plus a synchronizing check relay, circuit breaker position indicating lamps, electric motor operator on the molded case circuit breaker (with power provided from the generator potential), and circuit breaker open/close toggle.

The semiautomatic paralleling functions are essentially the same as permissive paralleling. With electric motor operated breakers the operator places the circuit breaker control switch in its closed position. When conditions for paralleling are verified the synchronizing check relay provides a signal causing the circuit breaker to automatically close.

9.4.4 Automatic Paralleling

Automatic paralleling combines the functions described in sections 9.4.1, 9.4.2, and 9.4.3 and accomplishes them without operator intervention. This is accomplished through the use of automatic synchronizing devices.

9.5 Paralleling Components

9.5.1 Synchroscope

A synchroscope (shown in Figure 48) is an instrument used for indicating whether two AC generators or other AC voltage sources are synchronized in time phase with each other. The indicator is typically a rotating pointer device on a 360 degree scale. The direction the pointer rotates indicates whether the frequency of the incoming generator is slower or faster than the frequency of the online generator. Similarly, the frequency at which the pointer rotates indicates the magnitude of difference in speed between the generator sets. For paralleling, engine speed is changed until the synchroscope pointer rotates very slowly (less than 10 rpm), again keeping the incoming generator set faster than the online generator set. When the pointer is at the 0 position, the circuit breaker can be closed (the units are synchronized).

Figure 48 – Synchroscope

Rotation of the indicator in the slow (counterclockwise) direction indicates the oncoming generator set is at a lower frequency than the online supply. If the indicator is rotating in the fast (clockwise) direction it indicates the oncoming (paralleling) generator set is at a higher frequency than the online supply.

9.5.2 Sync Check Relay

A sync check relay monitors voltage on both sides of a circuit breaker and determines that proper phase angle and voltage exist prior to closing the circuit breaker.

Sync check relays will only allow circuit breakers to close once specified phase angle conditions have been satisfied for a set period of time.

9.5.3 Automatic Synchronizer

An automatic synchronizer closes the generator breaker at the point of synchronism. It initiates the close command in advance of phase coincidence using breaker closing time and slip frequency.

9.5.4 Load Sharing Modules

The function of a load-sharing module is to proportionally share real load between two or more generator sets while the system frequency is held constant. The load-sharing module provides isochronous and droop load-sharing capability for engines in a generator set application.

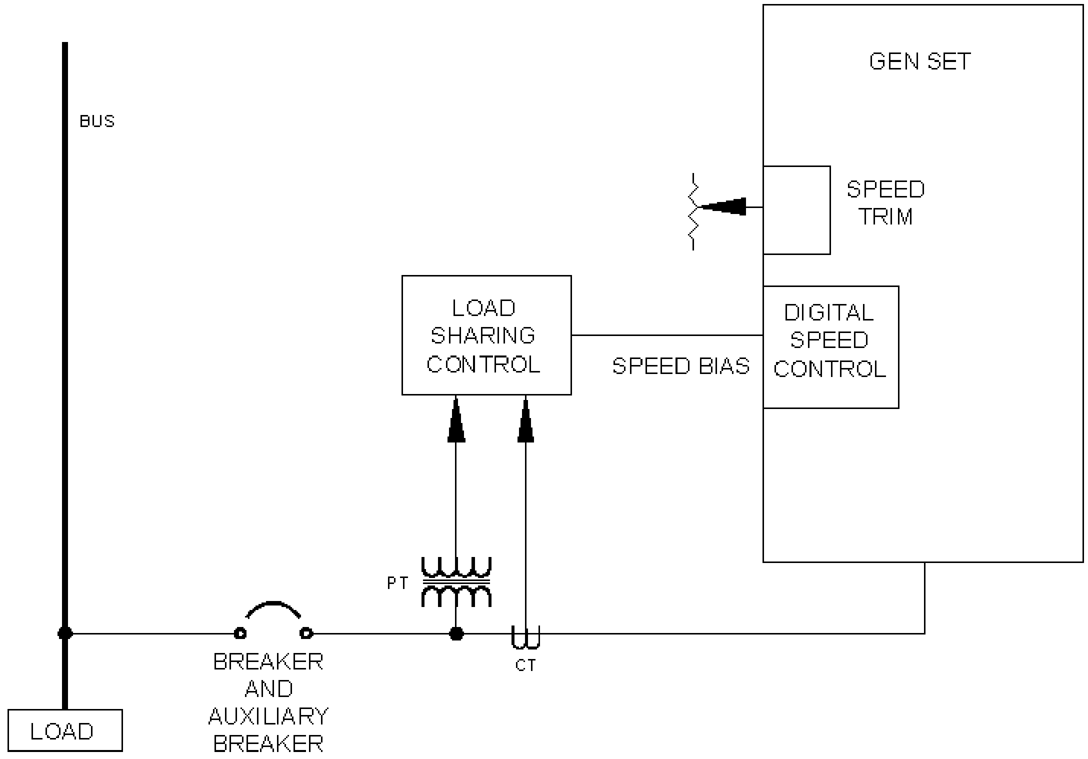


Figure 49 – Typical System Using a Load Sharing Module

9.6 Island Mode Operation

When multiple generators are paralleled on a common bus and isolated from the utility, the individual engine governors are tasked with maintaining system frequency while the individual generator voltage regulators are tasked with maintaining system voltage.

This is different from the scenario where the generators are paralleled to an infinite bus (see Section 9.7.1) in which the utility grid sets system frequency and voltage.

In a system with multiple paralleled generators the independent controls for speed and voltage would counteract each other and decrease system stability so a real (kW) and reactive (kVAR) load sharing control system must be used.

9.6.1 Real (kW) Load Sharing

The control system receives input from current transformers (CTs) and potential transformers (PTs) to calculate real (kW) power output from the generator.

As load is applied to the generator alternating current flows through the generator cables and induces current into the CTs. The current in the CTs increases proportionally with the load on the generator (see Figure 50). The generator voltage regulator maintains constant voltage throughout the load range.

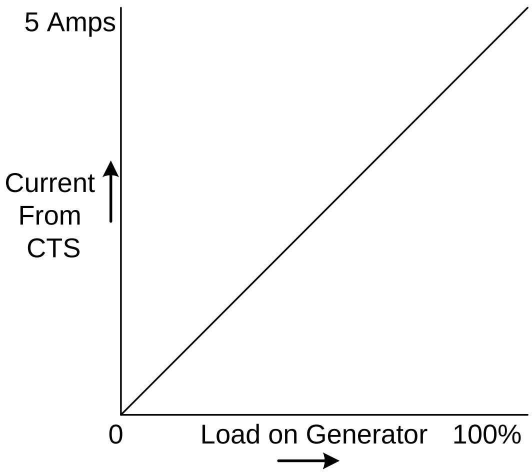


Figure 50 – Current Sensing

The control system generates an output which biases the speed control. The bias signal is fed into the closed loop governor speed control to balance real power proportionally among all paralleled generators.

9.6.2 Circulating Currents in Paralleled Generators

Circulating currents exist in paralleled generators when multiple generators are attempting to operate at different voltages although they are connected through the common bus.

This current will exist when the internal excitation voltage produced by each generator is slightly different but the terminal or bus voltage is the same. These circulating currents reduce the effective excitation of one or more generators and increase the effective excitation of others. Generator voltage is directly related to exciter output; hence an attempted generator voltage difference is the result of different exciter output. The voltage regulator controls exciter output. Control of circulating currents is accomplished by biasing the voltage regulator.

An example to illustrate the effect of the voltage regulator on the generator system can be seen using two generators and a load. If the open circuit voltage is exactly the same on both generators they will divide the load equally when they are paralleled (Figure 51). Differences between open circuit generator voltages will, upon paralleling, result in circulating currents (Figure 52).

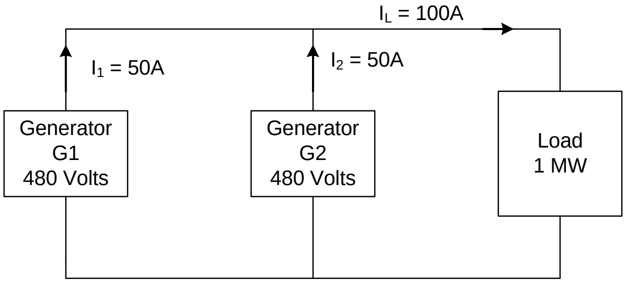


Figure 51 – Paralleled Generators – Balanced Voltage

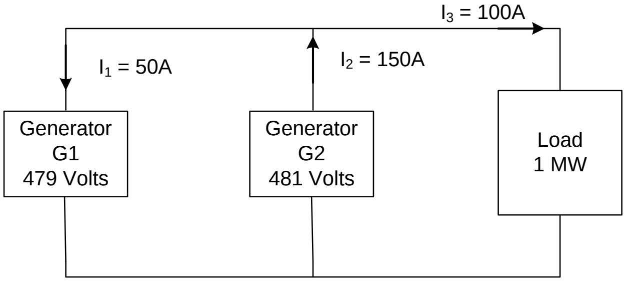


Figure 52 – Paralleled Generators – Unbalanced Voltage

In practice the manual, precise matching of voltages is not possible. Some means must be provided to make load sharing between paralleled generators simple to control.

Because circulating current or load unbalance is the result of voltage mismatch, the voltage regulator will act as the control system using paralleling compensation circuits called reactive droop compensation or reactive cross-current compensation.

The principle of operation of the reactive droop circuit can be described by the curve in Figure 53.

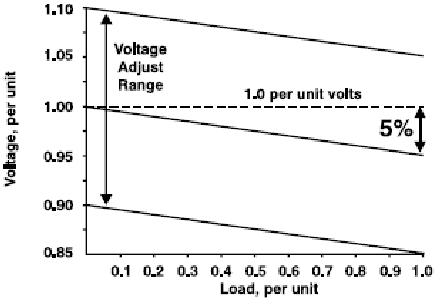


Figure 53 – Reactive Droop Curves

Using a regulator designed to maintain precise voltage regulation a circuit is added that accepts a current signal derived from the generator's output. This current signal is combined with the generator's sensing voltage signal to develop a vector-summed voltage proportional to reactive load.

For example, if voltage decreases from 480V to 458V from no load to rated reactive (kVAR) load, the voltage droop is –4.3% droop. If two generators are operated in parallel with their droop curves set the same and their voltage set points adjusted to proportionally share the reactive load, any unbalance that would increase the load on one machine and decrease the load on the other would cause the droop circuits to change the voltage set points in a direction to bring the load back into balance. With droop compensation, the bus voltage will droop with changing reactive load.

By building this characteristic into the regulator of each generator operating in parallel, sharing of the load is controllable.

To parallel two generators voltage should be matched prior to closing the breaker to minimize the current surge at breaker closing.

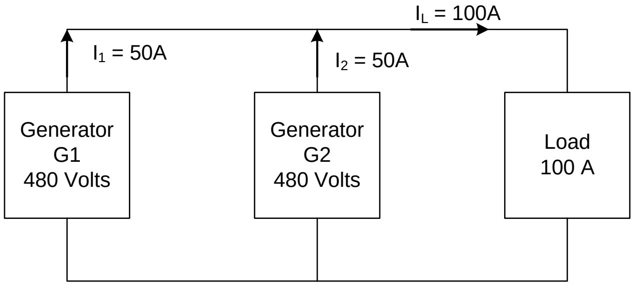


Figure 54 – Paralleled Generators – Balanced Voltage

With voltages balanced (Figure 54) and 100A load, each generator will supply its share of the load. If G2 voltage is increased its output current will try to increase. This increase will cause a voltage droop which counteracts the voltage increase. G1 will see its output current decrease resulting in a droop circuit action to increase voltage. The result is a load balance control action that works to hold loading balanced when two or more generators are operating in parallel.

9.6.2.1 Cross-current Compensation

Cross-current compensation is a method of controlling the reactive power supplied by AC generators in a paralleling system so they share equally the total reactive load on the bus without significant voltage droop.

For droop operation, the droop adjustment is used so each generator droops similar amounts at its rated load; then the generators can be paralleled and each generator can be adjusted to carry its proportional share of the reactive load.

For generators paralleled with reactive differential compensation, equal currents are needed to cancel opposite currents so that no droop in the generating system is present.

The unequal currents presented by the current transformers will force the cross-current loop to operate at an imbalance and maintain circulating currents. To decrease the imbalance of current through the cross-current loop, all burden resistors should be set at maximum resistance; the burden resistor across the current transformer with the smallest secondary current should be adjusted for a smaller resistance so more current can flow through the resistor. The burden resistor should only be adjusted for a small amount.

Decreasing the burden resistance causes the response of the generator to be less sensitive to imbalances in the loop due to reactive loading. The burden resistor should only be adjusted a small amount so as to maintain proper control of circulating currents and also to decrease the current imbalance of the loop due to the current transformers.

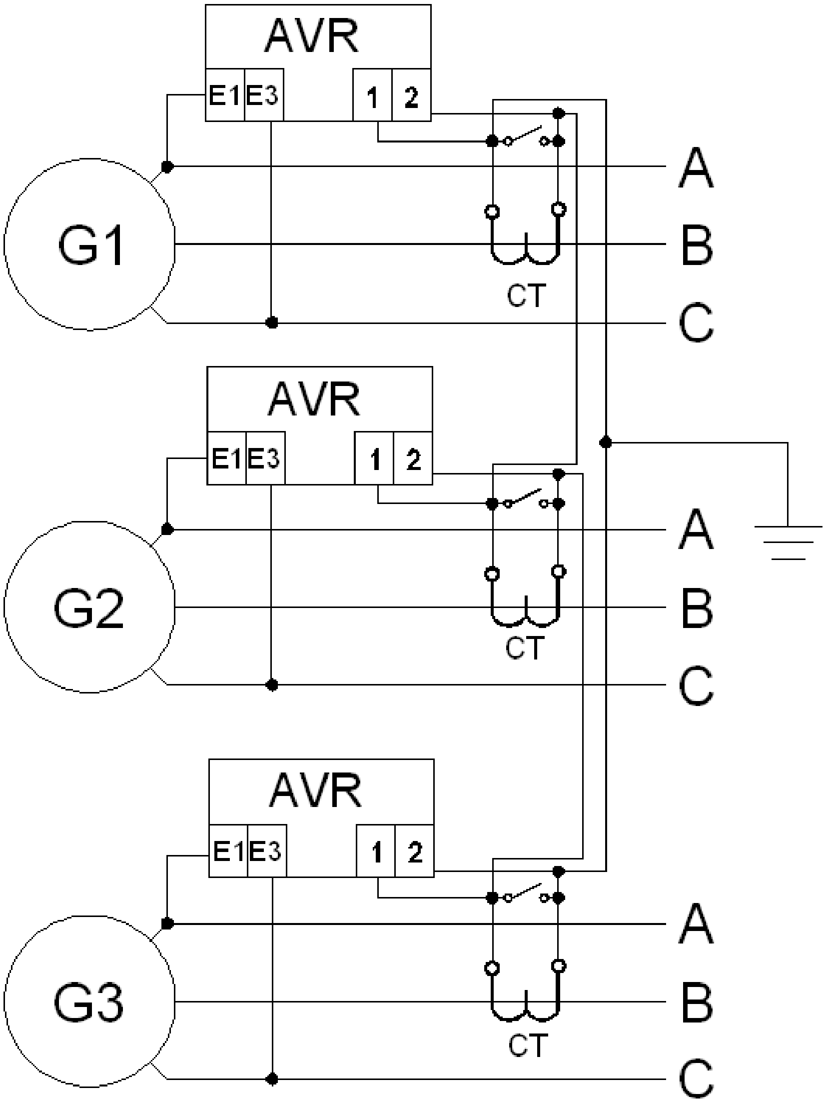


Figure 55 – Cross-Current Compensation

9.7 Utility Paralleled Operation

9.7.1 Infinite Utility Bus

One way to simplify the analysis of utility parallel operation is to adopt the concept of an “infinite bus” for the utility grid. This assumption can be used if the capacity of the utility grid at a point of interconnection is at least 10 times greater than the capacity of equipment connected at PCC. The concept holds true when the utility voltage and frequency are not changed when real and reactive currents change at the PCC.

An example is a generator connected to a utility grid with a generator size of 100kW and the connection point being an industrial plant served by a 10MVA transformer. With the transformer being fed from a line having a capacity of 150MVA any changes in load flow caused by fuel or excitation changes at the 100kW generator will have no measurable effect on the voltage and frequency of the transformer secondary. This is also referred to as the stiffness of the grid.

9.7.2 VAR/Power Factor Regulation

When synchronous generators are tied to a utility bus conditions may occur where the transmission or distribution voltage may be sensitive to local load fluctuations. The bus voltage may be normal in the early morning but then drops progressively through the day as system loading increases. In other cases high reactance in the transmission and distribution line can cause undesirable voltage drops with increased system loading. This reduces the available voltage at the load forcing local area generators to supply more VARs into the utility bus to meet the demands of the system. Depending upon the impedance of the transmission or distribution line at the area of the local generating station and the voltage regulation of the system bus, a smaller generator tied into the utility bus can become severely overloaded or under excited. The severity depends upon the magnitude and direction of the system voltage change.

The regulator's ability to compensate for large changes in bus voltage can be exceeded. Two examples serve to illustrate typical problem areas:

1. A generator equipped with a voltage regulator adjusted for 4% droop can have a variation in VAR (volt amperes reactive) load from 0 to 100% with a 4% decrease in bus voltage. Further decreases in bus voltage would overload the generator.
2. An increase in bus voltage can cause leading power factor conditions with the associated danger of the machine pulling out of synchronization.

To minimize the possibility of either scenario occurring, the voltage regulator is often adjusted for operation in a "safe" region rather than a region that utilizing the generator's full kVA capability.

VAR/power factor (PF) controllers regulate VAR flow or power factor when operating in parallel with another power system. The excitation is adjusted automatically to compensate for bus voltage changes.

The VAR/PF controller senses generator output voltage and current and provides an output signal that is electronically injected into the voltage regulator.

The VAR/PF controller has two modes of operation:

- VAR mode.
- Power Factor mode.

When VARs are controlled the voltage regulator changes its output until the programmed reactive load current is attained. When the power factor is controlled, the regulator changes the excitation until the selected power factor is obtained.

A sample generator capability (reactive capability) curve showing the engine limits with relation to VAR and PF is shown in Figure 56**.**

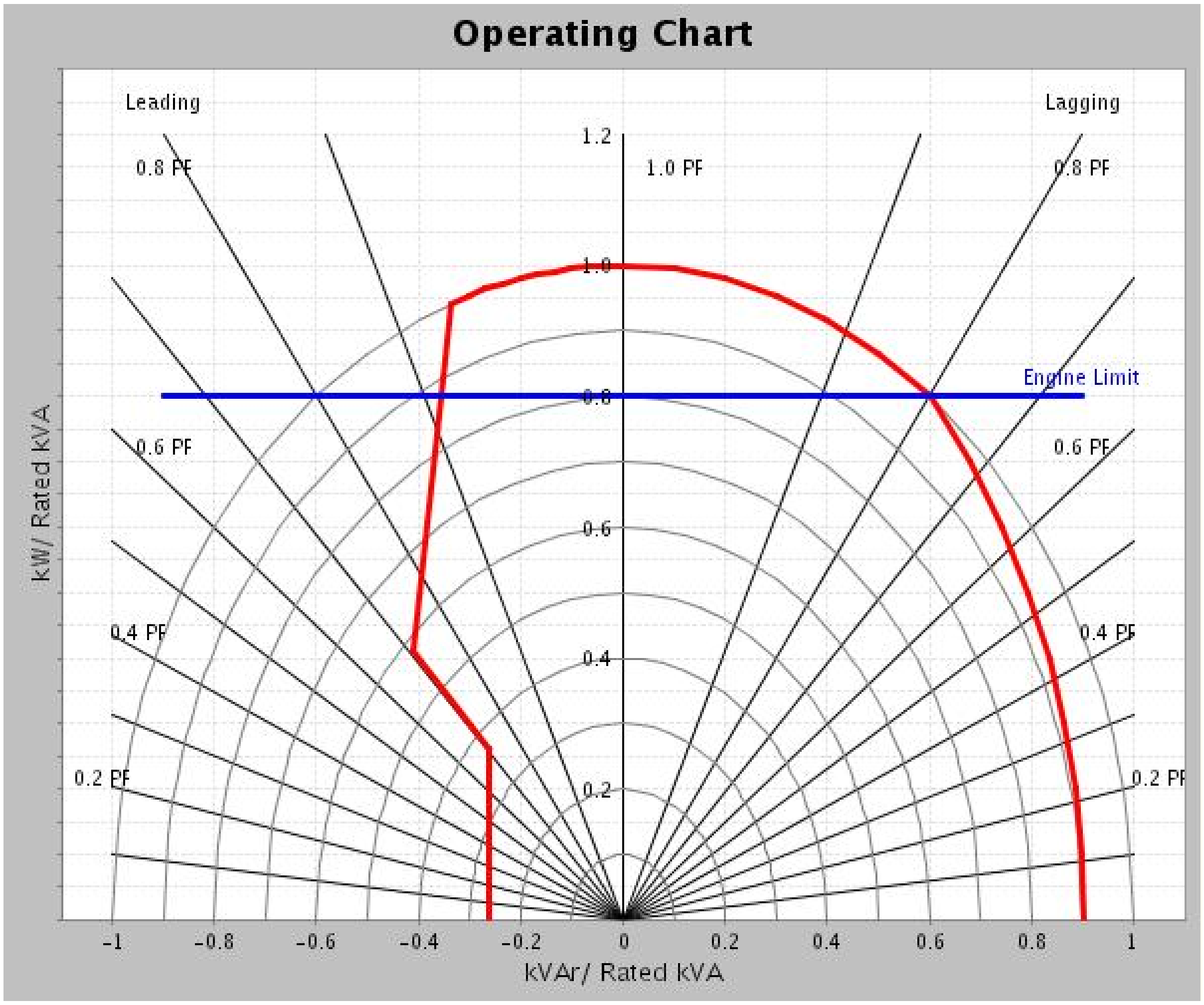


Figure 56 – Generator Capability Curve

10 APPLICATIONS

10.1 Standby

Standby switchgear is used for backup power generation. In the event of a power outage, the standby switchgear effectively switches from utility power to generator power. Standby generators are typically operated isochronously.

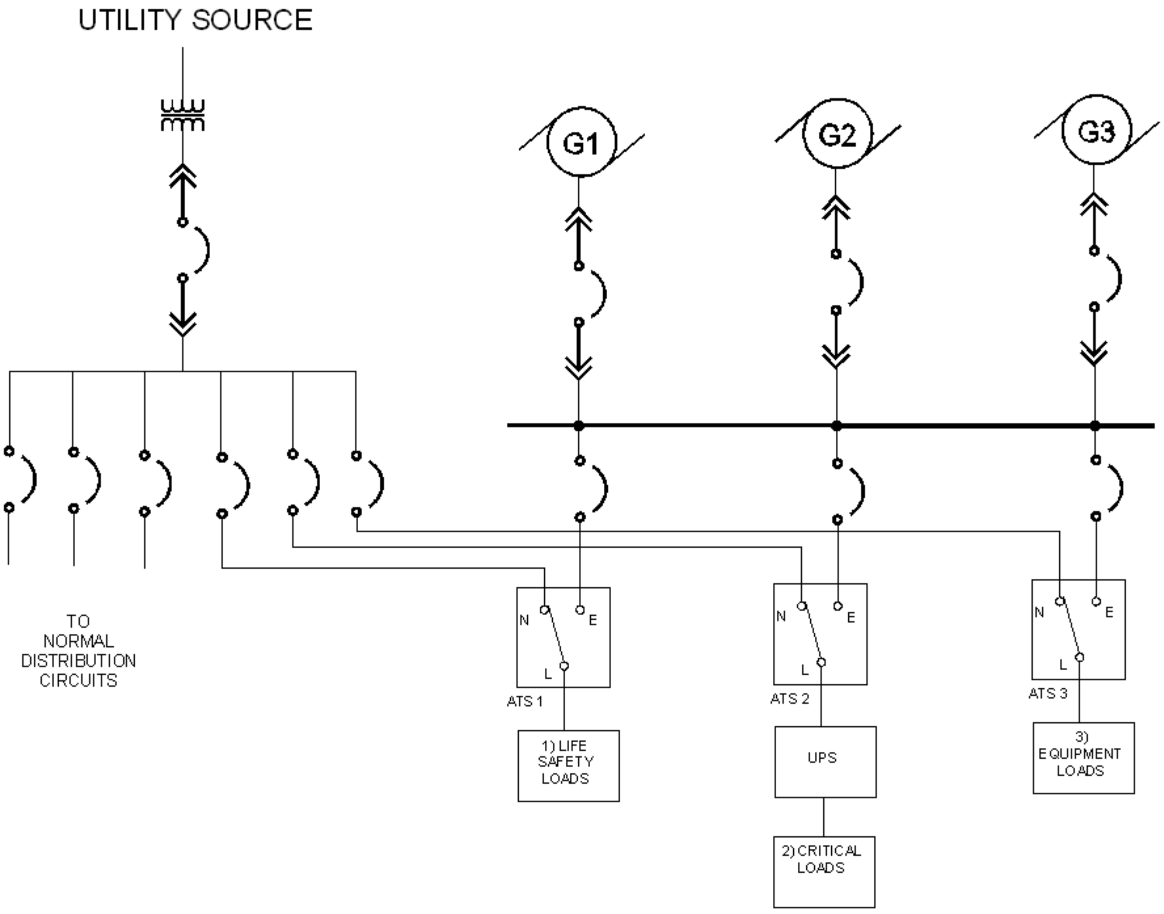


Figure 57 – Typical Emergency Power System with ATS & UPS

10.1.1 Automatic Transfer Switch Integration

The automatic transfer switch (ATS) is a device that transfers electrical loads between two independent sources of power by using either automatic or manual controls.

The ATS includes sensing circuits to detect when a failure of the normal power source occurs. The ATS controls include a contact used to start the engine when the emergency power source is an engine generator. When the generator reaches the rated voltage and frequency the ATS switches its main contacts from the normal source to the emergency source. When the normal source is restored the ATS re-transfers the load circuits back to the normal source.

An ATS may include discrete or data communications to the switchgear for annunciation of status and integration of control including:

- Timer settings.
- Pickup/dropout settings.
- Testing functions.
- Alarm functions.
- Transfer-inhibit control.

10.1.2 Uninterruptible Power Supply Integration

An uninterruptible power supply (UPS) system is an assembly of equipment used with electrical loads sensitive to power source disturbances or that require absolute continuity of power. The UPS can store energy for a period of time during power outages. The UPS continually conditions power and if the normal power source is not available the UPS provides power to the critical load until the standby power generation can come online. The generator set should be sized to the UPS rating, not the load.

Continuity and isolation from power source disturbances can be assured by using either a rotary or a static UPS system.

Rotary systems use a motor-generator set to isolate the critical load combined with kinetic inertia storage technique or batteries to carry the critical load while cranking a diesel engine.

Static systems isolate critical load through solid-state devices which use batteries to bridge power interruptions until a generator set is available to power the system.

UPSs can also be used to perform an orderly engine shutdown to minimize restart damage.

Static UPS systems use static components to provide quality power to critical equipment independent of the quality or availability of the normal power source. The simplest systems consist of a rectifier (converter), a DC storage battery bank, and an inverter.

The rectifier, sometimes called a converter, is a device that converts AC current to DC current.

The inverter uses solid state technology to convert DC to a waveform that is then filtered so it is suitable for powering the critical load.

A bank of storage batteries “floats” online to provide seamless DC power to the inverter in the event of power source loss to the rectifier. The batteries get their restoring charge and standby float charge from the rectifier’s DC output.

The DC output of the rectifier provides two functions during the time when an AC power source is available at its terminals:

- It provides regulated DC to the inverter for powering the critical load.
- It maintains the “state of charge” on the bank of DC batteries, including recharging if the state of charge has been depleted by a recent normal power outage.

10.2 Parallel with Utility

Paralleling generators with the grid is typically done for economic reasons. Paralleled generators can also be used as standby.

Common applications/modes of operation include:

- Base load.
- Import/export.
- Peak shaving.
- Zero power transfer.

10.2.1 Base Load

The least demanding power management type on an engine is base loading. The generator operates at a constant load and the utility imports power when the load exceeds the generator output. The user can also export power to the utility if the load is below the output of the generator. Figure 58 shows a base loading system and indicates when power would be imported or exported.

Since overloads are handled by the utility and the generator set is operating at a constant load, size and engine response time are not as crucial as in peak shaving.

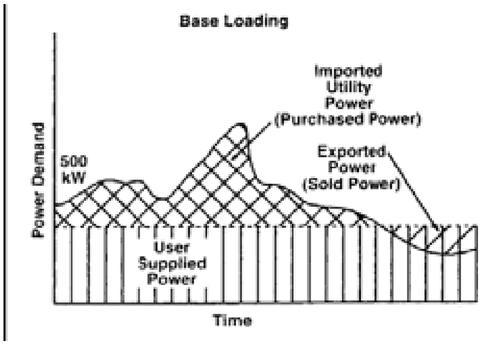


Figure 58 – Base Loading

10.2.2 Zero Import/Zero Export

The load management type (in which the customer supplies all the electrical needs to the facility), while still paralleling with the utility, is called “zero import/zero export control” or “import tracking”. Refer to Figure 59 for an illustration of this control. If the power requirements fluctuate widely a series of generator sets can be used and brought online as required. Since the customer remains paralleled to the utility the demands made on the engines for this type are similar to base loading.

Reliability is the chief concern for these customers; utilities will often invoke demand charge penalties each time they are called upon to supply power.

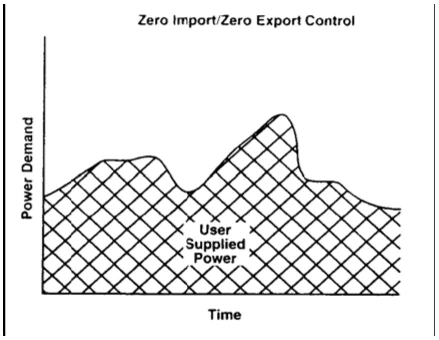


Figure 59 – Zero Import/Zero Export Control

10.2.3 Peak Shaving

Figure 60 shows how a utility customer can qualify for a discounted rate by not allowing the power demand to be above 500kW. Any power generated over 500kW is supplied by the customer’s generator. Thus, the customer “shaves” the peaks from the utilities’ responsibility. Peak shaving can be very demanding on an engine; it must be able to start quickly and automatically parallel to the utility. The response time of the engine is crucial because of the load fluctuations.

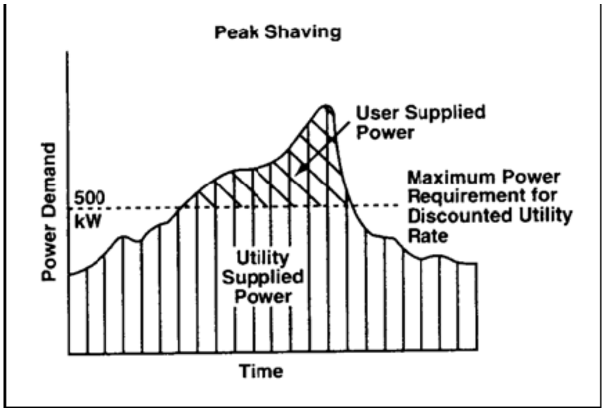


Figure 60 – Peak Shaving

10.2.4 Zero Power Transfer

Zero power transfer is the action of opening the point of common coupling with no power flow going through it. The entire load is transferred from one power source to the other: standby to normal or normal to standby.

10.3 Prime

In a prime power application where there is no other source of power available, the generator sets are the only source of power. Generators are operated isochronously.

11 MISCELLANEOUS

11.1 Distributed Generation

Distributed generation produces electricity from many small energy sources. It has also been called onsite generation, dispersed generation, embedded generation, decentralized generation, decentralized energy, or distributed energy.

Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building.

Typical distributed power sources have low maintenance, low pollution and high efficiencies.

11.2 Site Conditions

11.2.1 Altitude Correction

Above 3000 feet both insulation and current carrying capacity are affected. For such applications, the published ratings of circuit breakers are modified by using factors found in manufacturers' technical specifications or in NEMA standards.

11.2.2 Temperature Compensation

Temperature affects the point at which the thermal-type circuit breaker trips on overload' the higher the ambient temperature the lower the current at which the breaker trips.

Extremely high temperatures can also damage the control panels. Various manufacturers market insulating sprays to prevent corrosion and other sprays to remove moisture and terminals.

11.2.3 Humidity

High humidity has a deteriorating effect on instruments, apparatus, and insulation in generator control panels. As mentioned above, insulating sprays are available from the factory to remove moisture and protect switchgear equipment.

In addition to insulating sprays, space heaters are often used to reduce moisture inside generators, switchgear, and control panels. These space heaters commonly use thermostats or humidistats to automatically reduce moisture and are typically connected to the normal AC power source.

12 MAINTAINING SWITCHGEAR

To ensure trouble free and reliable operation, switchgear should be given care, and a regular maintenance program should be established per manufacturers' maintenance schedules and procedures.

12.1 Planned Maintenance

Frequency of maintenance operations will depend on the location and the frequency of operation of the circuit breakers. In extremely dirty atmospheres it may be advisable to clean and inspect the equipment every one to two months. Under normal conditions a semi-annual inspection of the equipment is satisfactory although if the circuit breakers are operated frequently it may be advisable to inspect and service them more frequently.

Routine maintenance of the switchgear should involve cleaning of the structure and especially the insulating supports for the bus.

- All electrical connections should be checked to make sure that bolts and terminal screws are tight.
- Relays should be tested in accordance with the manufacturer’s instructions.
- Megohmeter tests may be made to check the insulation of both the primary circuits and the control circuits. Records of these readings should be kept; a low megohmeter reading may not indicate trouble but a reading which has been falling steadily over a period of time indicates that trouble is

developing and corrective action should be taken.

Care of the circuit breakers involves periodic inspection, cleaning, and lubrication. Frequency of servicing will depend on conditions of the atmosphere and frequency of operation. Breakers, which are operated several times daily, should be serviced more frequently. However, breakers which are not required to be operated for long periods of time should be opened and closed several times every two or three weeks to burnish the contacts and make sure that all moving parts operate freely. When servicing, make sure all bolts are tight.

When possible, check the over-current trip devices to be sure they are operating properly. With static trip devices, a function test of the over-current trip device can be made with very little equipment. Devices are available from manufacturers which can also be used to check calibration and timing; these devices are relatively inexpensive. Equipment for testing magnetically operated trip devices is much more expensive. For this reason, testing of these magnetic trip devices often is not practical; however, they should be inspected to see that parts move freely.

Where dashpots are used for timing, they should be inspected to be sure that the oil is clean and it flows freely through the orifice.

12.2 Spare Parts

Depending on the criticality of the application, ample supply of spare parts may be recommended.

12.3 Safety

Safety is one of the most important considerations with switchgear planning and maintenance. It requires a periodic review of all equipment and operations by a qualified, safety-minded, and trained team. The team must know and be familiar with all of the equipment they operate.

Whether high-voltage lines or feeders should be grounded after being de-energized so that men can safely work on them depends upon the qualifications of the men doing the grounding, since it is necessary for the line to be dead before it is grounded. The hazards are great and the consequences are very serious if energized.

12.3.1 NFPA 70E

NFPA 70E is the Standard for Electrical Safety Requirements for Employee Workplaces. This standard gives guidelines, which should be used to protect work personnel from shock and arc flash/blast.

Shock:

Shock can cause immediate:

- Muscle contraction.
- Tingling.
- Pain.
- Difficulty in breathing.
- Dizziness.
- Surface burns.
- Internal tissue burns.

Shock can also cause long term:

- Memory loss.
- Nervous disorders.
- Chemical imbalances.
- Damage to vital organs.

Surface burns are caused by entrance and exit of electrical currents through the body resulting in 1st to 3rd degree burns. Internal tissue burns are 3rd degree burns caused by current, in excess of 1.5 amps, flowing through organs of the body. This affects the internal organs and is typically fatal.

The primary means NFPA 70E uses to prevent shock is:

1. Placing circuits in electrically safe working conditions by locking out and tagging out all sources
2. Verifying that no electrical energy is present in the circuits.

Arc Flash/Blast:

Arc flash/blast occurs when insulation or isolation between electrical conductors is breached and can no longer withstand the applied voltage. As personnel work on or near energized conductors or circuits, movement near, or contact with the equipment, or a failure of the equipment may cause a phase-to-ground and/or a phase-to-phase fault. Arc temperatures can reach up to 35,000F. Affects of arc flash on personnel can be:

- Radiation burns.
- Arc eye.
- Hearing/brain function damage.
- Shrapnel injuries.

NFPA 70E is designed to protect personnel when equipment is under normal conditions:

1. Panel covers are in place.
2. Equipment plugged in normally.
3. Designed protection in place.

NFPA 70E defines boundaries around equipment with personnel restrictions for each level of boundaries. The boundaries defined are:

1. Limited approach boundary.
   a. Entered only by qualified persons or unqualified persons that have been advised and are escorted by a qualified person
2. Restricted approach boundary.
   a. Entered only by qualified persons required to use shock protection techniques and personnel protective equipment (PPE).
3. Prohibited approach boundary.
   a. Entered only by qualified persons requiring same protection as if direct contact with live part.
4. Flash protection boundary.
   a. Linear distance to prevent any more than 2nd degree burns from a potential arc-flash.

For compliance with NFPA 70E, flash hazard analysis must be conducted on the system. The analysis shall determine operating voltage, personnel protective equipment, and the shock protection boundaries by using tables within the standard.

Other important standards outlined in NFPA 70E are:

1. Labeling equipment.
2. Equipment de-energization.
3. Personnel protection safeguards.

13 GLOSSARY OF TERMS

Alternator:

A device for converting mechanical energy into alternating current electrical energy; it may also be called an AC or synchronous generator.

Arc Extinguishers:

Confine and extinguish the arc which will be drawn between contacts each time they interrupt current.

ATS (Automatic Transfer Switch)

A switch designed to sense the loss of one power source and automatically transfer the load to another source of power.

Bias Control:

Bias is direct current (DC) signal applied between two points for the purpose of controlling engine speed or generator voltage.

Circuit Breaker:

A mechanical switching device capable of making, carrying, and breaking currents under normal circuit conditions. It is also capable of making and carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of a short circuit.

Closed-Transition Transfer (Make-Before-Break):

A transfer between sources that provides momentary paralleling of both power sources during a transfer in either direction. This results in no interruption of power to the loads during the transfer. The closed transition transfer is only possible when the sources are properly synchronized and interfaced. The duration of the two sources being in parallel is typically less than 100 milliseconds.

DGPS (Distributed Generation Power System):

Typically a local engine generator set and automation connected to the utility system to peak shave or export power.

EPS (Emergency Power System):

Provides emergency power sources and emergency distribution to down-stream loads.

Emergency Standby Power Application:

Typical usage is 50 hours per year with a maximum of 200 hours per year. Generators can be applied at their standby rating with a typical variable load factor of 70%.

Feeder Breaker Controls:

Automation controls to allow control of the distribution feeder devices for load shed/load add control and monitoring.

Generator:

A machine for converting mechanical energy into electrical energy. The electrical energy may be direct current (DC) or alternating current (AC).

Generator Demand Priority:

These controls automatically match the online engine generator capacity to the load to avoid unnecessary engine generator set operation when loads are low. This is alternatively called Load Sense Load Demand.

Governor:

A device that regulates prime mover speed by adjusting the fuel input to maintain constant speed.

HMI Human Machine Interface:
Typically a touch-screen used by the operator for interfacing with the paralleling generator system.

Impulse Withstand:

An impulse-withstand voltage assigned by the manufacturer to the equipment, or to a part of it, characterizing the specified withstand capability of its insulation against over-voltages.

Interrupting Capacity:

The maximum short circuit current that the breaker can safely interrupt.

Load Shed/Load Add:
Automated controls for distribution devices when only partial emergency engine generator sets are available for duty. The task is typically accomplished by assigning priority levels to each controlled distribution device.

Master Controls:
All processors, HMI, and programming to implement the desired modes of operation of engine generator sets in a paralleling switchgear system.

Molded Case:

A housing of insulating materials

NFPA 70:

A US standard for the safe installation of electrical wiring and equipment.

NFPA 99:

Requirements for emergency systems in health care facilities.

NFPA 110:

Standard for the assembly, installation, and performance of electrical power systems to supply critical and essential needs during outages of the primary power source.

NPS (Normal Power System):
Normal power system. The utility service entrance equipment and distribution circuits to downstream loads.

Operating Mechanism:

Opens and closes the breaker.

Over-currents:
Any current in excess of the rated current of the equipment or the amp capacity of a conductor.

Paralleling:
The procedure of connecting two or more generators or other power sources of the same phase, voltage, and frequency characteristics that supply the same load.

Peak Shaving:

Process by which the utility customer minimizes utility charges by either a) generating power and eliminating excessive demand charges or b) by shedding load.

Point of Common Coupling (PCC):

Used to refer to the point where the electrical facilities or conductors of the wire owner are connected to the power producer’s facilities or conductors, and where any transfer of electric power between the power producer and the wire owner takes place.

Prime Power Application:

Unlimited hours of usage. Requires generators to be applied at their prime power rating with a typical load factor of 70%.

Processor:

A specially configured logic controller with appropriate input-output capability and programming.

Shore Power:

Typically used to reference utility power.

Short-time Rating (aka Withstand Rating):

Defines the ability of the breaker to remain closed when a high fault current exists.

Station Battery:

A power supply utilized for control of switchgear.

Synchronizer:

A device which will synchronize an oncoming electric generator set with the bus or another electric generator set and allows multiple power sources in be connected in parallel.

Synchroscope:

This instrument provides a visual indication of proper closing time for the breaker when manually synchronizing generators to connect them in parallel with another source.

Terminal Connectors:

Used to connect the circuit breaker to the power source and the load.

Tie Breaker:

A breaker that is used to connect or separate/isolate between two different generation systems.

Trip Elements:

Monitor current, trip the operating mechanism, and open the contacts in event of a fault connection

Utility Protection:

A collection of protective relays or a multi-function relay required by the utility to detect abnormal conditions and open the utility breaker.

VARs:

The combination of volts and amps acting in a reactive circuit; that is, one that is either inductive, as in the case of a motor load, or capacitive, as in the case of some forms of electronic loads. VARs are like kilowatts but since the volts and amps are out of phase, the product of the two is not the same as if they were acting on a non reactive circuit.

14 APPENDICES

14.1 Appendix A

Device Number Function and Description

1 MASTER ELEMENT is the initiating device, such as a control switch, voltage relay, float switch, etc. which serves either directly or through such permissive devices as protective and time-delay relays to place a piece of equipment in or out of operation.

2 TIME-DELAY STARTING OR CLOSING RELAY is a device which functions to give a desired amount of time delay before or after any point of operation in a switching sequence or protective relay system, except as specifically provided by device functions 48, 62, and 79. Also known as a Timer.

12 OVER-SPEED DEVICE is usually a direct-connected speed switch which functions on machine over-speed. Generally covered within the protective scheme of the generator controller or engine controller device.

15 SPEED OR FREQUENCY MATCHING DEVICE is a device that functions to match and hold the speed or frequency of a machine or of a system equal to, or approximate to, that of another machine source or system. Also known as a Synchronizer.

21 DISTANCE RELAY is a relay that functions when the circuit admittance, impedance, or reactance increases or decreases beyond pre-determined limits.

25 SYNCHRONIZING OR SYNCHRONIZM-CHECK DEVICE is a device that operates when two AC circuits are within the desired limits of frequency, phase angle, or voltage to permit or to cause the paralleling of these two circuits.

27 UNDER-VOLTAGE RELAY is a device that functions on a given value of under-voltage.

32 DIRECTIONAL POWER RELAY is a device that functions on a desired value of power flow in a given direction or upon reverse power.

38 BEARING PROTECTIVE DEVICE is a device that functions on excessive bearing temperature or on other abnormal mechanical conditions associated with the bearing such as undue wear, which may eventually result in excessive bearing temperature or failure.

39 MECHANICAL CONDITION MONITOR is a device that functions upon the occurrence of an abnormal mechanical condition (except those associated with bearings as covered under device function 38) such as excessive vibration, eccentricity, expansion, shock, tilting or seal failure.

40 FIELD RELAY is a relay that functions on a given or abnormally low value or failure of machine field current, or on an excessive value of the reactive component of the armature current in an AC

machine indicating abnormally low field excitation.

41 FIELD CIRCUIT BREAKER is a device that functions to apply or remove the field excitation of a machine.

43 MANUAL TRANSFER OR SELECTOR DEVICE is a manually operated device that transfers the control circuits in order to modify the plan of operation of switching equipment or of some of the devices.

46 REVERSE-PHASE OR PHASE-BALANCE CURRENT RELAY is a relay that functions when the polyphase currents are of the reverse phase sequence, or when the polyphase currents are unbalanced or contain negative phase-sequence components above a given amount.

47 PHASE-SEQUENCE VOLTAGE RELAY is a relay that functions upon a predetermined value of polyphase voltage in the desired sequence.

49 MACHINE OR TRANSFORMER THERMAL RELAY is a relay that functions when the temperature of a machine armature winding or other load-carrying winding or element of a machine or power transformer exceeds a predetermined value.

50 INSTANTANEOUS OVER-CURRENT OR RATE-OF-RISE RELAY is a relay that functions instantaneously on an excessive value of current or when an excessive rate of current in an AC circuit exceeds a predetermined value.

51 AC TIME OVER-CURRENT RELAY is a relay with either a definite or inverse time characteristic that functions when the current in an AC circuit exceeds a predetermined value.

52 AC CIRCUIT BREAKER is a device that is used to close and interrupt an AC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.

59 OVER-VOLTAGE RELAY is a relay that functions on a given value of over-voltage.

60 VOLTAGE OR CURRENT BALANCE RELAY is a relay that operates on a given difference in voltage, or current input or output, of two circuits.

62 TIME-DELAY STOPPING OR OPENING RELAY is a time-delay relay that serves in conjunction with the device that initiates the shutdown, stopping or opening operation in an automatic sequence or protective relay system.

64 GROUND PROTECTIVE RELAY is a relay that functions on failure of the insulation of a machine, transformer, or other apparatus to ground, or on flashover of a DC machine to ground.

Note: This function is assigned only to a relay that detects the flow of current from the frame of a machine or enclosing case or structure of a piece of apparatus to ground, or detects a ground on a normally un-grounded winding or circuit. It is not applied to a device connected in the secondary circuit of a current transformer, or in the secondary neutral of current transformers, connected in the power circuit of a normally grounded system.

65 GOVERNOR is the assembly of fluid, electrical, or mechanical control equipment used for regulating the flow of water, steam, or other medium to the prime mover for such purposes as starting, holding speed or load, or stopping.

67 AC DIRECTIONAL OVER-CURRENT RELAY is a relay that functions on a desired value of AC over-current flowing in a predetermined direction.

79 AC RE-CLOSING RELAY is a relay that controls the automatic re-closing and locking out of an AC circuit interrupter.

81 FREQUENCY RELAY is a relay that operates on a predetermined value of frequency (either under or over or on normal system frequency) or rate of change of frequency.

86 LOCKING-OUT RELAY is an electrically operated hand, reset relay or device that functions to shutdown or hold equipment out of service (or both), when abnormal conditions occur.

87 DIFFERENTIAL PROTECTIVE RELAY is protective relay that functions on a percentage or phase angle or other quantitative difference of two currents or of some other electrical quantities.

SUFFIX LETTERS permit a manifold multiplication of available function designations for the large number and variety of devices used in the many types of equipment. They may also serve to denote individual or specific parts or auxiliary contacts of these devices or certain distinguishing features, characteristics, or conditions which describe the use of the device or its contacts in the equipment.

Letter suffixes should, however, be used only when they accomplish a useful purpose. For example, when all of the devices in equipment are associated with only one kind of apparatus, such as a feeder or motor or generator, it is common practice, in order to retain maximum simplicity in device function identification, not to add the respective suffix letter F or M or G to any of the device function numbers.

Some commonly utilized suffix designations are the following:

A	AUTOMATIC
M	MANUAL
27R	VOLTAGE RESTRAINT
27C	VOLTAGE CONTROLLED
R	REVERSE
RV	REVERSE VARS
G	GENERATOR OR GROUND
T	TRANSFORMER

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