



Primary Substation Transformers

501 – 10,000 kVA 3 ϕ
with & without LTC



INTRODUCTION

This publication covers Primary Substation Transformers manufactured at the Rome, Georgia plant of General Electric. They are rated 501 – 10,000 kVA with a winding temperature rise over ambient of 65°C in accordance with ANSI Standards.

General Electric Primary Substation Transformers have won an enviable reputation for reliability. It's natural that they should. Years of experience have given General Electric extra insight into substation performance requirements. General Electric researchers and engineers have attacked these requirements with innovative transformer designs. Unparalleled manufacturing and testing facilities carefully translate these designs into transformers that will meet your specific substation applications.

The achievement of a high degree of reliability and short-circuit strength is the common thread that joins together all General Electric transformers manufactured at the Rome plant. The design, manufacturing and testing techniques and processes employed may vary according to the rating of the unit, but regardless of the methods used, the resulting mechanical and electrical reliability is of the same high degree of magnitude in all transformers.

The information and data on the following pages will give you specific details on "what we do" and "how we do it" concerning the design, construction and testing of Primary Substation Transformers.

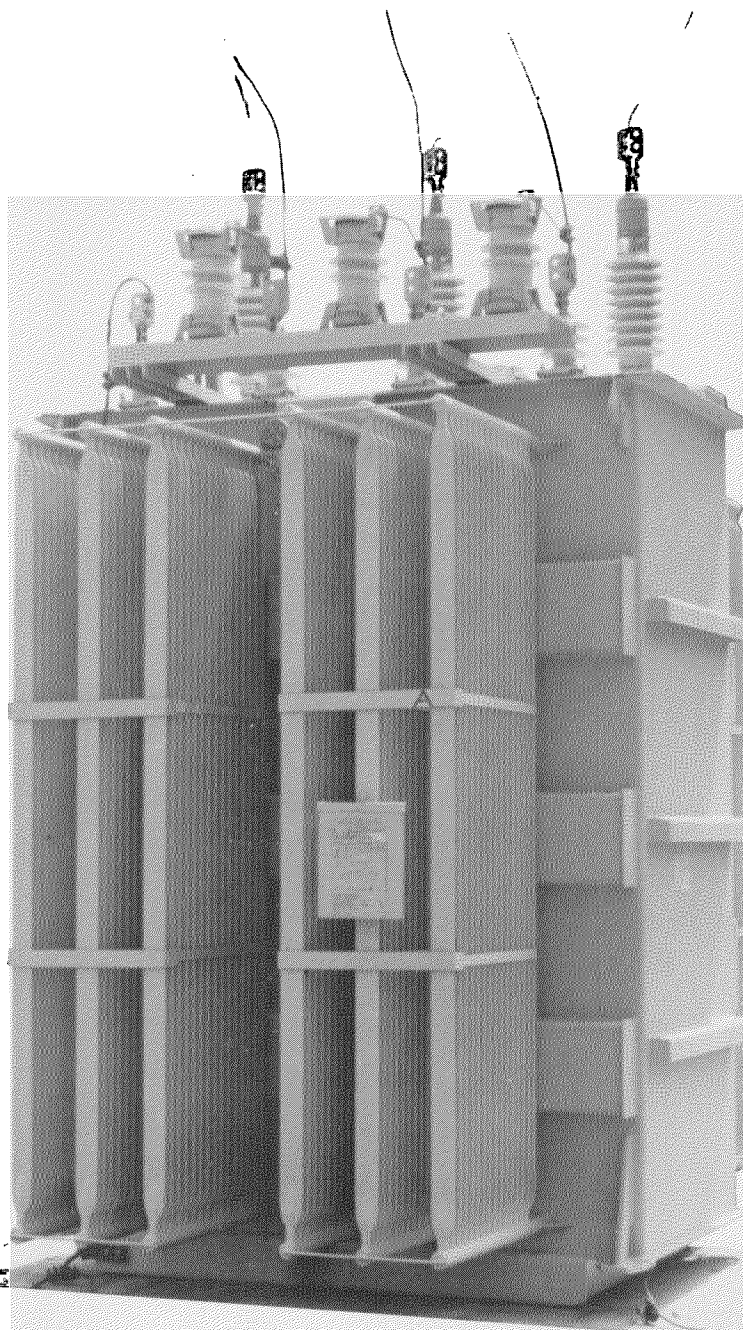


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PERSONNEL AND RESEARCH

Modern manufacturing facilities, coupled with the skills and know-how of experienced personnel, bring you the utmost in product quality and performance reliability. Working with the most sophisticated equipment, GE scientists and engineers probe deep into the behavior of

metals, insulating liquids, paper and other transformer materials. This sustained research allows GE engineers to utilize the best combination of materials and methods when designing your transformers.

There are many possible designs which will meet a particular transformer

specification; only one will be better than all the others. An individual engineer could not exhaust all the possibilities, and therefore might miss the best design. The design logic of General Electric's best transformer engineers is stored in computers. This tool enables the engineer to design the optimum transformer quickly and accurately, enumerate the detailed drawings required, and schedule the transformer through the factory. This is the kind of professional engineering and manufacturing know-how that gives General Electric transformers added reliability and the ability to meet your delivery requirements with on-time shipments.



SHORT CIRCUIT STRENGTH AND TESTING

In order to assure satisfactory service, power transformers must be designed to withstand anticipated short-circuits and the effects of internal electromagnetic forces they will generate. Almost from the inception of power transformers, the subject of short-circuit strength has been an important design consideration. Through the years this aspect of design and in-service performance has gained increased attention as larger systems resulted in higher magnitudes of short-circuit currents; as new operating techniques and breaker operating practices evolved; and as transformers themselves became more complicated.

With the announcement of its Proposed Short-Circuit Test Code in 1970, General Electric committed its research, development, engineering and production facilities to the design and manufacture of power transformers that are second to none in reliability. A continuous program of short-circuit testing of full-size production units has yielded valuable data that is used by our design engineers to shape transformer designs for maximum short-circuit capability, optimum performance and long life. For years designers had to deal with short-circuit forces empirically, but today—with sophisticated computer programs—utilizing the data from the GE short-circuit testing program—they are able to control and minimize these forces in every transformer design.

When this design expertise is coupled with the latest in materials, manufacturing, testing and quality control procedures, the resulting Primary Substation Transformers have a built-in short-circuit strength and capability unequalled in the world.



General Electric's experience in short-circuit testing is summarized in publication GET-6710 which gives a complete listing of units tested.

INSULATION SYSTEM

All Primary Substation Transformer core-and-coil structures are designed with the aid of a computer. Design requirements for flux density, winding type, insulation, cooling, sound levels, and structural integrity are accurately computer calculated. In addition, optimum weight, size and configuration for each core and coil is computed. Result: a structure which is both physically and electrically designed to your specifications.

The insulation system is the most important system within the transformer. Its design is a major consideration in the overall design of the transformer. Sufficient strength must be built into the insulation system to withstand normal operating voltages, as well as abnormal over-voltages caused by lightning and switching surges. Since the insulation system is under continual electrical stress, even under normal operating conditions, it must be designed to withstand this stress in order to prevent breakdown and interruptions in service.

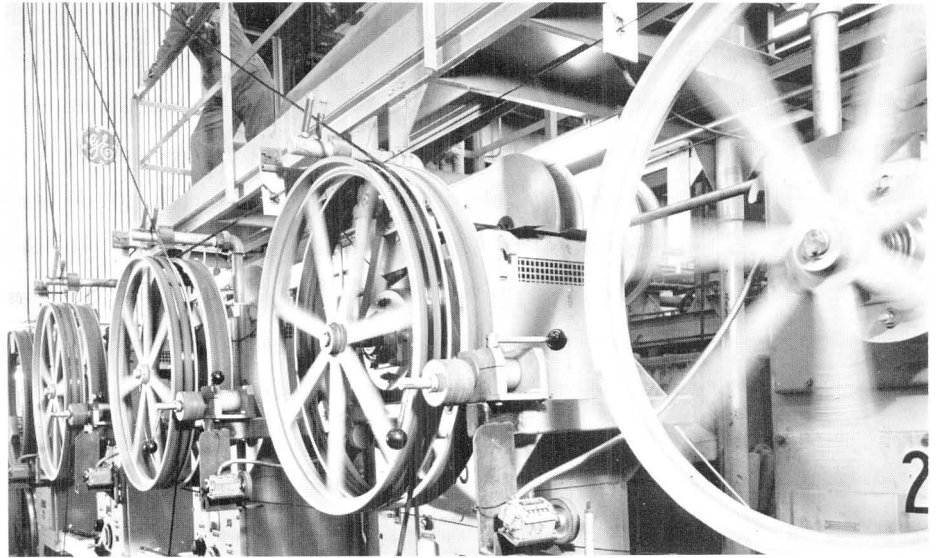
The Insulation System's useful life can be greatly curtailed by moisture created from the decomposition of cellulosic materials. Generally, these materials are the paper parts used in the insulation system near and in the windings where higher temperatures cause more rapid aging. Moisture from decomposition reduces the tensile and dielectric strength of the paper from which it was generated, and accelerates the rate of decomposition. It also reduces the dielectric strength of oil and other insulations as they absorb the moisture that is produced. To minimize these effects, General Electric uses a "thermally uprated" insulation system. Model transformers, built to scale and using the same materials that are in production transformers, are life tested. By carefully controlling the temperature, it is possible to run accelerated life tests on proposed designs and various configurations of insulation systems and materials in order to locate and eliminate possible weak spots in each particular system and structure.

The insulation system of General Electric Primary Substation Transformers contains the following four basic elements:

1. CONDUCTOR INSULATION

High-quality winding insulation aids short-circuit protection.

General Electric controls the quality of its conductors by special processing done completely in our own plant. Rod is first shaved to remove surface irregularities and impurities, then drawn to proper diameter, and finally rolled into rectangular shaped



Automatic equipment applies Formex[®] insulation to conductor wire.

wire. Conductor corners are rounded during the rolling operation to eliminate sharp edges and to provide a surface that will permit the uniform application of film insulation.

Once the raw rod is drawn and rolled into a rectangular cross-section, it is annealed to yield a strong, uniform and burr-free conductor. Then it is coated with Formex[®] film insulation. This unique material, which is a component of the high temperature insulation system, is applied to the conductor using special equipment which uniformly covers, cures and securely bonds the film to the wire. Formex has high dielectric strength and is practically immune to damage by bending, stretching, or scraping. Transformers rated up to 550 kV BIL use wire insulated with Formex.

For higher stressed turns, and for entire turns on high-voltage windings above 550 kV BIL, several wrappings of thermally-uprated paper are used in addition to Formex.

2. WINDING FORMS

Rectangular windings are combination-wound on a rectangular insulating form that serves as the major insulation between the core and the low-voltage winding. This winding form is constructed of heavy electrical grade Kraft paper. Individual wraps of paper are bonded during manufacture by the use of a special adhesive, resulting in a winding form free of voids and capable of absorbing the insulating liquid.

Cylindrical windings are wound on separate insulating cylinders which support the winding and serve as major insulation between the core and low-voltage winding and between the low-voltage and high-voltage windings.

The *low-voltage* winding, which experiences crushing compressive forces

under short circuit, is wound on a special insulating cylinder of high physical and dielectric strength. These cylinders are constructed of Kraft paper impregnated with polyester-resin.

High-voltage winding cylinders are constructed of heavy electrical grade Kraft paper. Individual turns are bonded during manufacture by the use of a special adhesive, resulting in a rigid cylinder free of voids and capable of absorbing the insulating oil.

3. ELECTRICAL GRADE KRAFT PAPER

One of the other components of the high temperature insulation system used in General Electric transformers is electrical-grade Kraft paper ("Electrical-grade" signifies the best in both chemical and mechanical qualities of paper insulation). Purchased from long-established suppliers, this material is subjected to a continuing quality control program of "aging tests" to provide both initial design data and information on the ability of the paper to withstand the operating demands of time and temperature inside the transformer.

4. INSULATING OIL

Refined especially for this application, the oil is desiccated and deaerated upon receipt at the factory. Each incoming batch is routinely tested for dielectric strength and for the presence of impurities. Further, the product of each supplier is subjected to a continuing program of screening tests to provide initial design data and aging characteristics.

CORE AND COIL STRUCTURE

All Primary Substation Transformer core-and-coil structures are designed with the aid of a computer. Design requirements for flux density, insulation, cooling, sound levels, and structural integrity are accurately computer calculated. In addition, optimum weight, size and configuration for each core and coil is computed. Result: a structure which is both physically and electrically designed to your specific application.

1. CORE DESIGN & CONSTRUCTION

Cores are built of high-grade, grain-oriented, silicon steel laminations. The steel is first subjected to rigid quality tests. It is then slit to width, cut to length, and built into high quality cores having the desired performance characteristics.

Laminations of the core legs and yoke are interleaved in mitred joints. This construction improves flux distribution and reduces losses and sound emission.

The core (Fig. 1) must be securely and tightly contained to assure that the designed loss and sound levels are maintained, and to reduce the possibility of damage during shipping.

2. WINDINGS

Rectangular coils are combination-wound on a rectangular insulating form that serves as major insulation between the core and the low-voltage winding. The winding form is constructed of heavy electrical grade Kraft paper. Individual wraps of paper are bonded during manufacture by the use of a special adhesive, resulting in a winding form free of voids and capable of absorbing the insulating liquid. The rectangular form is placed on a matching rectangular mandrel for the winding operation (Fig. 2).

The major insulation between the low voltage and high voltage coils is made by winding an electrical grade Kraft paper directly over the low voltage with duct spacer assemblies when required. The high voltage coil is then wound with one or more Formex insulated rectangular (aluminum or copper) conductors in multiple layers with sheets of electrical grade Kraft paper between layers for insulation. Cooling ducts are located in the coils where necessary.

During winding the tension on the paper insulation and on the strip or rectangular conductors is controlled to obtain tight coils. Increased tension is obtained by reverse bending the strip or rectangular conductors. A thermosetting resin is used on the insulating paper and cooling duct spacers. The coils are compressed and

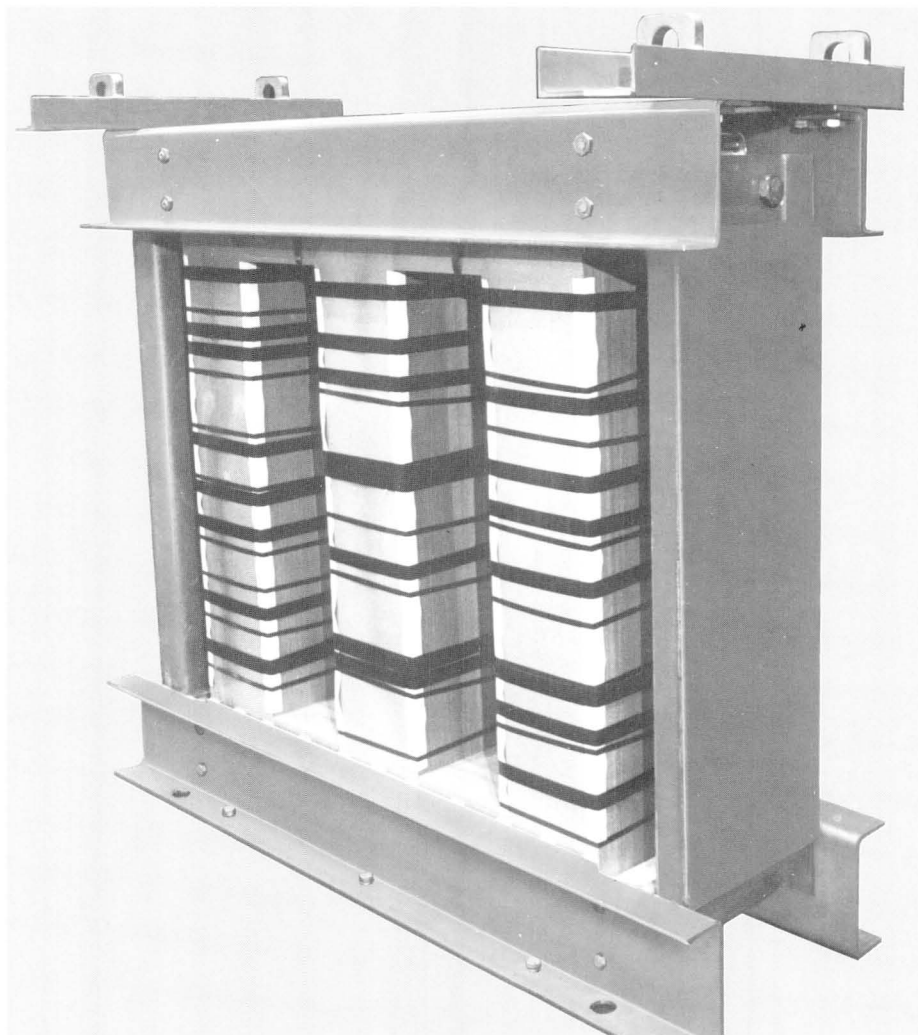


Figure 1



Figure 2

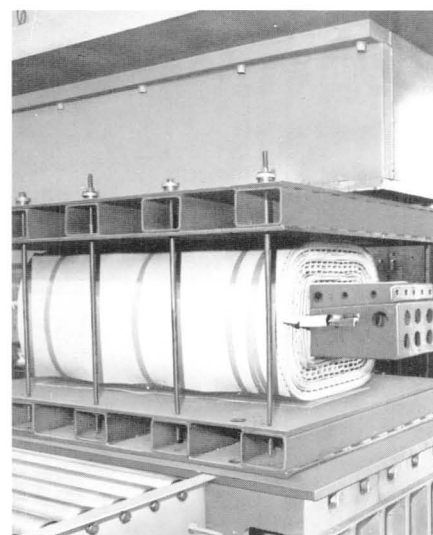


Figure 3

clamped to dimension in the in-window direction using a predetermined and specified pressure (Fig. 3). They are then heated to activate the resin and bond the

coil conductors to the insulation. This procedure produces a solidly bonded rigid winding that effectively resists the axial and radial components of short-circuit forces.

On LTC transformers a tap winding made from copper strips is wound first on the insulating winding form. Taps are brought out by coldwelding copper strips at the proper turn locations and the coil height is kept the same as the other coils by inserting paper strips between the copper ones. Paper insulation is wound over the tap winding with ducts as required, and then the low- and high-voltage coils are wound over the top winding.

On non-LTC transformers, the low voltage coil is wound first and may be either a strip or rectangular conductor winding. The high current low-voltage coils (greater than 500 amperes self-cooled) are wound with aluminum or copper strips in parallel to simulate a full-width sheet and make each turn extend the full height of the winding. Special electrical grade mechanically tough paper is simultaneously wound with these strips to insulate between turns and/or layers. The edges of the strips are conditioned to prevent damage to this paper layer insulation. Lower current low-voltage coils are wound with one or more Formex insulated rectangular (aluminum or copper) conductors in multiple layers with sheets of electrical grade Kraft paper between layers for insulation.

The relative heights of the low- and high-voltage coils are selected to minimize electromagnetic forces. Because these coils are combination-wound and because the position of each layer is fixed by insulation pieces at both ends, any possible displacement between coils due to manufacturing variations is negligible. High-voltage winding taps are located, by design, to minimize their effects on turn unbalance. These procedures reduce the axial component of short-circuit force to magnitudes that can be contained by the clamping technology currently in use.

After the combination-wound compression-bonded coils are assembled on the core legs (Fig. 1), the space between the core and the winding form is packed with hard insulation material. The compression-bonded inner coil has only a small amount of inherent strength to resist the radial forces pushing inward. Therefore, these radial forces must be transmitted through the winding form and the hard insulation packing to be resisted by the solid rectangular core. Because the amount of force transmitted to the core is not equal in all directions, there is a resultant force tending to move the outer core legs away from the center leg. Since this force can become quite significant, and the core must be firmly supported to prevent movement and damaging effects on its loss, exciting current, and sound performance. Boxed channel members on the top (Fig. 2) and wide flanged clamp members on the bottom hold the core yokes securely. Any movement in the long axis direction is prevented by the use of a

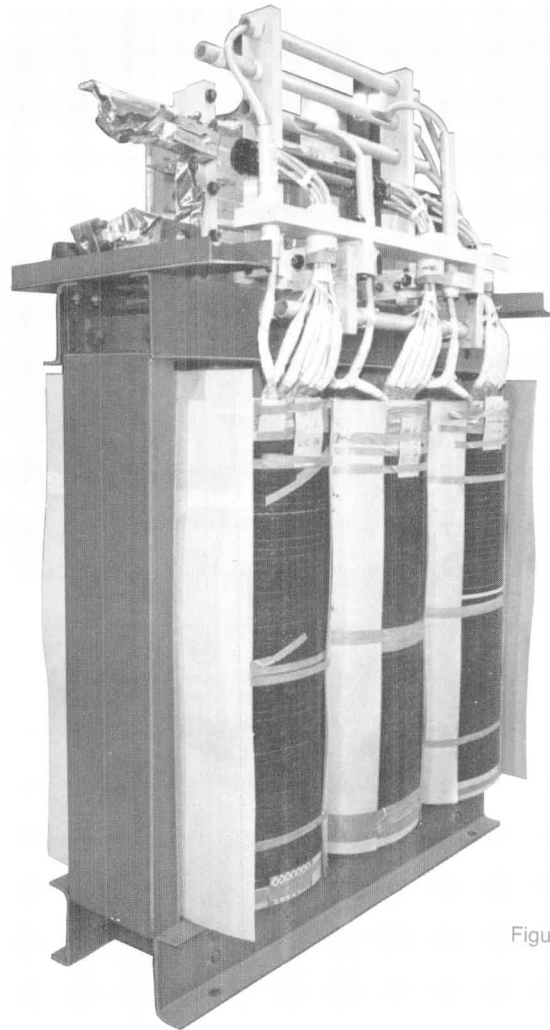


Figure 1

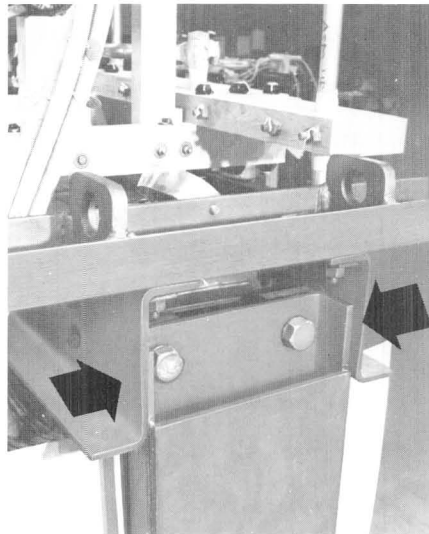


Figure 2



Figure 3

clamping arrangement (Fig. 3) that assures the top and bottom end clamp members and associated insulation are pressing firmly against and supporting the core.

Because the radial forces pushing outward on the outer coil cannot be completely resisted by the inherent strength of this compression-bonded coil,

they must be resisted between legs by the corresponding force from the adjacent leg and by massive top-to-bottom clamp channels at the two ends. This requires adding insulation fill pieces between adjacent compression-bonded coils and between the two end coils and the end clamp channel.

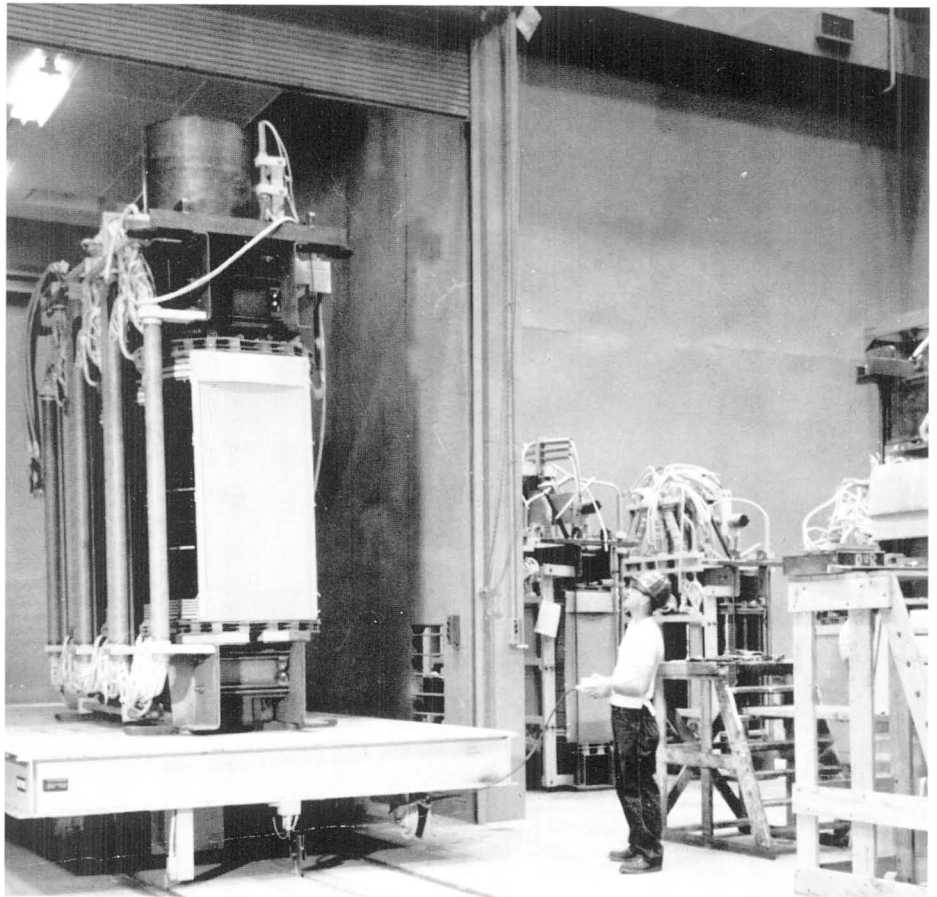
DRYING & MOISTURE CONTROL

Excess moisture can severely curtail transformer life. General Electric removes moisture from the core and coil during manufacturing by a special Vapor Phase Drying Process. Hot oil vapor is released into a specially designed compartment containing the core and coil assembly. When the hot oil vapor condenses, its heat vaporizes any moisture in the insulation. A vacuum system then draws off the moisture leaving a moisture-free core and coil assembly. Drying of the completed core and coil assembly is superior to the drying of individual components that could absorb damaging moisture during assembly.

In contrast to conventional oven heating, the completely automatic Vapor Phase Process permits internal drying by its ability to circulate hot oil vapors through cooling ducts and other internal passages.

Upon completion of the Vapor Phase Process the core and coil assembly is immediately moved to a dehumidified room where the relative humidity is maintained at 2 percent maximum. Here the final finishing, tightening and clamping operations are performed prior to tanking without the risk of moisture entering the assembly. When the internal assembly is complete, it is placed immediately in its tank. The tank is then filled, under vacuum, with deaerated oil.

From initial design through final assembly and drying of the internal structure and its insulation system, each GE Primary Substation Transformer is the product of the skills and dedication of the hundreds of engineers, designers, production craftsmen, quality control



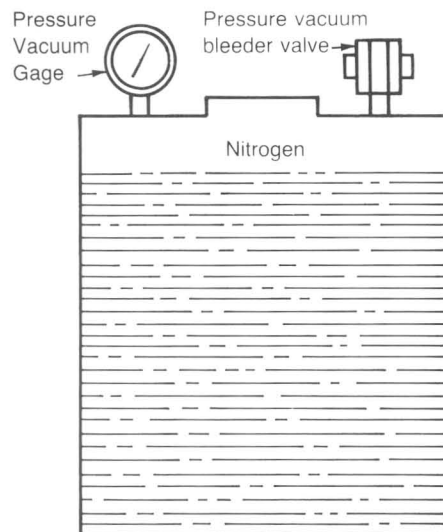
The Dry Room, at the Rome, Georgia facility where relative humidity is maintained at 2%.

inspectors and test technicians in the Rome plant. Each of the hundreds of steps taken to complete your transformer is done

with pride, and the final result is a transformer of exceptional quality and reliability.

OIL PRESERVATION SYSTEMS

Once the transformer has been installed, temperature changes due to weather and load variations cause the oil to expand and contract. If the tank were completely sealed, excessive positive and negative pressure would result. On the other hand, if the tank were freely vented, moisture-laden air would be drawn into the transformer when the oil contracted during cooling. Such moisture intake, occurring on every cooling cycle of every day, would seriously deteriorate the insulation system in a very short time, and result in greatly reduced transformer life. To minimize moisture intake during these expansion and contraction cycles, many types of oil preservation systems have been developed. ANSI standards describe three methods of preservation. The *sealed tank* method is standard for all General Electric Primary Substation Transformers.



Sealed Tank

Sealed-tank transformers are provided with a gas space above the insulating liquid. This space serves to cushion the tank against changes in pressure created by expansion and contraction of the liquid. Under normal operating conditions the space remains sealed from the atmosphere, thus protecting the insulating liquid against contamination and maintaining its dielectric strength at a high value over a long period of time. When the space available in the main tank is limited, additional space is sometimes provided by piping down to the channel braces, or, occasionally, by the use of a separate expansion tank. Liquid-filled units are equipped with a pressure-vacuum bleeder which maintains the internal pressure or vacuum within the operating limits shown on the transformer nameplate.

TANKS & RADIATOR CONSTRUCTION AND FINISHING

At General Electric each Primary Substation Transformer tank is designed to permit optimum heat dissipation, to protect the insulating liquid and to minimize maintenance routines once the unit is in operation.

BASIC TRANSFORMER TANK

On units rated 10 mVA and below, the tank is fitted with welded-on radiators.

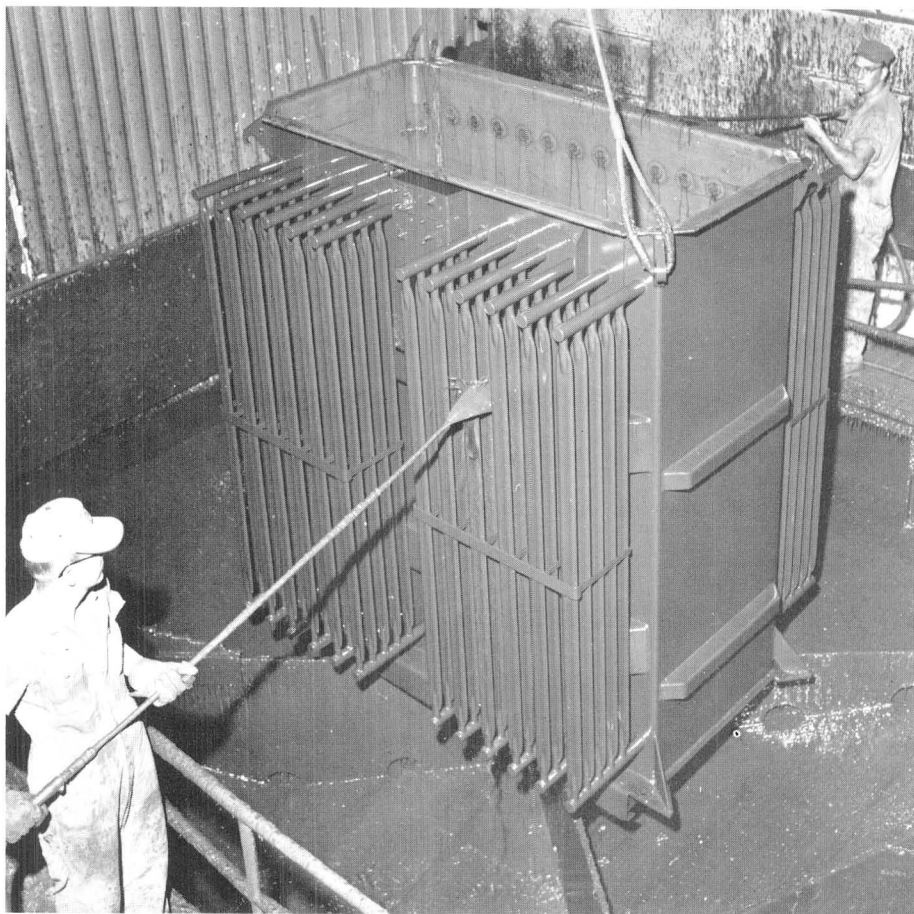
It is a standard procedure at General Electric to thoroughly leak test, under pressure, every tank assembly and radiator unit, during the production cycle. To compliment this thoroughness in the manufacturing cycle, great care is exercised in the selection and application of all gaskets and seals. A variety of materials as well as joint and seal designs are utilized to meet specific environmental and operating requirements.

A. TANK DESIGN AND CONSTRUCTION

The design engineer, working with numerous computer programs, formulates the best tank configuration for each application. Placement and size of external braces are accurately determined and help assure a rigid tank capable of withstanding the many stresses to which it will be exposed. Structural joints are welded, using the flux cored CO₂ shielded process, for deep penetration and uniform strength. After fabrication all tanks are thoroughly leak tested. Since one of the primary functions of the transformer tank is to protect the core and coil assembly from moisture entering the tank, forming and attaching the cover is an important step. Attaching the cover by welding is the standard method. To prevent weld spatter from entering the tank during the welding operation, a glass-rope gasket is cemented to the tank flange inside the weld area.

The selection and application of gaskets is an integral part of tank design procedures. Where separate connections enter the tank from outside, it is necessary to seal the opening to prevent leakage of insulating oil, as well as to prevent moisture from entering the tank.

Transformer gasketing procedures must maintain a leak-tight seal for the life of the unit under conditions of exposure to hot dielectric liquids, weathering, sun light, ozone attack, and mechanical disturbances caused by changes in operating temperatures and pressures. In many cases, dimensionally stable gaskets are



Flow coating of intermediate coats.

required to prevent failure from excessive swell. Thus, proper gasketing is a combination of selecting the right material for the intended environment and designing a joint which is adequately suited to the physical properties of the gasket material.

B. TUBE HEADERS: DESIGN & CONSTRUCTION

To achieve the design requirements for transformer cooling, multiple banks of tube headers are welded directly to the transformer tank.

Heat from the insulating oil is transferred to the atmosphere through the use of flat cooling tubes mounted in a predetermined number of tube header banks.

It is standard procedure at General Electric to thoroughly leak test, under pressure, every tube header assembly during the production cycle, and again after final assembly — once the unit has been filled with insulating oil.

FINISHING & PAINTING

All external surfaces are coated with special enamel to prevent rust and to minimize maintenance. Internal tank surfaces are also painted.

Before painting, the tank surface is cleaned by steel-grit blasting to remove all traces of scale or dirt.

A primer coat is then applied to protect against corrosion and provide a sound base for the subsequent coat. The intermediate coats of enamel are applied and baked. These are followed by a final appearance coat of modified alkyd enamel, sprayed and air-dried.

The standard paint color for Primary Substation Transformers is light grey ANSI #70 (Munsell No. 5.0BG 7.0/0.4).

Optional color available:

Dark Blue-Grey ANSI #24 (Munsell No. 10B2.40/1.18).

TAP CHANGING EQUIPMENT

ON-LOAD TAP CHANGER

LRT-200 LOAD-VAC Load tap-changing equipment is available on all three-phase Primary Substation Transformers 1000-10,000 kVA. The LRT-200 load-vac tap-changing equipment, which utilizes the *reactor limiting method* of switching, is designed to change transformer voltage

ratios under load. The standard design (Fig. 1) provides a plus or minus 10 percent voltage regulation in 32 approximately 5/8 percent steps; 16 above and 16 below rated voltage. Vacuum interrupters (Fig. 2) are used to break the load current when changing tap positions.

Their long contact life, a minimum of 500,000 operations at full load, means less maintenance is required over the life of the transformer. The clean oil switching they provide allows maintenance inspection schedules to be established at 10 year intervals.

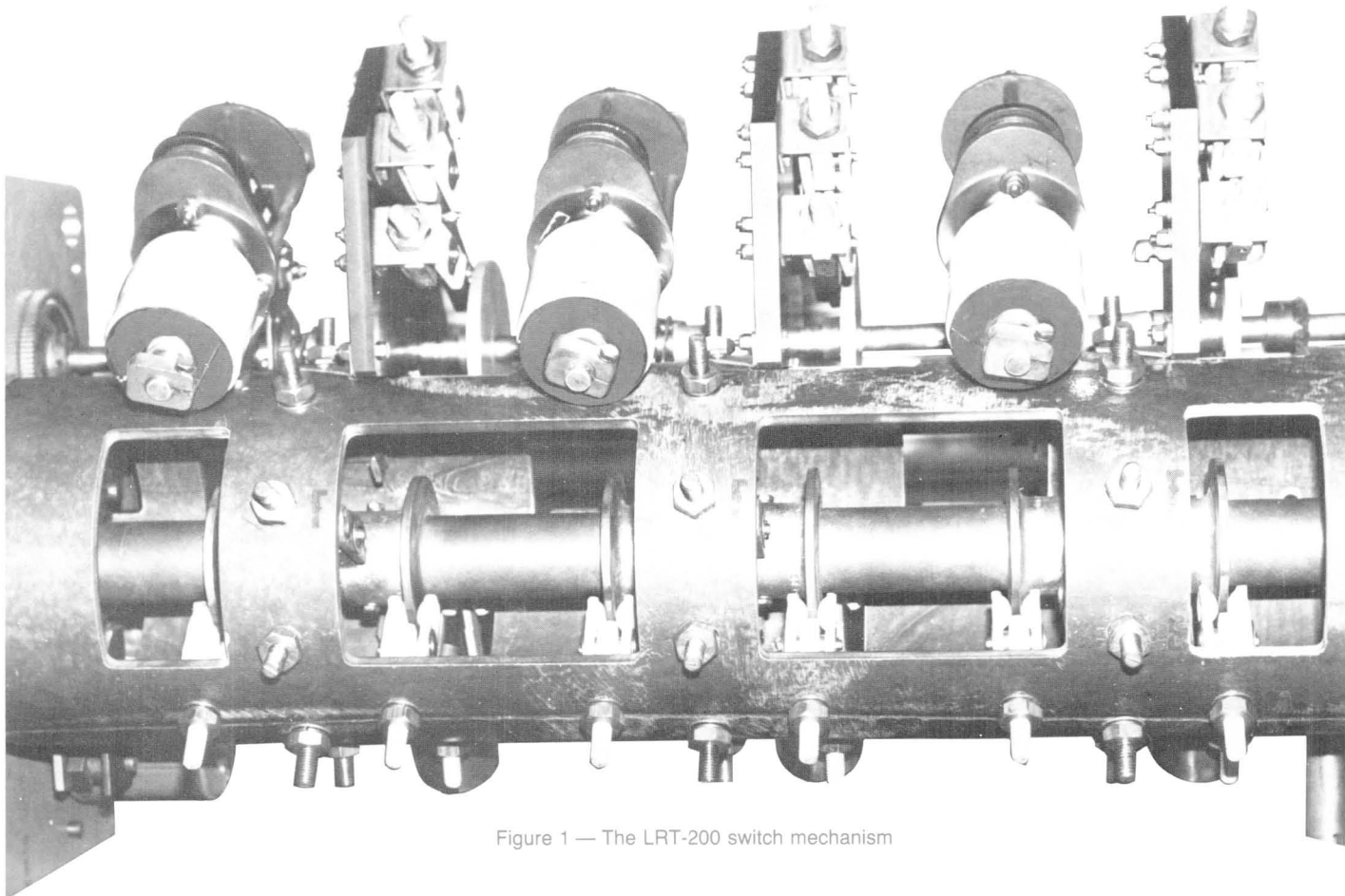


Figure 1 — The LRT-200 switch mechanism

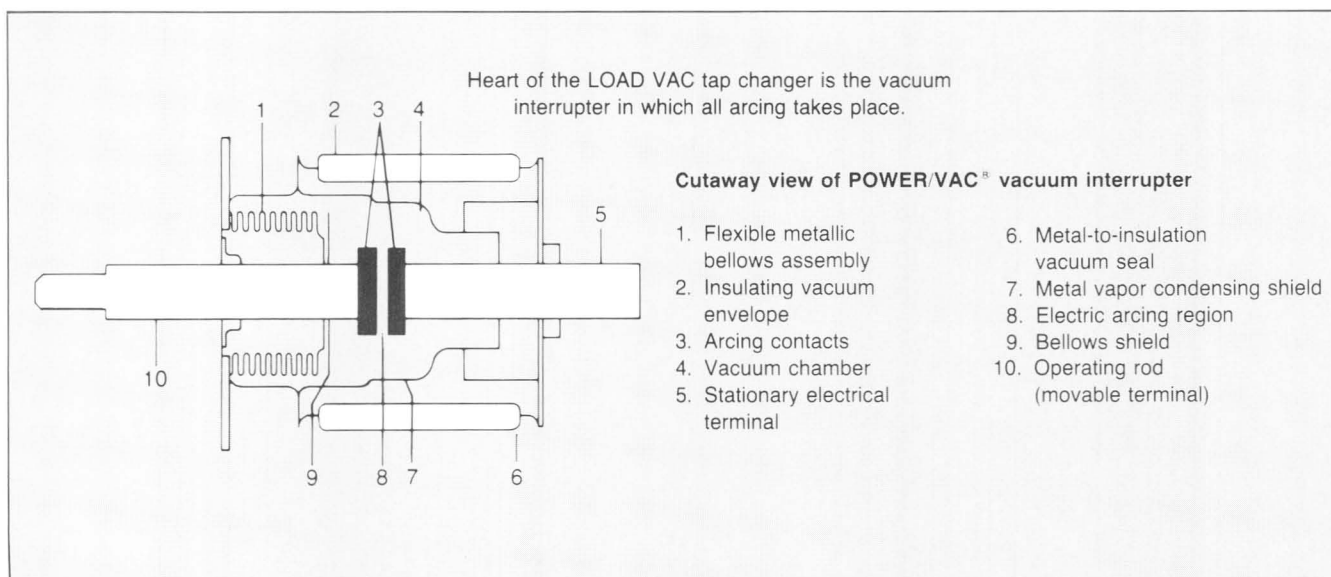


Figure 2 — Vacuum Interrupter

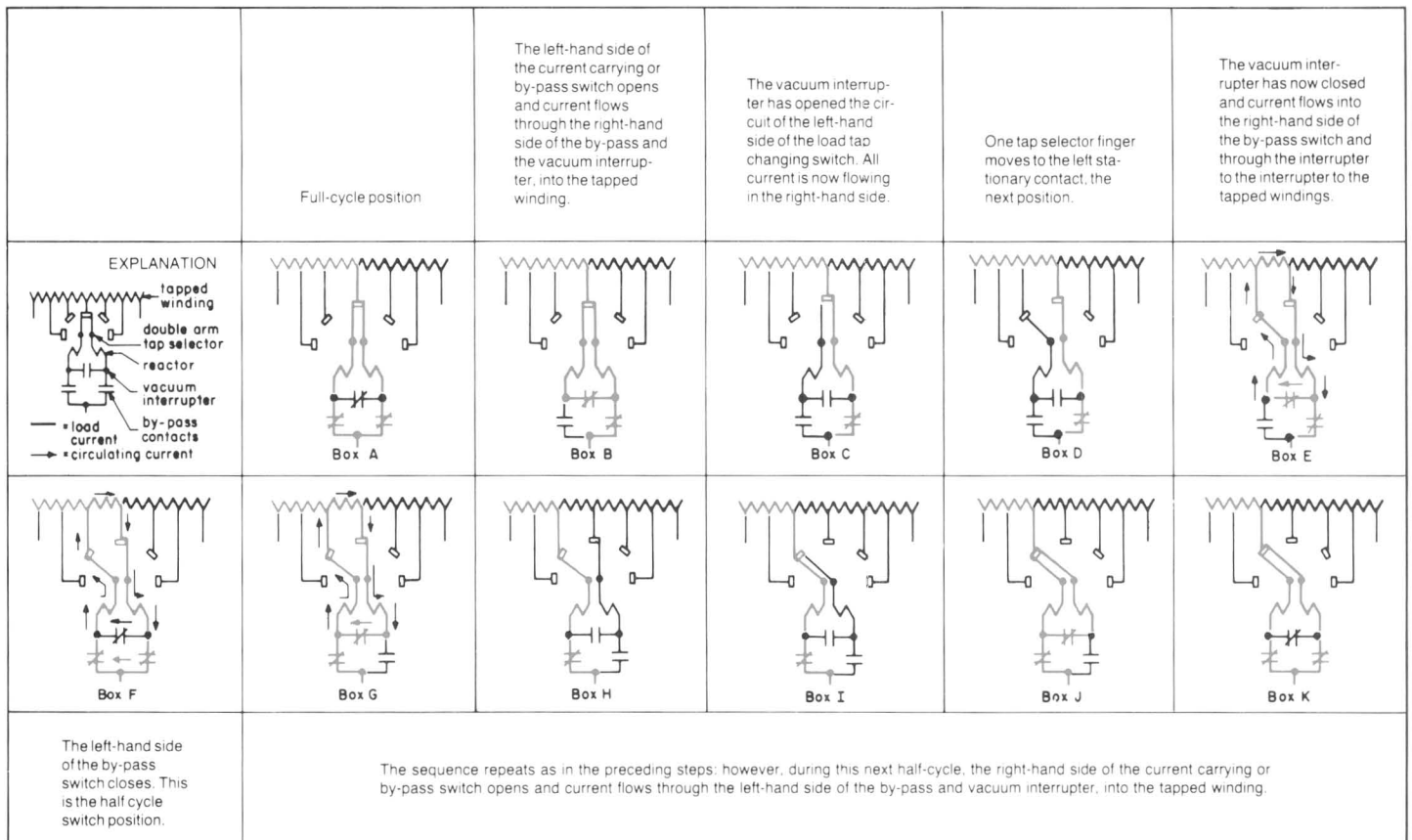


Figure 3 — Tap Changing Sequence. (Boxes A and K show the full cycle starting and finishing positions. Box F is the half-cycle position. Boxes A, F and K are operating positions. Circulating current, as shown by the arrows, flows in the tapped section of the winding back through the vacuum interrupter. At full cycle position, Box K, the tap selector fingers have moved to the left stationary contact.)

SOLID-STATE STATIC CONTROL FOR LTC IS SIMPLE, PRECISE AND TROUBLE-FREE

General Electric's solid-state static control system for LTC offers simple adjustment of significant control functions, such as voltage level and band-width, with dial-type controls on the front panel.

The control panel is mounted in an air-filled compartment readily accessible from ground level. This solid-state control is maintenance-free, eliminating problems associated with moving electrical contacts and sensitive rotating devices. The control package is immune to shock or vibration, providing reliable service in various environments without maintenance (Fig. 4).

POSITION INDICATOR AND OPERATIONS COUNTER

A position indicator is provided with drag hands to record the range of operation of the load tap changer. The drag hands have an electrical reset button located in the control compartment to allow resetting the maximum operating range indicator hands from ground level. An operations counter is provided in the control compartment to record the number of load tap changes.



Figure 4 — Solid-state Static Control.

TAP CHANGING EQUIPMENT

CONTROL CIRCUITS FOR PARALLEL OPERATION OF LTC TRANSFORMERS

Optimum load sharing between transformers operating in parallel with automatic voltage control is insured through use of circulating current control circuits (Fig. 1). In the circulating current method of paralleling, the circulating current component is separated from the load current component and is applied to the LDC in a direction opposite to that of the load current. This reversed compensation effect causes the tap-selecting equipment to operate in a direction to reduce the circulating current to a minimum. Although any number of units can be paralleled using this method, only the corresponding phases of two units are shown. The circuit for each transformer includes a current transformer (CT), potential transformer (PT), voltage sensor (VS), and auxiliary transformer (LCT), paralleling reactor (XTR), and a line-drop compensator with adjustable resistance (RLDC) and reactance (XLDC) elements. Note that for proper parallel operation the CT's and PT's must be connected in the corresponding phases of each unit and produce voltages and currents of the same polarity.

To illustrate the function of these devices, Fig. 1 depicts the case where the no load output of unit number 1 is higher than that of unit number 2. The solid arrows indicate normal load currents and the dashed arrows indicate the circulating current which will result from the difference in output voltages. By virtue of their secondary winding interconnections, the auxiliary current transformers (LCT's) permit free flow of load current through the line drop compensator elements but block the flow of circulating current. The circulating current is forced through the paralleling reactors (XTR's). Note that the effect of the circulating current through the paralleling reactor is to oppose normal compensation on the unit with the higher output, unit number 1, and to add to the normal compensation on the other unit. This will result in voltage corrections in the direction which will reduce circulating currents. The reduction of circulating current is independent from the magnitude of load current and line drop compensator settings.

By responding to current rather than tap-changer position, the circulating current method of paralleling provides extreme flexibility in the parallel operation of similar transformers. Transformers with variations in kVA rating, number of on-load taps, time required to complete a single tap change,

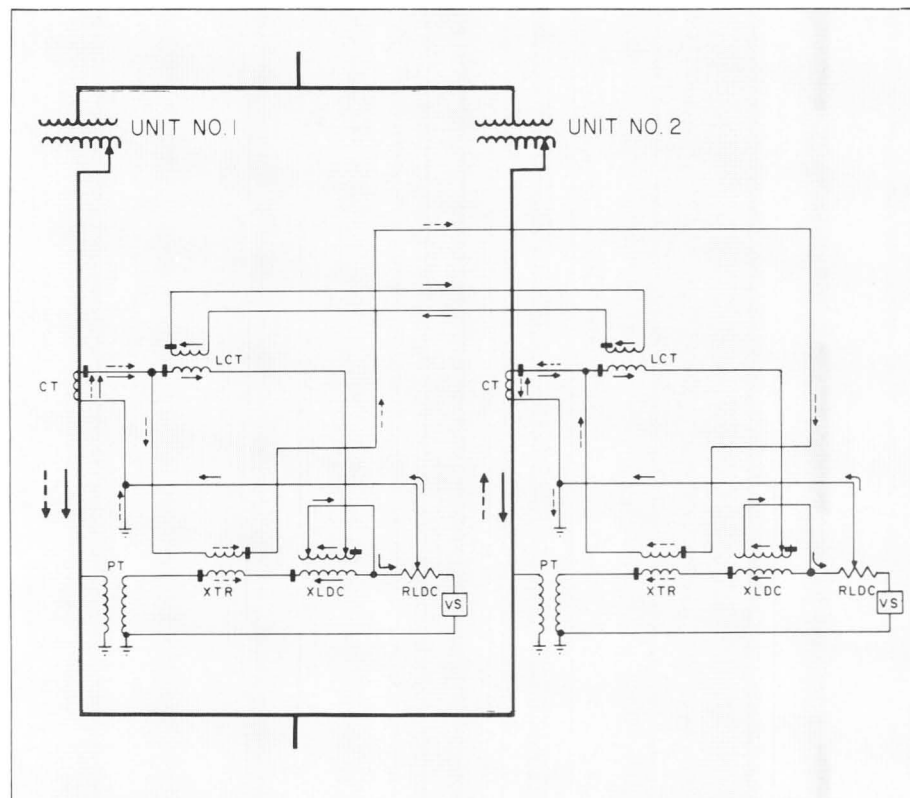


Figure 1 — Circulating current method allows parallel operation with existing transformers of either the resistance type or reactance type located in either the low voltage or high voltage windings.

and relative impedance with tap position, can be controlled to optimally share their combined loads. Provision is also made for switching units in and out of parallel without having to make control adjustments to maintain a constant bus voltage. This is accomplished by using a second set of auxiliary current transformers to force a division of load current among all parallel line drop compensators even when some units are out of service. Existing transformers with no provision for circulating current type paralleling can normally be adapted to its use by addition of two auxiliary current transformers, a paralleling reactor and the necessary interconnections between units. It is necessary that a current source which is in phase with the automatic control sensing voltage at unity power factor load be available. In some cases an additional auxiliary current transformer may be

required to make the level of this current source compatible with the current sources provided on other transformers in the parallel bank. These current sources must be equal when all transformers are carrying their rated outputs.

While the described method of paralleling is on the basis of transformers directly in parallel between two buses, this is not essential. The same devices may be used in parallel transformers in which long feeders are used to connect the transformers to the paralleling bus or network. These paralleling devices will operate satisfactorily even though the feeders are of different lengths and require different degrees of line-drop compensation. This may result in the transformers operating, under load, on different taps to provide correct voltage through the different feeders.

DE-ENERGIZED TAP CHANGERS

General Electric's wedge-type de-energized tap changers are used to change the voltage ratio when the transformer is de-energized.

The standard wedge-type tap changer has six contacts providing five operating positions, and features self-aligning contacts, high current-carrying ability, high dielectric and mechanical strength, and low contact temperatures. Contacts operate with a wiping action which assures a low-resistance contact.

Wedge-type changers for de-energized operation have an operating handle which protrudes through the tank wall at a convenient height, and provision is made for the handle to be padlocked.

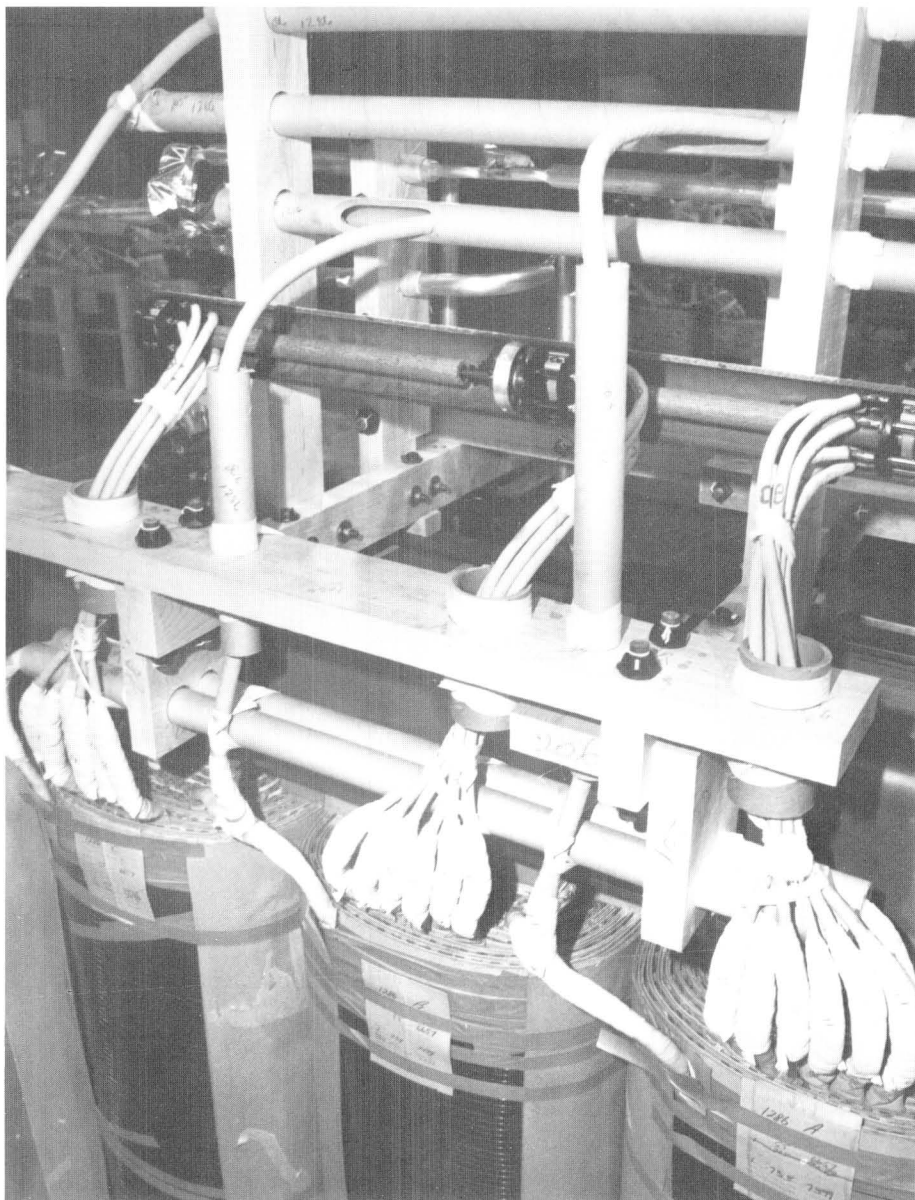


External Operating Mechanism with cover on and lock in place.

The wedge-type tap changer provides a means of changing the voltage ratio of a de-energized transformer without breaking the transformer seal. It is shipped in place, and is set on the position corresponding to the rated voltage shown on the transformer nameplate.

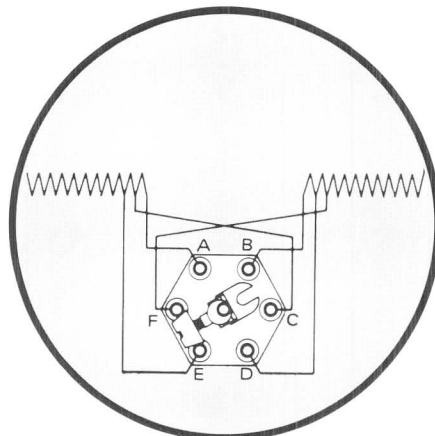
Tap leads from the transformer windings are connected to a circular group of nickel-plated copper rods which are held together between two insulating heads. A wedge in the middle can be moved by a crankshaft to wedge between any two adjacent rods. A spring between the wedge and crankshaft maintains a high-pressure line contact between current carrying components.

When the crankshaft is turned to move the wedge from one operating position to another, pressure is gradually reduced on the spring and the wedge is withdrawn from between rods. A "U"-shaped guide on the opposite side then pivots the wedge around to the next set of rods. As the crankshaft continues to turn, pressure is again applied to the spring and the wedge is forced into position with a wiping action, insuring positive contact.



Gang operated 3 Ø tap changer mounted in superstructure above core and coil assembly on ratings 69 kV high voltage and below.

Typical connection of a wedge-type tap changer.



HIGH-VOLTAGE CONNECTIONS LINES ON		
VOLTS (Percent)	DIAL POS.	TAP CHANGER CONNECTS
105	1	A to B
102.5	2	B to C
100	3	C to D
97.5	4	D to E
95	5	E to F

COOLING EQUIPMENT

INTRODUCTION

Auxiliary cooling equipment is designed to supplement the self-cooled characteristics of Primary Substation Transformers. While the transformer is operating within its self-cooled rating, natural convection carries the oil up through the windings, down through the cooling tubes and back into the tank. As the load and/or the ambient temperature

increases, additional cooling is provided by the auxiliary cooling equipment. This equipment is desirable under any of the following conditions:

1. When occasional heavy overloads or wide seasonal load variations occur.
2. Where economic considerations favor forced-air cooling over self-cooling for present or future loads.
3. In locations which have the highest

ambient temperatures over long periods of time.

4. Where future load growth is unpredictable.

Auxiliary cooling equipment consists of fans, and controls. A wide variety of control functions are available beyond the activation of fans — alarm contacts, remote indication and other options can be supplied to meet specific requirements.

The following table shows the various cooling classes and the resultant increase in load carrying ability available for each:

TYPE OF COOLING	SELF-COOLED kVA (INCLUSIVE)	*PERCENT OF SELF-COOLED kVA WITH AUXILIARY COOLING
	THREE-PHASE	
OA/FUT FA	501-2499	115
OA/FUT FA	2500-10000	125

*Continuous capacity @ 65°C average winding temperature rise, and 80°C winding hottest-spot rise.

COOLING FANS

Fans are controlled either automatically from the top oil temperature, or manually. Winding temperature control and alarm contacts are optional equipment. When OA/FA (or OA/Future FA) cooling is specified the control is set for *single stage cooling*. That is, as the load and/or the ambient temperature rises above the OA rating, the control switch activates the cooling fans.

Since cooling fans can be a source of sound generation, blades are carefully balanced to keep sound levels to a minimum and to ensure long trouble free life.

The following data summarize the important physical and electrical characteristics of GE cooling fans.

FAN SIZE — 12" or 20" dia.

POWER SUPPLY** — 230 volts,

60 hertz, single-phase

FAN SPEED — 1625 RPM,

60 hertz/1350 RPM 50 hertz

TYPE OF MOTOR — Capacitor start, capacitor run

HORSEPOWER — $\frac{1}{20}$ or $\frac{1}{3}$

NAMEPLATE CURRENT — .5 or 2.0 amperes

OVERLOAD PROTECTION —

Thermal protectors with automatic reset

FAN BLADE MATERIAL — Aluminum

LUBRICATION — Motors are

lubricated and sealed at the factory and, therefore, require very little maintenance. Under normal operating conditions (running approximately 12 hours per day in an average ambient of 30°C) the bearings should be relubricated at 10-year intervals.

WEIGHT — 15 lbs. to 2499 kVA.

45 lbs. above 2499 kVA.

**Motors for other voltages are available when specified.

Auxiliary controls and fan wiring is protected and routed by the use of galvanized steel conduit (EMT). Fans are prewired and are connected through watertight connectors. (See photo).



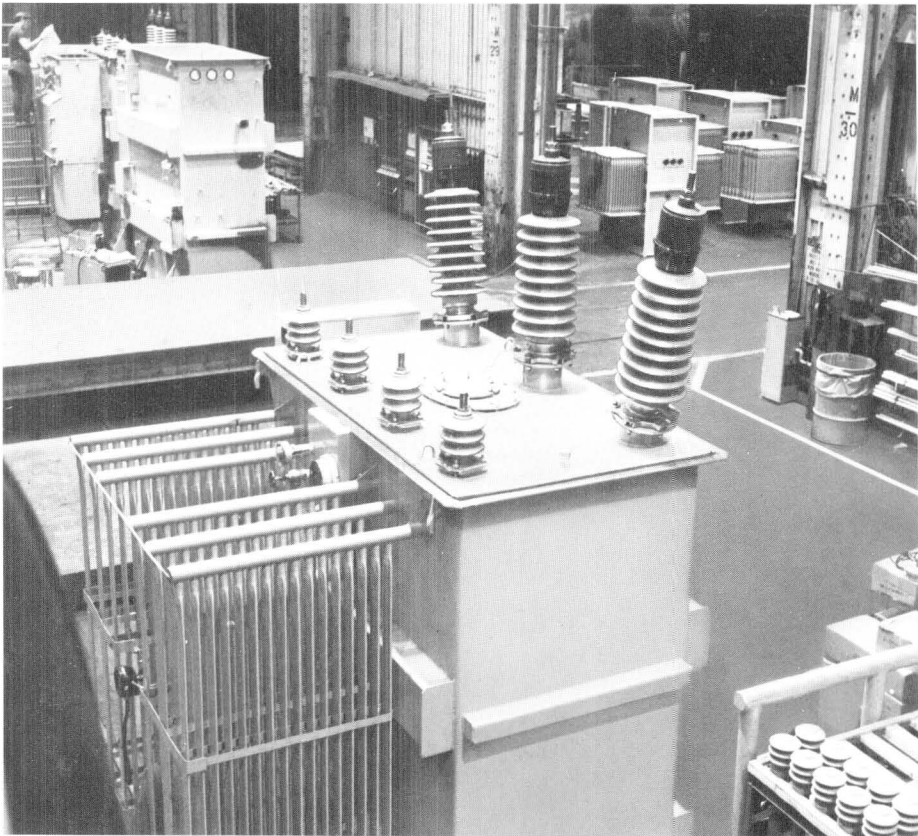
BUSHINGS

The major components of high voltage oil-insulated bushings are:

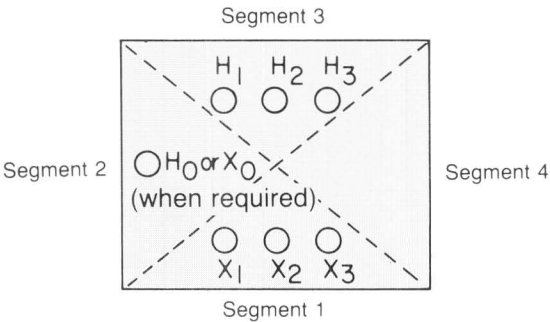
- Core, consisting of a hollow copper tube
- Internal, solid insulation consisting of oil-impregnated paper wound on the tubular core
- Oil expansion chamber or dome
- Exterior procelain
- Mounting flange and ground sleeve
- Interior procelain

The internal solid insulation consists of alternate layers of plain kraft paper and kraft paper printed with stress equalizers in the form of a herringbone pattern. This paper is wound onto the tubular core in the form of two continuous sheets. Near the outer surface of the insulation, a foil metal layer is included with a lead running to an external connection which is used for power factor testing of the bushing. This connection is, in effect, a type of "capacitance tap" that provides sufficient capacity for operating a bushing potential device only on bushings rated 115 kV and above.

TBI (Transformer Breaker Interchangeable) bushings are standard above 69 kV. Non-TBI bushings are standard 23 kV through 69 kV. Sidewall bushings are supplied, where necessary, for terminal compartments, connection to switchgear, or when specified by purchaser.

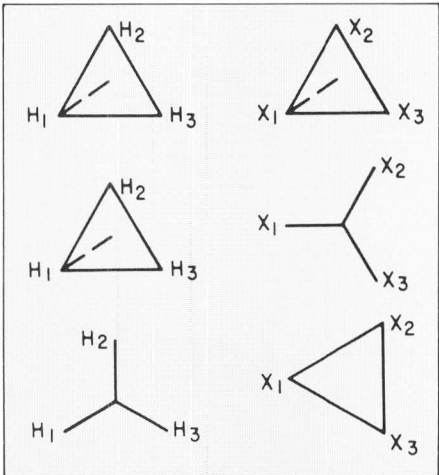


STANDARD TERMINAL ARRANGEMENT FOR COVER BUSHINGS ON THREE-PHASE TRANSFORMERS IS AS FOLLOWS:



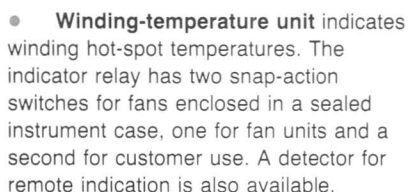
POLARITY, ANGULAR DISPLACEMENT, AND TERMINAL MARKINGS

Three-phase vector relations are as follows:



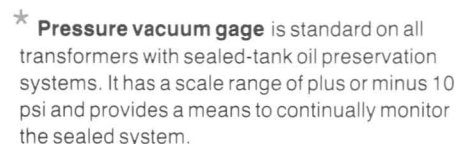
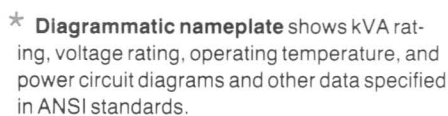
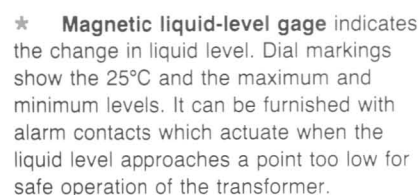
Bushings Ratings and External Creepage Distance Per ANSI C76-2			
BUSHING BIL-kV	BUSHING VOLTAGE RATING (kV)	MINIMUM CREEPAGE DISTANCE (inches)	EXTRA-CREEPAGE BUSHINGS DISTANCE (inches)
110	15	11	<div> <div>USE NEXT HIGHER RATED BUSHING</div> <div>66</div> <div>92</div> <div>114</div> </div>
150	25	17	
200	34.5	26	
250	46	35	
350	69	48	
550	115	79	
650	138	92	

OPERATING ITEMS

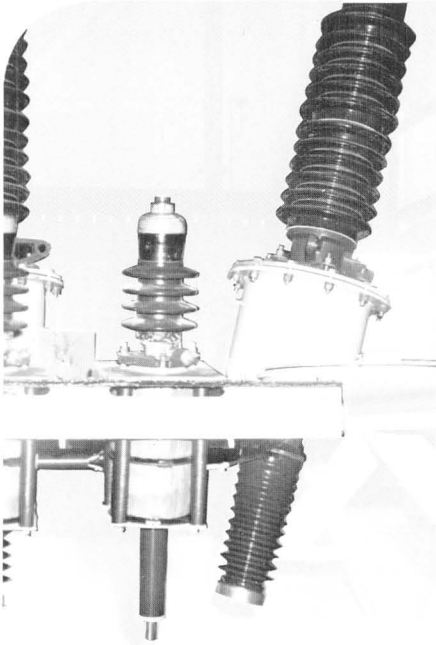


* **Dial-type liquid thermometer** indicates the top-oil temperature. It is factory calibrated and has a maximum reading pointer with an external reset. Dial readings range from 0 to 120 C. Alarm contacts are included when specified.

Dial indicators, mounted on one panel, are easily read from the ground. All gages have tempered glass faces to resist breakage. Temperature indicators are tipped 30 degrees from the vertical when mounted at heights greater than 96 inches. Years of testing and constant use have proved the reliability of General Electric instruments and gages.



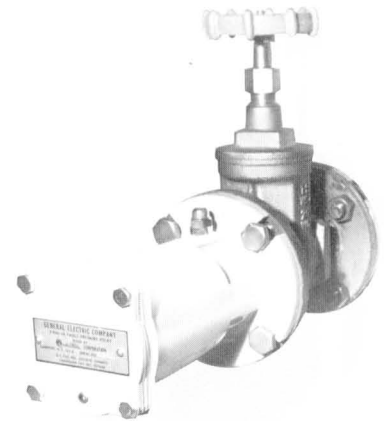
PROTECTIVE ITEMS



- **Bushing-type current transformers** can be supplied on request. Relay-type current transformers have accuracy classes in accordance with ANS C57.13 and NEMA Standard SG-4. In some cases, their accuracy may be acceptable for metering, as well as for relaying.



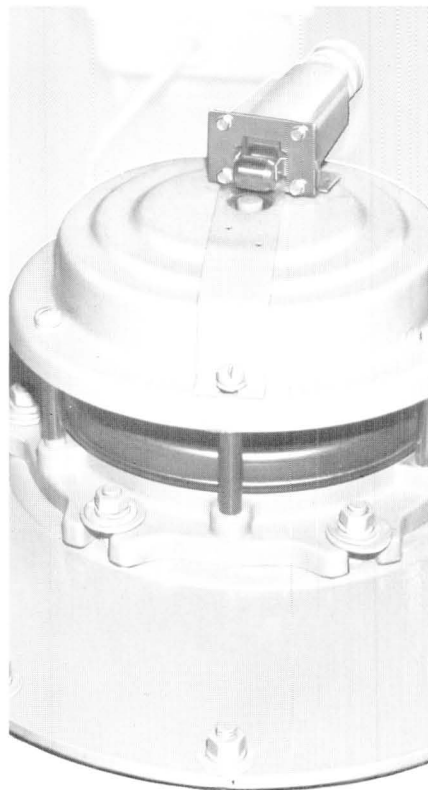
- ★ **Grounding pads** are on diagonally opposite corners of the tank base for ground connections.



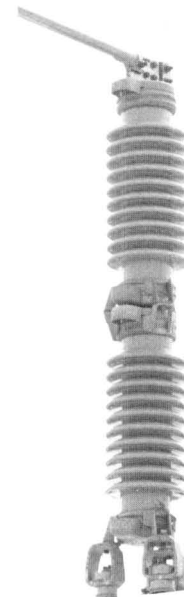
- **Model 900-1 fault pressure relay** signals a faulted condition. It responds quickly to internal faults by reacting to the primary shock wave transmitted through the insulating oil.



- ★ **Pressure vacuum bleeder** maintains the internal pressure within predetermined operating limits and is equipped with a sampling valve. It is factory calibrated to function at the operating pressure shown on the nameplate.



- ★ **Pressure relief device** is mechanically operated, self-resetting and reclosing, and has a visible operating signal. Alarm contacts (shown) for remote monitoring are optional.



- **Surge arresters** provide protection from excess voltages resulting from externally generated sources. Depending upon the application: station, intermediate, or distribution-type arresters are available.

★ STANDARD ACCESSORIES

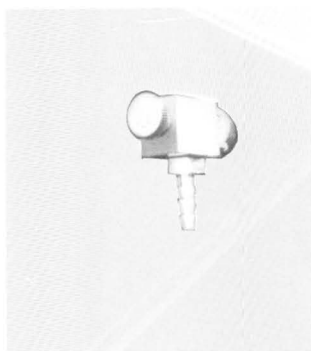
● OPTIONAL ACCESSORIES

FEATURES AND ACCESSORIES

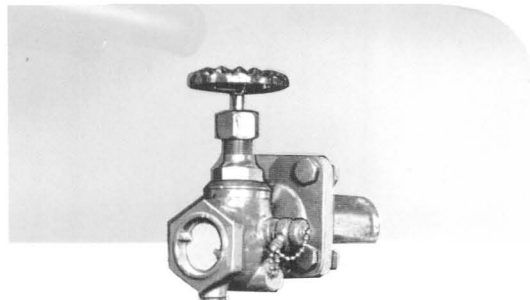
MAINTENANCE ITEMS



- ★ **Upper filter-press valve** is globe-type.



- ★ **Gas sampling valve** vents gasses from the transformer tank.



- ★ **Combination drain and lower filter-press valve** is globe-type with drop-seat construction that allows full drainage. The integral sampling device is designed for easy testing and sampling of the insulating liquid.



- ★ **Handholes or manholes** on cover provide access to the interior of the transformer.

● **OPTIONAL ACCESSORIES**

★ **STANDARD ACCESSORIES**

INSTALLATION ITEMS



★ **Lifting lugs** for cover and lifting lugs on tanks are strong. Slings and cables can be easily connected.



★ **Jacking facilities** located at all four corners of the base.

★ STANDARD ACCESSORIES

● OPTIONAL ACCESSORIES

APPLICATION DATA, WEIGHTS AND DIMENSIONS

TRANSFORMER RATINGS

Self-cooled and forced-air-cooled, ratings are continuous and are based on not exceeding 65°C winding temperature rise by resistance or an 80°C hot-spot temperature rise at altitudes of 1000 meters or less. The thermally uprated insulation system is a high temperature system designed to provide reliable service life.

The transformers are designed to operate at nameplate rating in ambient temperatures of 40°C maximum, with an average temperature for any 24 hour period not exceeding 30°C.

Standard kVA Ratings

OA FA Ratings

65C Self-cooled	65C Fan-cooled
750	862
1000	1150
1500	1725
2000	2300
2500	3125
3750	4687
5000	6250
7500	9375
10000	12500

Impedance

Impedance guarantees at rated voltage and 65°C self-cooled kVA ratings are shown in the following Table. These values are subject to 7.5 percent tolerance per ANSI C57.12.00.

HV BIL kV	LV BIL kV	Impedance-percent*
110	45 60-110	5.75 5.5
150	45 60-110	5.75 5.5
200	45 60-150	7.25 7.0
250	45 60-200	7.75 7.5
350	60-250	8.0
450	60-350	8.5
550	60-450	9.0
650	60-550	9.5

*For LTC transformers, add 0.5 to impedance values listed.

THREE PHASE 60 HERTZ TRANSFORMERS WITH LOAD TAP CHANGER

RATING (kVA)	HIGH VOLTAGE (kV)	LOW VOLTAGE (kV)	DIMENSIONS (inches)				WEIGHT (lbs.)
			Height Over Bushings	Width	Depth	Tank Height	
5000	34.5	15 or below	137	141	91	117	33202
	69	15 or below	154	153	83	124	39793
10000	34.5	15 or below	137	151	126	117	45746
	69	15 or below	161	167	104	131	56923
	115	15 or below	199	142	128	149	72091

THREE PHASE 60 HERTZ TRANSFORMERS WITHOUT LOAD TAP CHANGER

RATING (kVA)	HIGH VOLTAGE (kV)	LOW VOLTAGE (kV)	DIMENSIONS (inches)				WEIGHT (lbs.)
			Height Over Bushings	Width	Depth	Tank Height	
2500	25	15 or below	106	68	99	90	13210
	34.5	15 or below	113	69	96	93	13847
	69	15 or below	140	78	79	110	19967
5000	34.5	15 or below	127	81	122	107	21217
	69	15 or below	152	86	103	122	29141
10000	34.5	15 or below	141	153	126	121	33376
	69	15 or below	159	97	133	129	43603
	115	15 or below	200	117	112	150	55184

Standard audio sound levels

Each transformer will be so designed that when energized at rated voltage and frequency at no load and under standard test conditions and measurement procedure, the average sound level in decibels will not exceed the limits given in the following table (in accordance with NEMA Standards, TR-1).

Equivalent Self-cooled kVA (Three-phase kVA)	Sound Level-Decibels	
	Without Fans	With Fans
350 kV BIL and Below		
750,1000	58	67
1500	60	67
2000	61	67
2500	62	67
3750	64	67
5000	65	67
7500	67	69
10000	68	70
450-650 kV BIL		
750,1000	60	67
2500	62	67
2000	63	67
2500	64	67
3750	66	68
5000	67	69
7500	69	71
10000	70	72

STANDARD AND OPTIONAL ELECTRICAL TESTS

STANDARD TESTS

The following tests will be made on all transformers except as specifically stated below. The numbers shown do not necessarily indicate the sequence in which the tests will be made. All tests will be made in accordance with the latest revision of ANSI Standard Test Code for Transformers, C57.12.90.

1. Resistance measurements for all windings on the rated voltage connection of each unit and at the tap extremes of one unit only of a given rating on an order.
2. Ratio tests on the rated voltage connection and on all tap connections.
3. Polarity and phase-relation tests on the rated voltage connection.
4. No-load loss at rated voltage on the rated voltage connection.

5. Exciting current at rated voltage on the rated voltage connection.
6. Impedance and load loss at rated current on the rated voltage connection of each unit and on the tap extremes of one unit only of a given rating on an order.
7. Temperature Test
Winding temperature rise for standard transformers will be determined from basic design data which has been verified by test results of similar transformers.

- Temperature test or tests will be made only when specified. Customer must specify the exact ratings and number of units on which heat runs will be made. Tests, when made, will be made under conditions specified in ANSI Standards for Transformers.
8. Applied potential tests.
 9. Induced potential tests.

OPTIONAL TESTS

● IMPULSE TEST

With trend toward reduced insulation levels it is important that transformers be able to withstand the voltage surges that will occur in service. The ANSI Impulse test will give user this assurance. The ANSI Standard Impulse test consists of the following: one reduced full wave, two chopped waves and one full wave.

● AUDIBLE SOUND TEST

The trend to higher kVA substations (but smaller in physical size) and the closer proximity of residential areas require that audible second level of transformers be closely monitored. The NEMA Standard Sound test will do this and the details of the test can be found in NEMA STD TRI-1980.

CORONA TESTING (OPTIONAL)

CORONA — AN INCREASING NEED FOR DETECTION AND PREVENTION

The increasing emphasis on corona detection and prevention is brought about by two additional factors:

- (1) Today's transformers are being

specified with reduced insulation levels and better lightning protection. This reduction in insulation level permits the manufacturer to make units smaller, lighter and less expensive, by decreasing the amount of insulation. This means that operating and test voltage levels are getting closer together.

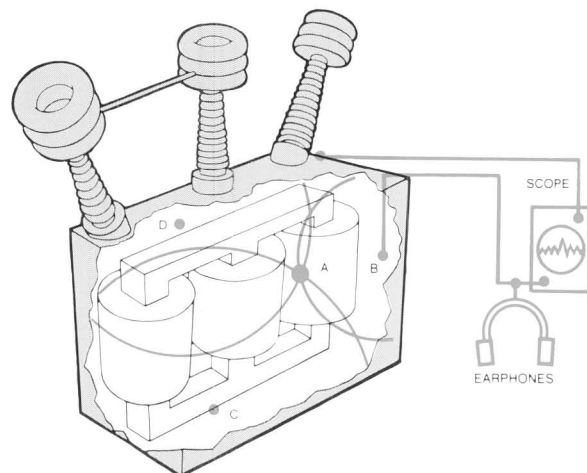
- (2) Operating voltage levels on the other hand have increased. These additional factors make it doubly important that transformer

manufacturers verify the integrity of the insulation system before the transformer is shipped from the factory. Standard industry insulation tests have proven inadequate in coping with all possible corona failures in transformers. The applied potential tests, induced voltage tests, etc., can in themselves, initiate corona if a weak spot exists in the insulation system. Therefore, passing all standard tests is no assurance that a transformer is free of damaging corona.

Corona is a warning symptom that the transformer's insulation system is being over-stressed. Without immediate and positive means of detecting and locating the damaging portion of this discharge, the transformer's insulation system can be totally destroyed. What are some of the effects of corona on insulation?

- Corona has an abrasive effect on transformer insulation. It scars and tracks and can eat into and physically erode insulations.
- Corona can cause chemical decomposition which degrades solid insulation and makes it brittle due to depolymerization of the cellulose molecules.
- Corona can decompose oil. Gas bubbles can then be carried by the oil throughout the insulation system and increase hazards elsewhere.
- Corona-generated RIV (Radio Influence Voltage) can interfere with carrier current communications.

Whatever its form, corona is capable thermally, chemically and mechanically of doing permanent damage to liquid and solid insulation materials.



Corona source is located by ranging from locations B, C, D. Oscilloscope measures time lapse between instantaneous electrical signal (via the bushing capacitance tap) and the slower sound signal heard by the transducer. Lapsed time indicates distance from transducer to corona source. Arcs drawn with these radii from each point intersect at corona location A.

TRANSFORMER PROTECTION

Transformer protection has three objectives:

1. To protect the transformer from conditions that can lead to damage or failure.
2. To protect a failed transformer from further damage that will increase the cost and time of repair.
3. To protect the remainder of a system from shutdown caused by a transformer failure.

In order to meet these objectives, GE offers a number of standard and optional transformer protection systems that are available to the purchaser, based on the relative importance of the transformer installation and the cost of providing such protection.

FAULT PRESSURE RELAY

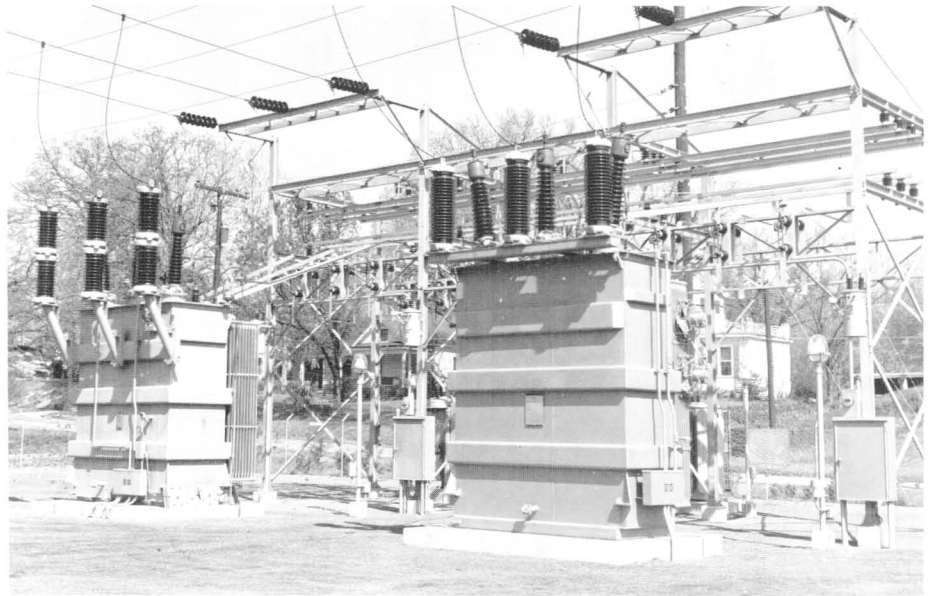
Once a fault begins to progress in a transformer, a pressure wave is set up in the liquid. A fault pressure relay will sense this disturbance and quickly signal the removal of the transformer from the system, thus sparing the unit the extensive damage that might be incurred if additional fault energy is allowed to flow. This simple and inexpensive device is usually mounted on the tank wall below the liquid level in a location that provides optimum sensitivity and reliability by placing the relay sensor near the winding which it is intended to protect. For adequate transformer protection a circuit breaker is used to disconnect the transformer from the power system.

LIQUID-LEVEL GAGE AND LIQUID THERMOMETER

The oil is a vital component of the insulation system of the transformer, and it is essential that it be maintained in adequate supply and at satisfactory temperature. A warning signal by either the liquid-level gage or the liquid thermometer is an indication that a potentially harmful condition exists in the transformer and steps should be taken to correct the situation. Alarm contacts are provided in these devices when specified by the purchaser to actuate the warning signal.

WINDING TEMPERATURE EQUIPMENT

While voltage and current are the system



characteristics most important to the operator, the condition of the transformer is closely related to the temperature of the windings. The life of the winding insulation is a function of its temperature, and continued useful service from the unit requires that insulation temperature be kept within clearly defined limits. Winding temperature accessory equipment is available to allow the operator to monitor this condition so that corrective action may be taken when needed. Equipment is available in three forms:

1. Local gages mounted on the transformer for visual indication.
2. Local relays that may be used to turn on transformer cooling fans or to sound an alarm, either locally or at a remote location.
3. Temperature-sensitive resistors which can be used in a bridge circuit to actuate a remotely-located gage for visual indication.

While winding temperature is a function of current carried by the winding, it is also affected by voltage since core loss affects the oil temperature, ambient temperature, and external environmental conditions such as the presence of wind or the operation of cooling fans. Winding temperature equipment integrates all of these factors through a simulation network to provide an accurate indication of the temperature of the hottest-spot in the transformer windings of two-winding transformers. For three-winding transformers where division of the load may vary between two output windings, a separate device is required in each winding for accurate indication.

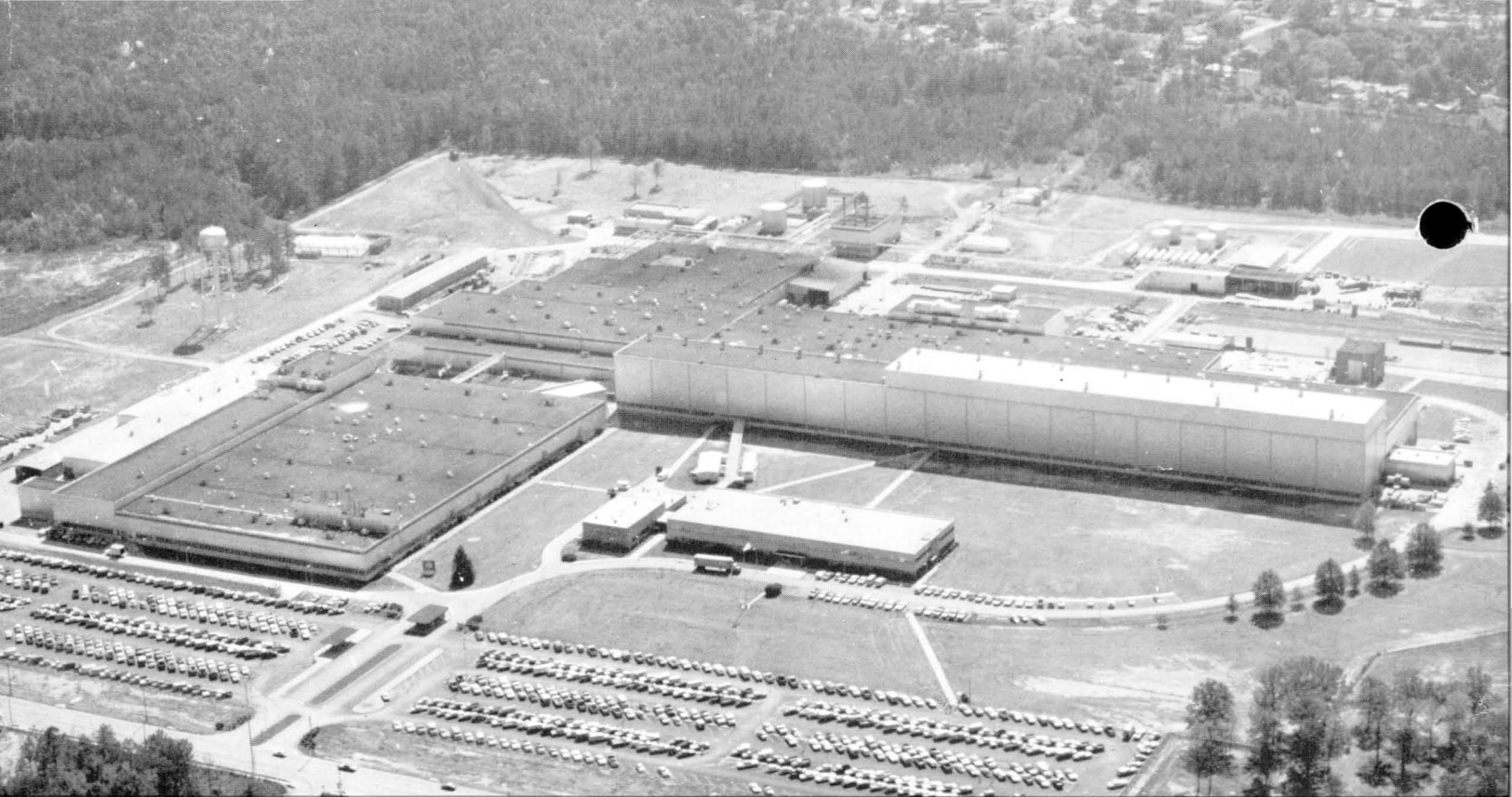
SURGE ARRESTERS

Voltage surges may appear on electrical transmission and distribution systems as a

result of lightning strokes on or near a line or because of switching of the current carried by the system. Damage to a transformer winding may occur if such a voltage is allowed to reach the transformer, and surge arresters are available for application to the system to prevent such an occurrence. The surge arrester provides a temporary low impedance path to ground allowing the electrical charge associated with the voltage surge to reach earth harmlessly and then re-establishes the insulation between the circuit and ground so that system voltage can not produce a flow of "follow current" after the transient disturbance has passed. Surge arresters are selected for application to the electrical system based on system characteristics, and then transformer BIL (basic impulse insulation level) is specified to allow sufficient margin of protection between surge arrester operating characteristics and transformer insulation strength.

DIFFERENTIAL PROTECTION

In this most sensitive and reliable of all systems, internal current transformers monitor the current in the high-voltage and low-voltage circuits and instantly detect any unbalance caused by a beginning failure. A relay immediately signals a primary circuit breaker to remove the transformer from the system even before the conventional overcurrent relays can operate. Potential internal damage to the transformer is held to an absolute minimum, and the system is generally spared any harmful disturbance. General Electric's Primary Substation Transformers can be provided with bushing mounted current transformers to detect the magnitude and flow of current through the transformer.



Keeping pace with your needs for improved, reliable primary substation transformers

Early in 1954, General Electric opened the Medium Transformer Department in Rome, Georgia to produce primary substation transformers in the 501 - 7500 kVA range, and a full line of secondary substation transformers for industrial applications. This plant, on a 265 acre site, was built with future expansion in mind.

Over the years expansion of facilities and modernization of equipment have kept pace with the increased demands for dependable electric power across the nation.

Our most recent expansion and modernization program added new Research and Development capabilities, and increased our capacity for designing, building and

testing of primary substation transformers with self-cooled ratings through 30,000 kVA. Increasing the plant facilities, although significant, is only one step in accomplishing our primary goal of furnishing the best and most reliable transformer to meet your particular requirements.

Research and Development, computer technology, design engineering, quality control, manufacturing innovations, testing techniques and improved safe-shipment practices all play an important part in reaching this goal. And each is significant in establishing General Electric's Medium Transformer Department as a leader in transformer reliability.

Every effort has been made by the General Electric Company to insure the accuracy and completeness of the information contained in this brochure. However, the Company makes no warranty or representation and assumes no liability for the accuracy of the information or for any use of such information. Further, the material provided does not cover all possible applications; any specific application not covered should be referred directly to the Company. All data in the brochure are subject to change without notice.

**GE COMPANY
TRANSFORMER BUSINESS DEPARTMENT
HICKORY, N.C. 28601**

