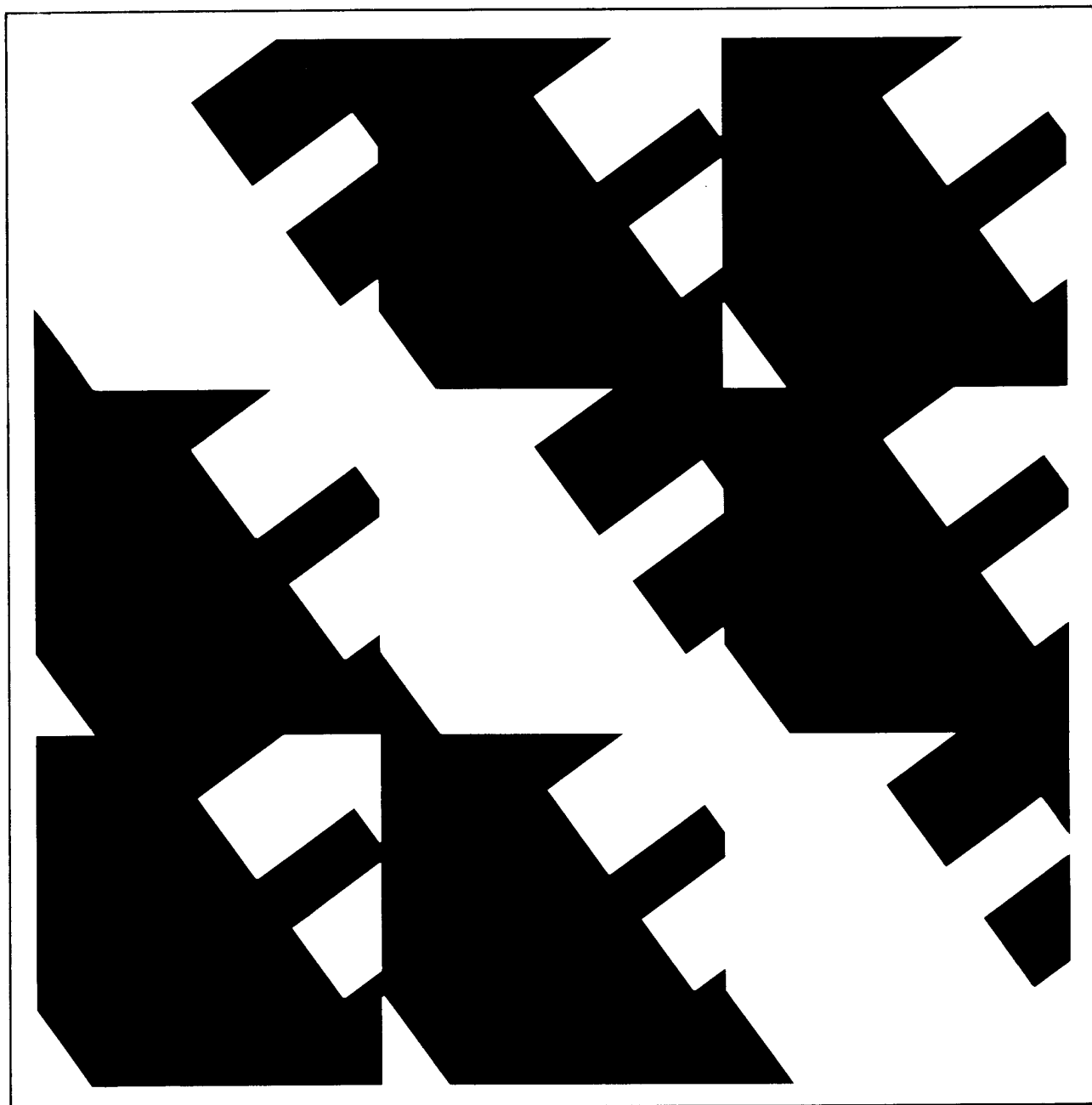


IEEE Recommended Practice for Electrical Heating Applications to Melting Furnaces and Forehearths in the Glass Industry



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IEEE Recommended Practice for Electrical Heating Applications to Melting Furnaces and Forehearths in the Glass Industry

1. Purpose

The purpose of this recommended practice is to present procedures and positions preferred by the IEEE for using electric heating in the glass industry's melting furnaces and forehearths and to provide criteria for the safe performance of these electrical heating applications.

It is urged that users and manufacturers cooperate and mutually agree to follow this recommended practice.

2. Scope

The provisions of this recommended practice apply to

(1) All electrical equipment and wiring between the point of connection in the power supply substation and the connection to the furnace or forehearth electrodes for the purpose of heating the glass by the passing of electric current through it.

(2) All electrical equipment and wiring that is connected directly to resistance heating devices that supply energy to the furnace or forehearth.

(3) All sensors and devices used to measure,

alarm, or regulate energy, mass flow, and temperature.

(4) The adequate electrical insulation from ground of the refractories containing the molten glass.

(5) The adequate electrical grounding of equipment and services.

(6) All equipment and procedures pertaining to safeguarding personnel.

3. Definitions

branch circuit. One, two, or more circuits whose main power is connected through the same main switch.

controller, automatic. A device that operates automatically to regulate a controlled variable in response to a command and a feedback signal.

direct coupled. The power modulation device is conductively connected directly to the electrodes carrying current into the molten glass.

impedance matching. The use of a transformer to match line-supply voltage levels to the voltage levels required by the molten-glass load.

indicating instrument. An instrument in which only the present value of the quantity measured is visually indicated.

induction regulator. A regulating transformer, having a primary winding in shunt and a secondary winding in series with a circuit for gradually adjusting the voltage, phase relation, or both, of the circuit by changing the relative magnetic coupling of the existing (primary) and series (secondary) windings.

recording instrument (recorder). An instrument that makes a graphic record of the value of one or more quantities as a function of another variable, usually time.

saturable reactor (saturable core reactor). A device that provides output voltage modulation by variation of its circuit reactance. This reactance is controlled by changing the saturation of its magnetic core through variation of a superimposed unidirectional flux.

sensor. A device that responds to a physical stimulus (such as heat and light) and transmits a resulting signal.

sharing transformer (ST), current balancing transformer (CBT), (current balancing reactor). Two-winding, iron core devices used in parallel current paths, connected so that any difference in current between the paths causes an induced voltage that opposes the current difference.

stepless. Power modulation by means of a device, such as a saturable reactor or thyristor that provides essentially infinite resolution in output voltage, current, or power.

stepped. Power modulation by means of discrete voltage steps, such as with a tapped transformer.

surge arrester. A protective device for limiting surge voltages on equipment by discharging or bypassing surge current. It prevents continued flow of current to ground and is capable of repeating these functions, as specified. As surge protective devices, arresters are connected from sensitive circuit points to ground, thus limiting dangerous surge voltage below damaging levels.

surge capacitor. Capacitors used to decrease the slope of the surge voltage wave fronts. They help to reduce the voltage stresses on protected apparatus by spreading the impressed voltage over a greater time span.

thyristor. A bistable semiconductor device comprising three or more junctions that can be switched from an *off* (nonconducting) to an *on* (conducting) condition, or vice versa, by the application of a small electric signal. Such switching occurring within at least one quadrant of the principle voltage-current characteristic.

time proportioning. An operation in which variable length bursts of full cycles of output voltage are alternated with variable length off periods to produce modulation of output.

transducer. A device that is actuated by power from one system and supplies power in any other form to a second system.

transformer coupled. The power modulation device is connected in the primary circuit of a transformer whose secondary circuit is connected to the glass.

transformer, dry type. A transformer that relies on convection or forced air rather than liquid, such as oil or water for cooling.

transformer, dry-type encapsulated water-cooled. Dry type (nonoil-cooled) transformer in which the windings are made from hollow conducting tubes that are cooled by transferring heat to water flowing in the tubes. Since the cooling is internal, the windings are usually totally encapsulated with epoxy resin.

transformer, liquid filled, or liquid cooled. A transformer that is immersed in a tank of insulating liquid that removes heat from the windings by conduction. The liquid is then cooled by running through external radiators.

variable. A quantity or condition that is subject to change.

zero voltage fired. A circuit in which antiparallel connected thyristors are fired at points of voltage zero in the alternating current voltage wave.

4. References

This standard shall be used in conjunction with the following publications.

[1] ANSI C2-1987, American National Standard National Electrical Safety Code.¹

[2] ANSI/NFPA 70-1987, National Electrical Code.²

5. Description of Glass-Melting Furnaces and Forehearths

5.1 Furnaces. In the glass-making process, raw materials are weighed and blended to form a suitable mixture for conversion to glass. This mixture is conventionally called *batch* and it usually contains some scrap glass called *cullet*. The conversion of the crystalline batch materials to an amorphous liquid at elevated temperatures, and the subsequent removal of gaseous inclusions, is referred to as *melting*. The container into which the batch materials are filled and energy is applied to achieve high temperatures (generally 1400 °C – 1600 °C) is called the glass-melting furnace. Historically, most glass furnaces have been heated by the combustion of a fossil fuel directly over the surface of the glass bath. More recently there has been a trend toward the use of electric power which is applied directly to the glass bath. In this case, the heating is accomplished by ionic conduction between electrodes immersed in the molten glass. Glass furnaces are typically constructed for continuous use, that is, glass is withdrawn at one end while raw materials are simultaneously introduced at the other. There

are also day tanks, which are discontinuous glass furnaces, in which the batch is periodically introduced, melted, and then withdrawn in a few hours by *hand shops*.

Glass furnaces vary in output and size from less than one ton of glass per day and a few square feet in melting surface area to hundreds of tons of glass per day and several thousand square feet of melting area. The furnaces that use electric energy have electric power input varying over a similar large range; for example, from less than 100 kW to tens of megawatts depending on the type of glass, the size of the furnace, and the product application. Inter-electrode voltages from less than 100 V to more than 1000 V and electrode current from a few hundred amperes to more than 10 000 A also reflect this broad range.

Furnaces that use electric energy are generally classified as one of three types:

- (1) All-electric
- (2) Booster-electric
- (3) Mixed-melter

Although all types have many common characteristics, each has particular attributes that require special attention in terms of control, operation monitoring, safety considerations, maintenance, production continuity, and life.

5.2 All-Electric Furnaces. Except for the initial start-up period when fossil fuel or indirect electric radiant heat is used to heat up the furnace (and melt the cullet to allow electric conduction), the all-electric furnace uses electric power exclusively for its melting energy. Power is applied to the glass by way of electrodes (typically molybdenum or graphite) installed through the furnace sidewalls, bottom, or breastwall.

Most of these furnaces are constructed in square or rectangular shape, with glass depths similar to that of fossil-fuel fired furnace. Significantly deeper furnaces with cylindrical or hexagonal shape are also used in sectors of the glass industry. Other configurations, such as bowl-shaped furnaces, are used in low volume or specialty glass applications.

Sidewall electrodes are used in the cylindrical and hexagonal-shaped melters almost without exception, whereas in the rectangular and bowl-shaped melters either sidewall or bottom electrodes are used. Some other specially designed electrodes are also used in the bowl-shaped melters.

¹This publication can be obtained from the Institute of Electrical and Electronics Engineers, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854. Copies are also available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

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, 1430 Broadway, New York, NY 10018.

Most continuous all-electric melters are designed for *cold top* operation in which the unmelted batch material completely covers the top surface of the glass.

Temperature measurements within all-electric furnaces are usually made with thermocouples inserted through the sidewalls or bottom paving since the batch cover over the glass surface prevents the use of optical or radiation pyrometry. Another option is to use the inter-electrode glass bath electrical resistance or conductance, that are measures of, and vary with, glass temperature.

5.3 Booster-Electric Melting. Booster-electric melting is the process of adding electric energy to the molten-glass bath in a continuous furnace that is heated primarily by other fuels, most often natural gas or fuel oil. Up to 50% of the total energy may be supplied electrically in such a furnace.

Booster-electric melting is used primarily to increase the output of a furnace in which the limit of fossil-fuel input has been reached. Reduction of furnace emissions, improvement in glass quality (lower stone loss), reduction in firing intensity, and extension of campaign life have also been attributed to booster-electric melting.

Both bottom and sidewall electrodes are used.

5.4 Mixed-Melter Furnaces. The mixed-melter furnace is essentially a booster-type continuous furnace in which 50% or more of the melting energy is supplied electrically. In many cases, the fossil-fuel firing system is designed quite differently and the glass depth can be greater than in a booster-electric or fossil-fuel fired furnace. With the exception of the batch delivery system, the problems to be addressed with this type of furnace are similar to those found in the all-electric.

5.5 Forehearth. The forehearth is a refractory-lined channel used in the continuous glass-making process through which molten glass flows from the furnace, in which it is cooled or heated, or both, as appropriate to the required glass forming (or fiberizing) temperature. The forehearth is to be considered in this standard are those that use electric energy for all or part of their heat input.

Two major types of electric heating are used

(1) Radiant heating

(2) Direct heating

In radiant heating, resistance heating elements are mounted over the glass as a substitute for fossil-fuel burners. In direct heating, groups of electrodes are immersed in the glass in the forehearth and an applied voltage causes current to pass through the glass between electrodes. The continuous forming of a product from molten glass demands the close control of temperature so as to maintain a constant glass viscosity at critical points in the process. Thermocouples immersed in the glass and radiation pyrometers, are most commonly used as primary elements for forehearth temperature control. The continuous measurement of glass circuit resistance or conductance has also worked well in closed loop control.

6. Melting Process Electrical Equipment

6.1 Introduction. Figures 1 to 6 show schematic diagrams for typical systems for power application and modulation in glass melting furnaces and forehearth. All diagrams show direct-heating applications since they constitute the majority of the installations.

Radiant heating is applied most commonly in forehearth applications with tapped transformers, power contactors, saturable reactors, or thyristors providing power modulation. Power is generally supplied from 600 V class distribution service and step-down (impedance matching) transformers are not usually required. Devices for line isolation are required, but load isolation is normally obtained by removing bolted connections to the radiant heaters.

In direct heating, one or more power transformers are required to provide isolation between the molten glass and the supply line, for impedance matching between the line and glass voltage levels and, in some cases, for stepped power modulation. If stepless power modulation is desired, induction regulators, saturable reactors or thyristors may be employed. In applications with 15 kV or 5 kV class line supply, saturable reactors are usually applied as primary controls, transformer-coupled to the glass load, while induction regulators and thyristors are usually applied as secondary controls directly coupled to the glass load.

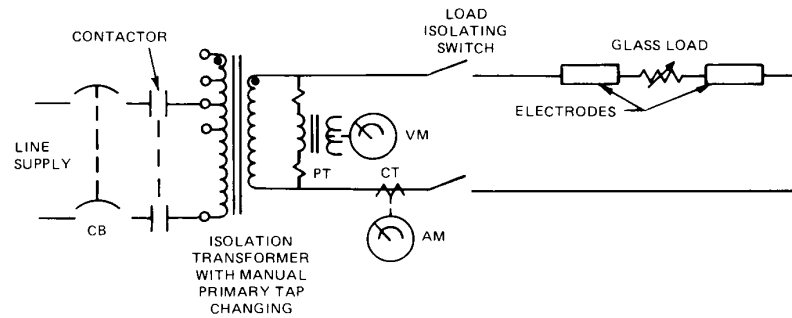
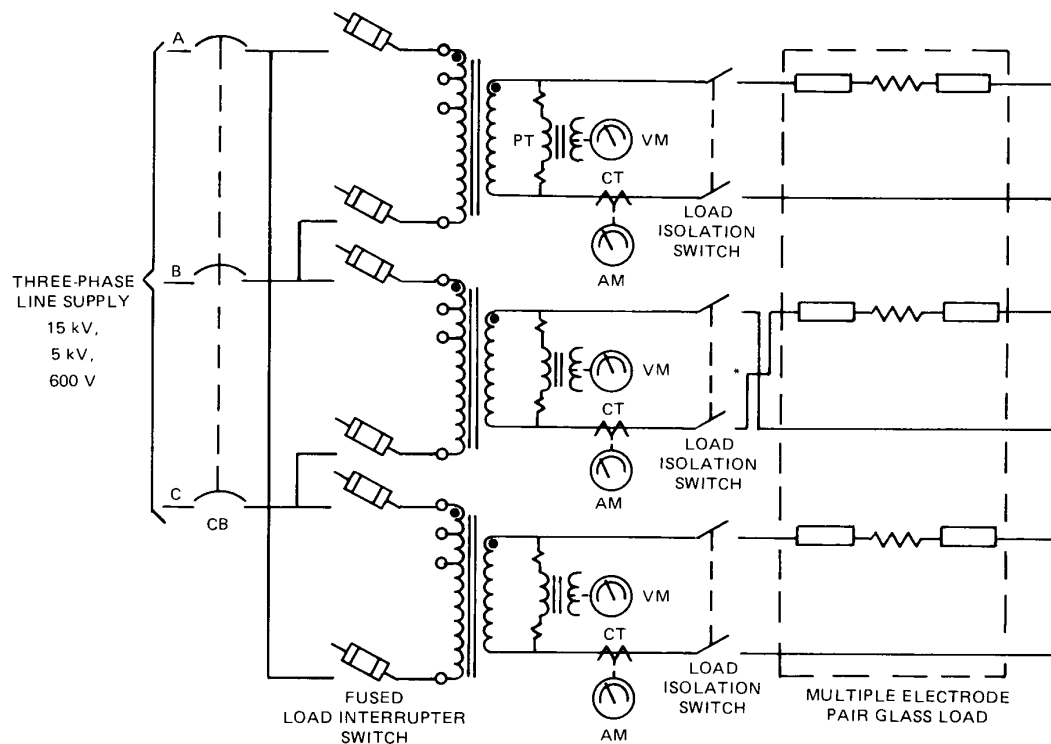
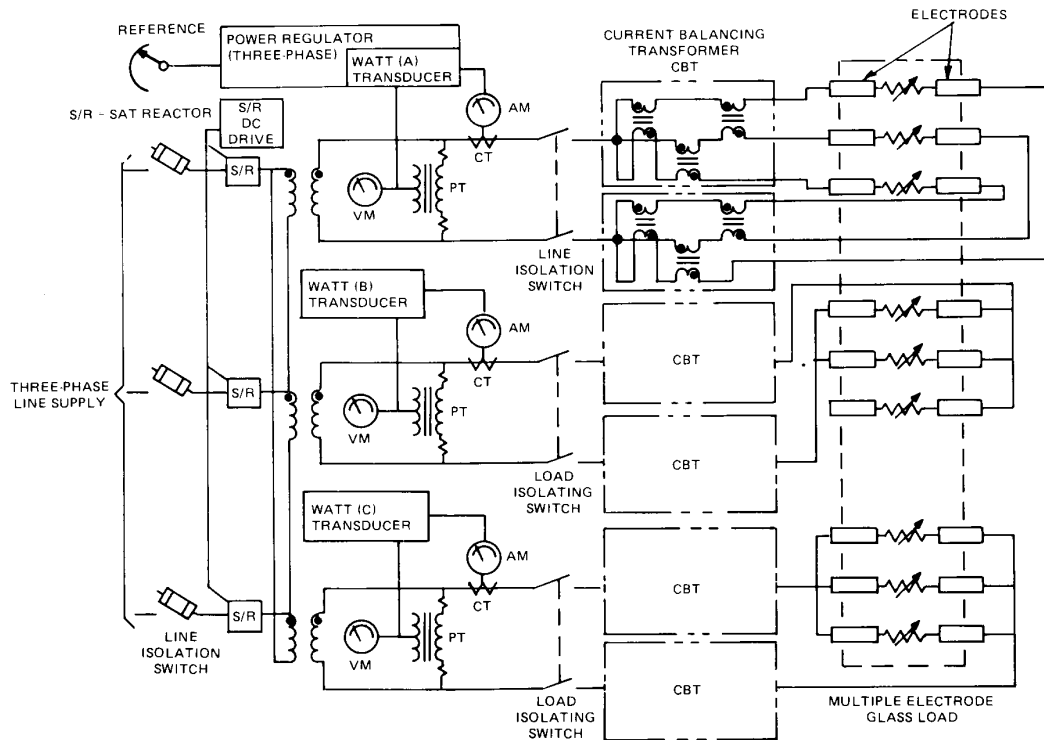


Fig 1
Single-Phase Manual Tap Change
System—Direct Heating



*NOTE THAT, IF DONE, POLARITY CHANGE TO REDUCE PHASE INTERACTION SHOULD BE MADE NEAR THE ELECTRODES TO PRESERVE 30° FLUX CANCELLATION IN WIRING RUNS.

Fig 2
Three-Phase Tap Changer—
Direct Heating



*NOTE THAT, IF DONE, POLARITY CHANGE TO REDUCE PHASE INTERACTION SHOULD BE MADE NEAR THE ELECTRODES TO PRESERVE 30° FLUX CANCELLATION IN WIRING RUNS.

Fig 3
Three-Phase Saturable Reactor Controlled
Power Regulated System—Direct Heating

Line supply voltages may be single phase or three phase, and predominantly, 15 kV, 5 kV, or 600 V class. Line disconnect and protective devices are used to provide branch-circuit fault protection. In 15 kV and 5 kV line applications, surge suppression in the form of surge (lightning) arresters and surge capacitors are generally used to protect against transient over-voltages caused by lightning or switching operations.

When two or more electrode pairs are paralleled from a single power source, sharing or current balancing transformers may be employed to force current balance among the paralleled electrodes. Sharing transformers may

also be used in place of interweaving to force current balance in long multicable conductor runs to a single electrode.

Load isolation switches may be used to provide isolation of the power supply from the glass load during maintenance to eliminate dangerous voltage feedback to the power supply in applications utilizing multiple power supplies feeding the same glass load.

6.2 Power Components

6.2.1 Line Disconnect and Protective Devices

6.2.1.1 Line Isolation Equipment for Use at 15 kV and Below. (1) Manual or motor operated, fused or unfused load-interrupter