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Revision Memo

12/00	<i>REFERENCES</i> - Updated C84.1. Deleted date from standards. Changed Exxon to ExxonMobil throughout document.
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SCOPE

This section applies to the distribution of electric power from the main source(s) of power, either main substations where purchased power is received or generator switchgear, to the plant unit substations and from there to the loads.

Instrument/computer power supplies and emergency power supplies required for safety in the event of a loss of the main power source are not included.

REFERENCES

DESIGN PRACTICES

- Section XV Safety in Plant Design
 Section XXIX-I Civil Work, Blast-Resistant Structures

INTERNATIONAL PRACTICES

- IP 2-1-1 Plant Noise Design Criteria
- IP 4-3-1 Plant Buildings for Operation and Storage
- IP 4-3-2 Blast-Resistant Buildings
- IP 10-11-1 Sizing of Drivers and Transmissions for Compressors, Fans and Pumps
- IP 15-7-1 Electrical Power Branch Circuit Design for Instrumentation
- IP 16-1-1 Area Classification and Related Electrical Design for Flammable Liquids, Gases or Vapors
- IP 16-1-2 Area Classification and Related Electrical Design for Combustible Dust
- IP 16-3-1 Wiring Methods and Material Selection
- IP 16-4-1 Grounding and Overvoltage Protection
- IP 16-5-1 Lighting
- IP 16-5-2 Security Lighting of Plants
- IP 16-6-1 Substation Layout
- IP 16-7-1 Motor Application
- IP 16-8-1 Instrument and Essential Services Power Supplies
- IP 16-9-1 Low Voltage A-C Motors Up to 200 HP (150 kW)
- IP 16-9-2 A-C Motors: Medium Voltage and Low Voltage Over 200 HP (150 kW)
- IP 16-9-3 Synchronous Generators
- IP 16-10-1 Power Transformers
- IP 16-11-1 Neutral Grounding Resistors
- IP 16-12-1 Switchgear, Control Centers and Bus Duct
- IP 16-12-2 Control of Secondary Selective Substations with Automatic Transfer
- IP 16-13-1 Field Installation and Testing of Electrical Equipment

♦ OTHER REFERENCES

ANSI/IEEE (Institute of Electrical and Electronics Engineers) Standard 141, *IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants* (IEEE Red Book)

NEMA MG1, Motors & Generators

NEMA C84.1, *Electric Power Systems & Equipment - Voltage Ratings*



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BACKGROUND

The electric power distribution system is part of the overall plant utility system and provides electric power to onsite, offsite and utilities areas.

The power distribution system may be supplied by purchased power, in-plant generated power, or by a combination of the two sources operating in synchronism or as separate sources (see [Section XXX-A, Power Sources](#)). Emergency power sources are normally provided to supply critical services during total power failures for plants which are supplied solely by purchased electric power.

Voltage ranges typically used in ExxonMobil plant distribution systems are 400 to 660 volts for low-voltage systems; 2.4 to 36 kV for medium voltage systems, and 69 kV where high voltage distribution systems are used.

Plant loads are almost exclusively motors driving rotating equipment (pumps, compressors, fans and blowers) required in the process, offsites and utilities facilities. In chemicals and synthetic fuel plants, there will also be solids handling equipment loads. In addition to the loads mentioned, the electric power distribution system will also serve instrument power and computer power supply equipment and plant lighting.

For various reasons, such as safety, economics and maintenance, the usual design embodies substations of convenient sizes located near the loads. These "plant" substations are generally in buildings of masonry construction and in the case of refineries, there is generally one for each major process unit. Areas of lower load density, such as offsites, may be served by smaller substations in masonry buildings or metal enclosures. The smaller groups of loads may be supplied from switchracks installed outdoors.

Distribution switchgear is controlled locally (at the breaker) and may also have remote control from a utilities or main control room. Motor control stations are always located adjacent to the motor and do not have facilities for starting the motors from their switching devices (starters) in the substation.

In some cases a motor may, in addition to the control station at the motor, have an emergency stop switch in the control room and/or automatic starting by means of a process pressure switch or other device.

DEFINITIONS

(Refer to [Section XXX-A](#) and the following.)

Plant

All the facilities at one geographic location. These may consist of one or many individual process units. The following are plants: Refinery, Mine, Chemical Complex, Pipeline Pumping Terminal, etc.

Plant Main Substation

The substation which provides power to the whole plant.

Unit Substation

A substation that is the last in line providing power to an individual unit within a plant. It is generally located on the same block as its associated unit or could supply power to more than one unit. In refineries and chemical plants, the unit substations that supply process units are called process unit substations. Offsite unit substations are identified by the unit they serve, such as cooling water pumphouse substation.

Source

The point(s) of power supply to a plant. Examples are generators and incoming power circuits from a utility company.

Switchrack

A group of switches and/or motor starters mounted together on a rack. They are usually located outdoors and may be protected by a roof but without any side walls.



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EQUIPMENT TYPES AND APPLICATION

POWER TRANSFORMERS

Oil immersed transformers with natural cooling (Type OA), i.e., natural oil circulation and natural air circulation, are generally used and in most cases have the capability to increase their rating by adding fans to force circulate the air (Type FA). The OA and FA ratings should be specified even when the fans are not fitted. By the insertion of an oil pump in the return cold oil pipe to the tank from the radiator, it is possible to increase the dissipation from the radiator surface as compared with natural oil circulation. This increased rating is designated as Type FO. When both fans and oil pumps are added, the rating is designated as Type FOA for one stage and Type FOA/FOA for two stages. The percentage increase in transformer rating for the various cooling methods depends on the transformer OA rating and is given in [IP 16-10-1](#) and industry standards.

The oil system may utilize a sealed main oil tank or have an auxiliary oil tank called a conservator. Generally, units 20 MVA and larger are equipped with conservators. For smaller units, the conditions of operation and local practice, i.e., sealed units in the Americas and conservator units in European locations and regions following European practices, determine the type of oil tank. With conservator units, a Buchholz relay is used for transformer protection. On sealed units, a sudden pressure relay is provided (see [Section XXX-E](#)).

Other than on main source transformers or generator transformers, it is rare to provide automatically operated load tap changers. Manually operated tap changers for de-energized operation are fitted on unit substation transformers. Four taps are provided at $\pm 2.5\%$ and $\pm 5\%$, which is an industry standard.

Reactance or impedance of the transformer is generally the manufacturer's standard unless the design requires a special value, which may be the case for a captive transformer which powers a motor or to decrease short-circuit current to permit the use of lower interrupting capacity switchgear. It should be quite clear as to whether the value of reactance or impedance, generally expressed as a percentage, refers to the OA or FA rating. Generally for in-plant distribution transformers, the OA rating is the base, but for larger units with integral fans and oil pumps, the FA rating may be the base.

Manufacturers will provide any voltage winding, the only limitation being that, to have a very high, high voltage winding and very low, low voltage winding on the same transformer would increase the cost. Transformers with a ratio 15/0.4 kV are readily available. Difficulty may be encountered in increasing the ratio beyond this, hence, it should be checked with manufacturers.

As a rule, the transformers installed in ExxonMobil plants are manufacturer's standard except that the switches on the thermometer and Buchholz (or fault pressure relay) are hermetically sealed.

Transformers are installed outdoors. Indoor location of transformers is limited to applications where an outdoor location cannot be used for such reasons as appearance, noise level, architectural considerations, etc. Transformers located indoors should be either dry type or filled with a non-flammable liquid.

All energized parts should be enclosed. This does not present any problem for transformers located at the plant substations.

SWITCHGEAR

For plant substations, switchgear is usually indoor, metal-clad type with the breaker cubicles bolted together to form a switchgear lineup. Breakers are withdrawable for isolation and maintenance purposes. They may be air break, air blast, bulk oil, minimum oil, SF₆, or vacuum type. Voltage and current transformers are located in or on the switch cubicles where required. The choice of breakers will depend on cost, space and maintenance. ExxonMobil plants have all the above types in use.

All the circuit breakers in a switchgear lineup must be rated for the maximum fault level, but their continuous current rating may vary. For the higher fault levels, breakers are not made in the lower current ratings, therefore, some breakers may have a much higher continuous current rating than would otherwise be required.

A 125 volt d-c battery is usually required for control of the switchgear. Other control systems such as a-c close and d-c trip (with a 48 volt tripping battery) or a-c close and capacitor trip, are sometimes used to suit special conditions. Where a d-c battery is required, this is located in the same room as the switchgear, except where local codes require a separate battery room. This was necessary when the battery cells consisted of open-top glass jars with the electrodes suspended in them, generally without any spacers between the plates. With this type of construction, droplets of acid would be given off at high-charge rates, which are harmful both to equipment and personnel, hence, the need for a separate room and exhaust fan. Currently, all cells, both in acid and alkali batteries, have covers and are fitted with breathers and filler plugs to prevent any acid getting into the atmosphere.

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EQUIPMENT TYPES AND APPLICATION (Cont)

The battery can be considered the heart of the electrical system, as without it, all the electrical protective devices are useless. It is, therefore, very important to have a good battery and charger. Despite the very high reliability required, it is not normal to provide duplicate batteries or chargers as both, when well designed and maintained, are extremely reliable. However, when separate switchboards are used to increase reliability, or break up a network for other reasons (examples are stub busses on a synchronizing bus network, and generators connected to different switchboards), separate battery/chargers should be considered for each switchgear lineup. A process substation with several switchgear lineups at various voltage levels would normally only have one battery/charger to serve all the lineups.

The size of the battery will depend very much on the type of switchgear closing mechanism. Solenoid closing requires a much larger battery than motor wound spring type. However, this should not deter the use of solenoid closing where available as it is generally less expensive, simpler, and permits faster reclosure. The selection of the closing method should be based on total cost, reliability, etc. Solenoid closing is no longer available in the U.S.A.

Switchgear, in addition to being used to control the transmission and distribution network, may also be used to control medium voltage motors and the larger low voltage motors. This can be an arduous duty for circuit breakers, especially for drives, such as loading pumps, which are switched frequently. Before using a circuit breaker as a motor starter, it should be checked with the manufacturer.

MOTOR CONTROL CENTERS & TURNAROUND POWER CENTERS (MCCS & TPCS)

MCCs and TPCs consist of multi-tier starters housed in steel cubicles with horizontal and vertical busbars that permit cubicles to be joined together. Supply to the MCC is obtained either by connecting the horizontal busbars directly, by bus duct, or by a cable fed from a circuit breaker on the main low voltage switchgear. MCCs may be at medium voltage or low voltage, whereas TPCs are always at low voltage.

The MCC provides control for process motors, whereas the TPC feeds the circuits required during a turnaround, i.e., lighting, welding outlets, convenience outlets, substation auxiliaries, etc. The philosophy being that the MCC can be isolated during a turnaround. This cannot always be achieved, nevertheless, with this approach it should be easier to shutdown an MCC for extensions and maintenance. The reliability of the MCC should be at least equal to the TPC. A short interruption of power to the TPC may not cause any plant upset, whereas for an MCC it would be serious. Control room and computer power supplies may be obtained from either the MCC or from the LV switchgear. As there will always be at least two circuits to control rooms and computer power supplies, it is possible to obtain the power from two MCCs or either side of the LV switchgear (see [IP 16-8-1](#)).

Control power for the MCCs/TPCs is nearly always obtained from each starter power circuit; hence no external d-c is required.

The fault level capability of the MCC/TPC can limit the size of the main transformers supplying the power. This can have a considerable cost impact, thus the maximum size of low voltage transformers that can be used should be confirmed at the Planning or Class V estimate stage.

CABLES AND BUS DUCT

Cables are required to supply power from the plant main substation to the process unit substations and offsite substations, and from the process unit substations and offsite substations to the loads (see [Figure 8](#)).

The connection between the transformer secondaries and the switchgear may be cable or bus duct.

Cabling methods vary from country to country and from refinery to refinery. However, the following may be used as a rough guide:

In the Americas, the onsite cabling method usually consists of single or multicore unarmored cables installed in conduits. An exception is the connection between the transformer secondary and the switchgear, which is bus duct. In the rest of the world, direct buried multicore (3 or 4 core) armored cable is usually used, either directly buried or pulled into conduits at roadways and congested areas. These conduits may be made of plastic, concrete, or some other composite material. The conduits or duct bank are not necessarily sealed at the ends other than to keep out sand and soil, as the cable is suitable for direct burial. With this type of installation, the cable is suitable for installation in the area classification where it is terminated so it does not require any additional protection above grade.

Offsite cable runs throughout the world are generally directly buried armored cables.

Outside the Americas, bus duct is not readily available except for larger generator connections, therefore, the connection between the transformer secondary and the switchgear is often made with either single core or multicore cables.

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EQUIPMENT TYPES AND APPLICATION (Cont)

SQUIRREL CAGE INDUCTION MOTORS

Most of the motors used in ExxonMobil plants (over 98%) are squirrel cage induction type. These motors offer the following advantages:

- Low cost
- High reliability
- Robust design
- Non-incendiary sparking in normal operation (Conventional squirrel cage induction motors are currently acceptable in many countries as being suitable for a Class I, Division 2 area classification. They are also available in explosion-proof designs for use in a Class I, Division 1 areas with little cost premium.)

Typical sizes and performance data of squirrel cage induction motors made in the U.S.A. are given in **Table 1**. In Europe it is more usual to designate motors by frame size (the height in millimeters from the underside of the motor feet to the centerline of the shaft) and then state the kW outputs depending on voltage, class of insulation, speed, type of cooling, etc. (see **Table 4**).

There is a rough relationship between output and voltage of motors as illustrated in **Figure 12**. It is possible to have machines specially constructed outside these limits, but the cost could be high.

The motor-rated voltage, especially at low voltage (660 volts or less) is nearly always below the system-nominal voltage to allow for the voltage drop in the motor feeder and in some cases, the transformer. This is explained in more detail in the Basic Design Considerations below. Typical values of system-nominal voltage versus motor-rated voltages are given in **Table 2**.

BASIC DESIGN CONSIDERATIONS

NUMBER OF SUBSTATIONS & THEIR LOCATION

Each onsite process unit will require its own substation unless the load is very low, say less than 1 MVA. Some of the process units with large electrical loads may require several substations. The deciding factors are the maximum transformer capacity that can be used and the distance of the loads from the substation. Ideally the substations should have the largest transformers possible to reduce the cost, on the other hand, the outgoing cables to the motors should be as short as possible, particularly in the case of the larger low-voltage motors. Transformer size will be limited by either the continuous current rating of the incoming circuit breakers or the short circuit rating of the downstream switchgear/MCC/TPC. A good rule of thumb is to limit low voltage cable runs to 600 ft (180 m) maximum with a target of 300 ft (90 m) or less, if possible.

Whenever possible, all cables from the substation to motors should be of one continuous length without any splices (joints).

Flexibility is required to isolate and maintain the equipment. This generally entails limiting a substation to supply only one main process unit and its associated processes, thus, permitting major maintenance and switchgear extensions to be carried out during that plant's turnaround. If one switchgear supplies motors on two large independent process units, it may be very difficult to shutdown even one half of the switchgear for maintenance or extension if the process units do not have the same turnaround dates.

Several switchgear lineups and MCCs/TPCs may be located in one substation building, but two important factors must be considered:

- Space is required for the outgoing cables. The more cables there are leaving a substation the more difficult it is to find a route for them from the substation to the loads. Also, the more cables in a group the greater the ampacity derating factor.
- If a substation supplies two or more facilities and one or more of the facilities is critical and independent, the minimum spacing between the substation and process equipment is required to be three times greater than if the substation only supplied one facility (see **IP 16-6-1**).

Substations must be located at the edge of process units at a distance of 50 to 150 ft (15 to 45 m) from process equipment with any outdoor transformers located on the side of the substation farthest from the process unit (see **Design Practice XV-G, Table 1, Item H**, and **IP 16-6-1**).

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BASIC DESIGN CONSIDERATIONS (Cont)**TYPES OF SUBSTATIONS**

The types of substations most commonly used in ExxonMobil plants are:

- Secondary Selective - **Figure 2** (also see **IP 16-12-2**)
- Spot Network - **Figure 1**
- Loop Fed - **Figure 5**
- Radial - **Figure 6**

In some cases, especially expansions, other types may be used but the above four types will suit most purposes. It is very rare for a Design Specification to include any other type. The vast majority of the substations will require a very reliable supply plus provision for maintenance. This usually means that most, if not all, substations will be secondary selective with automatic transfer. A few offsite substations could be radial or loop fed, but this is becoming more unusual as the importance of the offsite facilities is increasing. Examples of loads that could be supplied by loop fed or radial substations are:

- Administration Building
- Product Loading Facilities
- Waste Water Treating

However, with the absolute dependence on electrical power; to operate computers, typewriters, copying machines, and heating ventilation and air conditioning (HVAC) in offices; the high demurrage charges resulting from loss of product loading pumps and increased use of product pipelines; the severe restrictions imposed by national and local authorities on pollution; it is unlikely that other than a secondary-selective substation with automatic transfer (or spot-network substation) will provide adequate reliability and flexibility for these offsite loads. There may be special cases where a secondary selective substation with manual transfer should be used, such as locations where the load is small and there is no plant maintenance force, or an interruption to supply is not serious provided that it is restored within an hour.

SPOT-NETWORK VERSUS SECONDARY-SELECTIVE SUBSTATIONS

The vast majority of substations, certainly all those supplying continuous process units, should be provided with two separate supplies for reliability and maintenance purposes, as discussed above. The substation types for such a design are generally limited to spot-network substations (refer to **Figure 1**) or secondary-selective substations with automatic transfer (refer to **Figure 2**).

An advantage of spot-network substations is that during normal operation, with two infeeds, the voltage drop is less when starting large motors. However, due to the higher-fault level associated with the two infeeds being in parallel, it is not usually practical to install spot network substations at low voltage because of the high short-circuit level resulting from having two transformers in parallel. This limits spot network substations at low voltage to incoming transformers about 750 kVA or less. As a result, the spot-network substations in ExxonMobil plants are generally only at medium voltage.

Secondary selective substations are designed with a momentary rating based on only one incomer infeed (**IP 16-2-1**) as it is not possible to operate with the two supplies in parallel. An automatic transfer isolates one incomer before closing the tie breaker and a manual transfer automatically trips the incomer or tie breaker that has been pre-selected whenever all three breakers are closed. Thus, the two incoming supplies can only be paralleled for a fraction of a second during a manual transfer.

Since the secondary-selective substation is designed for the short-circuit rating of only one incomer, there is a smaller variation between maximum and minimum short-circuit level, as compared with the spot network which will range from the maximum level with two transformers, to the minimum level with one transformer. These large variations in short circuit level can cause problems in the protective relaying.

As the system should be stable at minimum short-circuit level, which may be taken as a reference point because it is generally a limiting condition, it follows that the spot network must be designed to operate at a much higher maximum short-circuit level than a secondary-selective substation. This often involves extra cost to purchase switchgear with a higher short-circuit rating.

Most substations at ExxonMobil plants are secondary selective. This is the standard design for process unit substations, unless there are very good reasons to do otherwise.

There are many other considerations in selecting the type of design. A summary of some of the advantages and disadvantages is given below.

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BASIC DESIGN CONSIDERATIONS (Cont)

SPOT NETWORK SUBSTATIONS

- Advantages
 - a. Generally during normal operation, with both incomers in service, starting large motors causes less of a voltage drop and therefore results in faster starts.
 - b. Due to the higher short-circuit level, some faults will be cleared quicker resulting in less of a disturbance.
 - c. The loss of one of the incoming feeders, either due to a fault, false trip, or switching error, does not interrupt supply to the bus. In the case of an incoming or outgoing feeder fault, the whole bus would suffer a voltage drop until the fault is cleared, but this is much shorter than an automatic transfer on a secondary-selective substation which would leave half the bus without supply for up to three to five seconds. This may avoid a step/stage reacceleration of motors for such an incident.
 - d. Complex automatic transfer relaying is not required and the risk of an automatic transfer not functioning correctly is avoided.
- Disadvantages
 - a. The ratio of maximum to minimum short-circuit level is much higher than with a secondary selective-substation. The minimum short-circuit level with only one incomer may make reacceleration much more difficult.
 - b. The upstream (utility) infeeds **must** be in synchronism at all times.
 - c. Circulating currents between sources are possible.
 - d. For any fault on an incoming or outgoing feeder, the whole bus “sees” the fault and motors must reaccelerate. Depending on relay settings, this may or may not be a stepped reacceleration.
 - e. Current transformers are required on the busbars for the tie breaker’s protection. In addition to reducing reliability, the busbar current transformers are more difficult to isolate when working on incomer or outgoing feeder current transformers.
 - f. If the tie breaker fails to operate for a bus fault, or uncleared feeder fault, the whole substation is shutdown.
 - g. Protective relaying is more complex (see [Section XXX-E](#)).
 - Relaying required on tie breaker.
 - Directional relays required.
 - Relay coordination is more complex due to current flow being possible in two directions.
 - Extra step of time graded protection added by the tie breaker relaying.
 - h. Often higher cost due to the more expensive switchgear required for the higher short-circuit level.

SECONDARY-SELECTIVE SUBSTATIONS

- Advantages
 - a. Variation in short-circuit level from maximum to minimum is much less than for spot-network substations. Therefore, a secondary-selective substation having the same maximum short-circuit level as a spot-network substation will generally have better stability than the spot-network substation when operating on one source.
 - b. If stability is not a problem with a secondary-selective substation, it may be possible to use switchgear with a lower short-circuit rating than would be required for a spot-network substation while maintaining the same minimum operating short-circuit level and thus achieve a cost saving.
 - c. For a disastrous failure, such as a loss of the d-c control power or a stuck breaker(s) during a fault condition, only half the substation will be lost.
 - d. No current transformers on the busbars, which improves reliability.
 - e. No directional overcurrent relays are used. These are often wired incorrectly and are much more difficult to test than non-directional overcurrent relays.
- Disadvantages
 - a. Auto transfer relaying is complex, and half the substation would be lost if the transfer does not operate properly; but the circuit in [IP 16-12-2](#) is fully proven.
 - b. During normal operation, the short-circuit level for motor starting may be lower than in a spot network substation with both infeeds, thus resulting in longer run-up times.