

IEEE Recommended Practice for Cement Plant Power Distribution

Sponsor
**Cement Industry Committee
of the
IEEE Industry Applications Society**

Approved September 22, 1994
IEEE Standards Board

Abstract: Electrical distribution systems in cement plants that would result in satisfactory equipment utilization, reliability, performance, safety, and low maintenance—all at a reasonable cost are recommended.

Keywords: alternate power source, power distribution, primary distribution voltage, quarry distribution, secondary-unit substation, surge arresters

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA
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ISBN 1-55937-453-5

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Introduction

(This introduction is not a part of IEEE Std 277-1994, IEEE Recommended Practice for Cement Plant Power Distribution.)

This recommended practice has been revised to reflect needed technical changes that have been suggested since the document was last published in 1983.

This recommended practice reflects the thinking of members of the Power Generation and Distribution Working Group, consisting of members from cement plants, machinery manufacturers, electrical equipment manufacturers, and cement plant designers and builders.

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IEEE Recommended Practice for Cement Plant Power Distribution

1. Overview

1.1 Scope

This document has been developed as a recommended practice for electrical distribution systems in cement plants with the objective of satisfactory equipment utilization, reliability, performance, safety, and low maintenance—all at a reasonable cost.

1.2 Purpose

The purpose of this recommended practice is to provide guidance in established practices, for the design, application, installation, and protection of electrical distribution systems. It is hoped that this recommended practice will be used to augment some of the principles outlined, as they apply particularly to cement plants.

2. References

This recommended practice shall be used in conjunction with the following publications:

ANSI C2-1993, National Electrical Safety Code.¹

ANSI/NFPA 70-1993, National Electrical Code.²

IEEE Std 141-1986 (Reaff 1992), IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (ANSI).³

IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (ANSI).

¹This document is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331. It is also available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

²The National Electrical Code is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. Copies are, also available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers.

IEEE Std 242-1986 (Reaff 1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.

IEEE Std 446-1987, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (ANSI).

IEEE Std 450-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations (ANSI).

IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems (ANSI).

IEEE Std C37.2-1991, IEEE Standard Electrical Power System Device Function Numbers (ANSI).

MSHA CFR 30/56-1987, Mine Safety and Health Administration—Surface Metal and Nonmetal Mines, and MSHA CFR 30/57-1987, Mine Safety and Health Administration—Underground Mines. Subpart K—Electricity.⁴

3. Power distribution for a new plant

Factors to consider in new plant construction include the main plant distribution substation, what cables to use, secondary unit substations, and safety ground check monitoring devices.

3.1 Main plant distribution substation

Source of plant power and the ownership of the main substation can greatly affect both the capital and operating costs of a plant. Type of equipment and substation design will be dependent upon these decisions, as well as selected voltage levels and plant load.

3.1.1 Purchased power vs. on-site generation or co-generation

A study should be performed to determine the economics of purchased power (utility) vs. on-site generation or co-generation. The trend in cement plants is to purchase power from the utility instead of generating power. The decision to purchase or generate power depends primarily upon economics. Many operators believe that the possible increased production by the use of efficient kilns more than offsets the additional cost of purchased power in most locations in the United States. Other advantages in using utility power are:

- a) Possibly better voltage regulation during the starting of large motors.
- b) Greater reliability of a larger system.
- c) Absence of operating problems associated with power generation.

Explore the possibility of a form of co-generation to be operated with a new plant. Available co-generation options include:

- a) Produce electricity for a portion of the plant (no large motors). This portion of the plant would not normally be connected to the utility.
- b) Sell all the electricity the plant produces to the utility and purchase all the electricity the plant uses from the utility. One possible drawback to this would be the cost of transforming the electricity produced to the distribution voltage of the utility.
- c) Produce electricity and tie in with the plant's distribution. This may complicate coordination and protection.

⁴Mine Safety and Health Administration documents are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

3.1.2 Locating plant substations above 15 kV

Locate the high-voltage (above 15kV) part of the main substation outdoors on the windward side of the plant. The costly practice of locating plant substations (above 15kV) indoors or under a roof to minimize dust settlement is no longer considered necessary.

3.1.3 Ownership of outdoor part of main plant substation

Make a study to determine whether the outdoor part of the main plant substation is to be owned by the plant or by the utility. Here again, economics, including initial, operational, and maintenance costs, should be compared with local utility rates at different voltages to determine who should own the outdoor substation. Excluding economics, the plant purchasing the substation has the advantage of choosing the substation equipment arrangement that best fits its needs. However, utility ownership may enable a quicker restoration of power subsequent to equipment failure since utilities generally stock spare equipment.

Wherever the substation is located, make sure the plant has access to the main metering equipment (computer capture of utility pulses) so that the plant knows instantaneous kilowatt usage. Time of use and level of use are important economic considerations.

A study is indicated instead of a recommendation because of the wide variation of utility rates and policies.

3.1.4 Extra-creepage insulators and bushings

Use extra-creepage insulators and bushings on the exposed electric equipment in the outdoor substation. The use of extra-creepage porcelain in the outdoor substation extends the time between cleaning periods and helps keep flashovers to a minimum. Many operators use silicone waxes or greases to facilitate the periodic cleaning of exposed insulators and bushings.

Bushings at the distribution voltage level (2.4 kV to 13.8 kV) are best kept enclosed in terminal chambers. It is also desirable to keep the number of bushings to a minimum by the use of three-phase instead of single-phase transformers.

3.1.5 Alternate power source

Provide for an alternate power source to the plant, especially for critical loads. This power source could be a full-capacity transmission line to the plant, a small-capacity line at some lower voltage, standby generation, or some combination of these. The use of a loop or alternate transmission line allows total plant operation, after a short delay, in the event of a transmission line failure. A low-capacity alternate feed or standby generation allows operation of critical loads during the line failure outages. Standby generation should be exercised under load once a week to help ensure its availability when needed. If possible, standby generators should also be exercised once a year under full load conditions by means of an external resistive load bank (see IEEE Std 446-1987⁵).

Some utilities offer rebates for remote interruption of plant power. If this is the case, and is economically viable, then provisions should be made for this interruption in the system design. This could include putting the shipping department and plant offices on a separate meter. Also, some utilities offer rebates for shedding a portion of the plant load on notification. In this case no separate meter is needed.

3.1.6 Use of circuit breakers

Use circuit breaker or circuit breakers for primary protection of substation apparatus. Circuit breakers are preferred over fuses for substation primary protection as they allow the use of fast, sensitive relays that quickly act to isolate faulted equipment and more easily coordinate with other protective devices used. When using a circuit breaker on the primary of a substation transformer, it is possible to extend the zone of protection to include the transformer secondary

⁵Information on references can be found in clause 2.

winding and the secondary main breaker. This would be done by including a ground current transformer with ground relay (50G, 51G, or 50/51G) and/or transformer differential relaying for transformer protection. This additional relaying would supplement the primary over-current relaying to protect against ground faults and high impedance phase-to-phase faults occurring in the transformer secondary winding or between the transformer secondary winding and the main secondary breaker. Fuses or circuit breakers primary overcurrent relaying (50/51) would be insensitive to faults occurring in this zone and would not clear the fault until considerable damage had been done to the transformer.

Ground faults occurring in the substation transformer secondary or between the transformer secondary and the main secondary circuit breaker cannot be isolated by the main secondary circuit breaker located on the load side of the ground fault. These ground faults when limited by a neutral grounding resistor are not seen by transformer primary fuses and must be isolated by a primary circuit breaker. If not isolated, these ground faults create a safety hazard and may result in the destruction of the faulted substation equipment and the grounding resistor.

A primary circuit breaker also enables the use of differential relays that quickly initiate action to clear faults, keeping fault damage to a minimum. The unfaulted half of a double-ended substation can usually be quickly restored to service subsequent to an outage initiated by a properly relayed substation using a primary circuit breaker. Where cost prohibits the use of a local primary circuit breaker, a means of remote tripping through a pilot scheme, carrier scheme, or a grounding relay can be used to affect remote tripping of a circuit breaker to isolate substation faults. When the transformer primary protection are switch and fuses, a grounding switch may be employed to place an intentional ground fault on the system to cause the upstream breaker to open, thus isolating the fault.

3.1.7 Double-ended substation

Use a double-ended substation in sizes above the 5000 kVA to 7500 kVA range in capacity. The double-ended substation, as used here, is defined as a substation having more than one, three-phase step-down transformer. More than one low side bus may be used where required (see 3.1.12).

The double-ended substation allows for greater reliability and flexibility. Double-ended substations permit insulator cleaning, no-load tap changing, and reduced-capacity operation without a power outage. The double-ended arrangement is desirable at lower capacities, but the additional cost of the double-ended arrangement usually does not justify its use in sizes below 5000 kVA. (Substation costs may be estimated from figures 1 and 2 in clause 7. for the single- and double-ended substations.)

3.1.8 Surge arresters

Use station or intermediate-type surge arresters selected to coordinate with equipment insulation levels to protect exposed substation equipment and rotating machines against lightning surges. Surge protection is most effective when applied at the terminals of the apparatus to be protected. Equipment connected by cable to an exposed (outdoor lines subject to lightning strokes) power source or directly to an exposed source generally requires lightning protection. Effective arrester protection requires that the arresters be installed with a low-surge impedance discharge path to ground. Where feasible, connect the arrester ground lead to the ground lead of the protected equipment. Leads should be kept as short as possible.

Protection against lightning is usually provided at the outdoor substation by station or intermediate-type surge arresters and overhead ground wires. Apparatus energized from exposed circuits should have arrester protection at the terminals of the apparatus to be protected. Apparatus energized through cables from exposed circuits should usually have arrester protection at the junction of the cable and the exposed source. If cables connect to the outdoor transformer terminal chamber, and the transformer primary source is exposed, the transformer should have primary arrester protection.

Rotating machines have lower basic impulse insulation levels than liquid-filled transformers, switchgear, etc. Thus, all rotating machines connected to exposed circuits should be protected by lightning arresters and surge capacitors at or very near to [less than 1 m (3 ft) from] the machine terminals. The lightning arrester limits the surge level while the capacitor reduces the slope to prevent any possible motor winding damage. Both are required for proper protection.

Even though large important rotating machines are not connected directly to exposed lines, it is still desirable to use surge arresters and surge capacitors to reduce the effects of induced lightning and switching surges. Extra creepage bushings capable of operating in the contaminants around the cement plant should be used.

Surge arresters for resistance-grounded systems usually used in cement plants are rated for line-to-line voltage (see IEEE Std 142-1991).

3.1.9 Grounding the power system

Ground the power system through a neutral-grounding resistor or resistors at the primary distribution voltage level (2.4 kV to 13.8 kV). Power systems are grounded to minimize the magnitude of the transient overvoltages that occur in ungrounded systems during ground faults. To minimize the damage due to the ground-fault current that flows in a solidly grounded system during a ground fault, a neutral grounding resistor is used. Limiting the ground-fault current will minimize the damage to the large motors used in the plant at the distribution-voltage level.

A 10 s resistor rating is satisfactory for plant distribution service, when ground faults are relayed to trip the faulted circuit.

To minimize the transient overvoltages during arcing grounds, the neutral ground resistor must limit the fault current allowed to flow during faults to a value that is slightly greater than the system capacitive charging current. When the system is designed to alarm on the detection of a ground fault and operate until such time as it is convenient to clear the fault, then high-resistance grounding is employed. For high-resistance grounding, the neutral grounding resistor is sized to allow capacitive charging current to flow during ground faults. Since the charging current increases with system voltage, the application at 480 V is very favorable, less so at 4160 V, and at 13 800 V has not been successful due to the very large charging current. Where in high-resistance grounded systems the typical ground currents are 5 A to 15 A, in low-resistance grounded systems typical values range from 50 A to 600 A and, when a ground fault is detectable, the protective device closest to the fault is tripped.

In low-resistance grounded systems, the value of resistance used should be low enough to allow the flow of sufficient ground-fault current to be selectively relayed with an adequate margin. Ground-fault current should not be limited to less than the system charging current (usually less than 15 A). Generally, the combination of grounding resistor and ground relaying used should result in the protection of 90% of the windings of motors and transformers. Effective protection of equipment is realized if ground relays pick up at 10% or less of the maximum ground-fault current.

3.1.10 Using one or more feeder circuit breakers

Use one or more feeder circuit breakers for each operating department at the distribution-voltage level. This sectionalizing of loads allows independent departmental (or production unit) operation and facilitates the metering of each department. The trend is toward the universal use of metal-clad switchgear with removable-type circuit breakers. A tie breaker is desirable in the double-ended metal-clad lineup for increased flexibility. It is desirable to use an additional circuit breaker to separate the large mill motors on the raw and finish mills from the raw and finish mill auxiliaries. This facilitates relay coordination and allows closer protection of the connected equipment.

Either indoor or outdoor metal-clad circuit breakers are used, depending upon available plant area. The preference is toward using indoor metal-clad circuit breakers located in clean pressurized rooms, rather than outdoor circuit breakers. The tripping voltage should be at least 125 V to minimize relay contact continuity failures due to dust (see IEEE Std 142-1991).

3.1.11 Allowing for margin in substation capacity

Approximately one-third extra apparent power capacity (in kilovoltamperes) over that needed for present plant operation is desirable in the initial substation installation. Circuit breakers also should allow for anticipated increase in utility short-circuit capacity for an approximate 10-year period. Consideration should be given to the providing of features in the substation to facilitate subsequent expansion.

It is desirable to choose the transformer's size of double-ended substations to be large enough to enable starting the large mill motors on a single transformer within tolerable voltage regulation (see 3.1.13). Mill torque limits should be observed both on single- and two-transformer operations.

A typical suggested substation size is 5000 kVA (with fans for 6250 kVA capacity) for each 200 000 ton per year plant capacity. The use or provision for future use of fans on the substation transformers should be considered.

3.1.12 Primary distribution voltage for plants

Use 4160 V as the primary distribution voltage for plants of 20 000 kVA and below. Above 20 mVA, either use the split-bus 4160 V system or the 13.8 kV system. The interrupting and momentary current capacity of the 4160 V circuit breakers and motor controls limits the allowable short-circuit capacity and, thus, the substation apparent power on a bus. However, most existing plants have short-circuit capacities within the limits of 4160 V equipment.

When short-circuit capacities are above the limits of 4160 V equipment, the 4160 V bus can be split to keep short-circuit capacities within equipment ratings. A higher distribution voltage can be used as well with the available equipment having higher short-circuit capacities. The next economical voltage choice is usually 13.8 kV.

The use of 13.8 kV as a primary distribution voltage may require an additional transformation to 4160 V or 2400 V to enable the economical use of large motors at the lower primary distribution voltages. However, the double transformation increases system impedance and voltage drop during the starting of the large grinding-mill motor and should be taken into account. It is recommended that a study be made to determine the economic motor voltage for plants of 20 000 kVA and above.

Figures 1–6 show relative costs for the electric apparatus at several distribution-voltage levels (see ANSI C2-1993 and IEEE Std 141-1986).

3.1.13 Limiting voltage drop

Design the power system to limit voltage drop during starting large motors (at the distribution voltage) to a maximum of 10% of system nominal voltage at the motor terminals. The possibility of equipment malfunction increases when the voltage drop exceeds 10%. Special precautions to maintain control voltage may be required where a greater than 10% drop in system voltage is anticipated.

During normal running, voltage at the large motors at the distribution voltage should not vary more than $\pm 5\%$ of rated motor voltage.

A motor starting study, short-circuit study, and a coordination study is required to properly design the power system.

When purchasing new transformers, an economic solution to changing voltage levels might be incorporating automatic tap changes on the new transformers.

3.1.14 Isolating synchronous machines

Isolate synchronous machines from the utility system prior to any reclosing action subsequent to a plant power interruption due to the utility system. A power interruption allows the synchronous machines to shift in phase position in respect to the utility system. Subsequent application of power to the machines, when out of synchronism, may result in inrushes and torque well above drive equipment mechanical limits. High-speed underfrequency relays without any intentional time delay can usually act to isolate loaded synchronous motors prior to a reclosing action. Note that lightly loaded motors or motors connected to high inertia loads or both may not decelerate in time to allow underfrequency relay action prior to utility reclosing.

Coordination with the utility to block or delay reclosing is suggested.