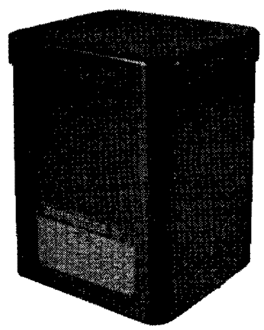
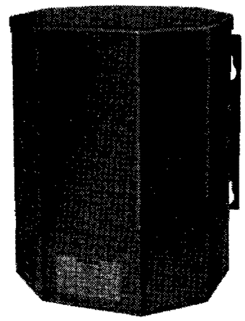
Westinghouse

Specialty Transformers
5000 Volts and Below



Type EP "Green Line" 2 Kva and Below



Type EP "Green Line" 3 Kva and Above

Type EPT 'Green Line" 3 Through 30 Kva

The transformer was one of the first developments of Westinghouse and has continued as a major product over the years. Extensive and continuous research in transformer design practice has been maintained as a cooperative effort, working with industry, utilities, and standardization bodies to better serve the needs of customers. Each innovation has been based on sound engineering experience and on extensive accelerated life testing prior to manufacture. This is your assurance that development is proven and progress is practical.

Dry type transformers with open and exposed core and coils have proved not to be completely satisfactory for general purpose use as they constitute a safety hazard and are vulnerable to damage. The next logical step is to enclose the core and coil in a metal case which can be ventilated or non-ventilated, there being advantages to either construction. However, cases can not be sealed and moisture and corrosive vapors can get to the insulation system. The metal case walls also serve as a good amplifier for the noise created by the magnetic circuit.

Core and coil assemblies can also be submerged in oil to provide improved insulation and cooling, and to make higher ratings possible; however, oil is a fire hazard, especially for indoor applications. Non-inflammable liquids can be substituted for oil but they are expensive, require use of special coil materials and, under failure conditions, become very unstable.

In response to the demand for a simple but safe dry type transformer, the Specialty Transformer Division developed the type EP and EPT dry type transformer; the most reliable and safest transformers ever built. Construction consists of a core and coil assembly embedded in a correctly proportioned mixture of epoxy resin and sand (Westinghouse patent 3030596), contained in a metal case. This design gives small volume and excellent reliability in the presence of adverse environmental conditions. The embedding technique results in a lower noise level than transformers with open core and coil construction. The resin was chosen because of superior electrical, mechanical, adhesive, and handling properties. Good adhesion is particularly important around leads and terminals to prevent the entrance of moisture and other contaminates. Another advantage of epoxies is that shrinkage is small compared to other resins, therefore, there is less tendency to exert pressure on parts and change electrical characteristics. Because of low shrinkage and high strength, the resin-sand mixture will withstand extreme thermal shocks.

This new insulation system has enabled Westinghouse to build smaller and quieter transformers with desirable electrical characteristics.

Application

The basic purpose of a drytype transformer is voltage transformation, in the load area, for economy and distribution of power. Loads are lighting, heating, ranges, air conditioners, exhaust fans, control circuits, appliances, and portable tools. Such loads are found in commercial, institutional, and residential structures. "High Rise" apartments are a rapidly expanding application for Westinghouse EP and EPT transformers. Other applications are found in mining and shipboard distribution systems, as well as in heavy machinery such as drag lines and power shovels for lighting and control circuits.

Since flammable liquids, vapors or toxic fumes are not found in the materials used, EP and EPT transformers are ideal for indoor installation where there is a concentration of people. These transformers are kept up to date in accordance with the latest revisions of ASA, NEMA, and IEEE standards. Ratings through 10 kva are Underwriters Laboratories approved, this being the scope of coverage by U.L. at present. Reference to the use of dry type transformers larger than this, may be found in the National Electrical Code, paragraph 450-,21.

Temperature

Types EP and EPT are made in two temperature classes as shown in the table below.

Temperature Rating	Class	Group	Hot Spot Allowance	Hot Spot Limiting Rise	Limiting Temp.
80°C Rise	B	II	30	110	150
115°C Rise	F	III	30	145	185

These are ASA standards, all based on 40°C ambient.

Past practice in the industry has been to speak of insulation as Class A, B, F, H, etc. or Groups I, II, respectively; but with regard to insulation systems, this is replaced by stating the temperature rise of the subject insulation. This leaves no doubt of the subject and eliminates need to remember classes and groups. The terms A, B, etc. are still used to describe individual pieces of insulation material.

August, 1970
Supersedes TD 46-860, pages 1-12, dated December, 1965
E, D, C/2071

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Application (Continued)

Ratings 15 kva and above, both single and three phase are now supplied with 115°C rise insulation systems, smaller ratings with 80°C insulation systems. The entire line was formerly 80°C rise and the larger ratings are still available with 80°C rise by negotiation.

Frequency

Standard types EP and EPT transformers are designed for 60 cycle operation only. Where transformers are required for other frequencies, they must be specially designed. 50 cycle designs require more active material (copper and iron) than 60 cycle designs. This can best be understood by referring to the basic transformer design equation:

$$N=\frac{34.9 \times 10^5 \times E}{f \times A\ net \times B}$$

transposing

$$f=\frac{34.9 \times 10^5 \times E}{N \times A\ net \times B}$$

where N = turns
E = volts on N turns
A = net magnetic cross section in^2
B = magnetic induction (gauss)
f = frequency

For a given induction and voltage it can be seen that a lower frequency requires more N or more A, or a compromise on both, which means more pounds of copper and iron.

Operating a 60 cycle transformer at 50 cycles results in the iron loss increasing 25 percent to 50 percent and the exciting current will increase 2 to 3 times. Also, the noise level will increase 6 to 10 DB. The temperature rise will increase. In general, it is unwise to operate 60 cycle transformers at 50 cycles, except under temporary emergency conditions, and then it is understood that the user accepts responsibility for results.

Occasionally there is a requirement for 25 cycle transformers. These require twice the kva of parts of a 60 cycle design for a given kva load. Standard 60 cycle transformers can be operated at 25 cycles, at half voltage and half nameplate kva.

Transformers for 400 cycle operation must be specially designed.

Voltage Variations

The nameplate voltages are the nominal or design center values. Transformers can be operated at 5 percent overvoltage for extended periods of time but iron loss and exciting current will increase. When transformers are operated at undervoltage, the iron loss and exciting current will decrease but the nominal current rating of the winding does not change. Operation at undervoltage amounts to derating.

Phase Changing Transformers

The common and practical winding arrangements for phase transformation are found in the section on three phase connections. Two phase systems are infrequent but where they still exist, two phase to three phase connections can be used to supply standard three phase equipment. Three phase to two phase connections transform power equally well in either direction and unbalanced loads have no worse affect than if the connection were three phase to three phase. Two phase systems are nothing more than two single phase systems displaced from each other by 90 electrical degrees, The two single phases can be connected together in different ways. Attention must be given to the location of grounds so as to prevent shorted windings.

It is practically impossible to transform from three phase to single phase by means of static transformation with balanced three phase conditions. The only practical method to transform from three phase to single phase is to simply use a transformer across one phase.

Single phase to three phase transformation is possible by creating a lagging voltage with inductive components and creating a leading voltage with capacitive components. Single phase power changes from a maximum to zero and back to maximum every half cycle, while three phase power is delivered at a constant rate. Therefore, any system capable of transforming from balanced three phase current to single phase current must be capable of storing energy during the interval of time when the power delivered to the single phase side is less than the power received from the three phase side. This cannot be done with a transformer.

D-c Generator Balance Coils

Type EP transformer parts can also be used as balance coils on d-c generators. The purpose is to provide an electrical neutral or mid tap for direct voltage generated from what is basically a two terminal source. The coil does not make unbalanced loads appear balanced to the generator but does create a stable voltage mid-point. A balance coil capable of handling a 25 percent unbalance has a VA rating equal to 9 percent of the generator rating. Balance coils have ungapped cores and are characterized by high a-c reactance and low winding resistance. For correct application, the following parameters must be stated on a design request:

1 Generator KW and Voltage.
2 Speed in rpm.
3 Number of Poles.
4 Unbalance (in percent of generator KW).
5 Number of Slip Rings.

Range Application

Standard electric ranges are designed to be supplied from a 240/120 single phase grounded neutral power supply. Often, only 208Y/120 is the source of power. A 208 volts to 240 volt auto transformer, with mid tap at 240 volts, will not work as the source and load neutrals will have a voltage difference between them resulting in a short circuit. Therefore, an isolation transformer with a 208 to 120/240 ratio is commonly used. Buck-boost transformers, properly connected, can be used in auto-connection for supplying ranges if local codes permit. This is discussed in price list 46-820.

Isolation Transformers

Some important electrical installations, such as hospital operating and x-ray rooms, require complete isolation of electrical apparatus from all other circuits, This is required for safety reasons presented in the National Electrical Code in the chapter on Special Occupancies and Special Equipment. Under such conditions, positive measures must be taken to prevent a primary circuit from contacting a secondary circuit under all fault conditions. This accomplished by separating the primary and secondary windings with a one turn metal barrier, positioned when the coil is wound. The barrier, commonly called a shield, is adequately insulated from adjacent windings. These shields are normally connected to the core and case grounding lug. They have an insulated break to avoid a short circuited turn. When windings are separated by a grounding surface, they can only fail to ground, not to another winding. Hence, accidental juncture of windings cannot be caused by molten metal resulting from failure heating.

Shields, between primary and secondary, also perform another function which may be desirable under some conditions. Capacitance cannot exist between windings when separated by a ground surface. The windings under such an arrangement will have a greatly increased capacitance to ground. This provides a low impedance path to ground for high frequency voltages and prevent high frequency disturbances from being passed through the transformer by capacitor coupling. Shields for such a purpose are called "electrostatic shields". Shielded transformers are specially designed items. When ground detection equipment is needed, it is supplied by the electrical contractor.

Specialty Transformers
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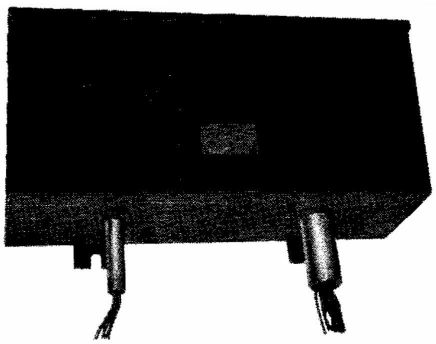
Explosion Proof Transformers



Explosion proof equipment is defined (by Underwriters Laboratories) as apparatus enclosed in a case which is capable of withstanding an explosion which may occur within it of a specified gas or vapor, and of preventing the ignition of the same surrounding gases by sparks, flashes, or explosion of the gas within. The U.L. definition of expolsion proof equipment is thereby tied to the ability of a metal case to contain an explosion with no consideration for the construction of the case contents.

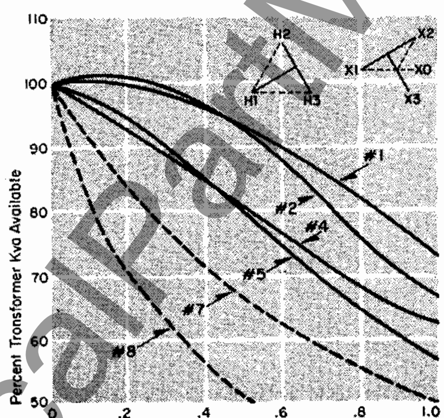
By completely filling a transformer case with resin-sand and bringing the leads out through embedded threaded conduit, no room is left for pockets of gas or vapor except for a very few cubic inches in the conduit. The customer can make connections to the transformer in explosion proof connection boxes which he attaches. It can be seen that this construction obviates the need for a thick wall metal case. To date there is no record of an EP or EPT failure causing the resin-sand to explode. This construction is finding much use in hazardous areas. However, the U.L. definition of explosion proof equipment is not met and the user makes the decision on his needs.

Transformers for Mixed Single and Three Phase Load

Example 1:
Assume that it is desired to supply a 5 kva three phase balanced load and a 1½ kva 1 phase load on X2-X3 of a T connected transformer. The ratio of the single phase load to the total load is $\frac{1.5}{5}$ or .3 Curve 1 shows that about 99 percent of the nameplate kva is available under these conditions. A 6½ kva transformer would handle the load. However, the next closest rating is 9 kva which would be supplied.

Example 2:
A 10 kva three phase motor load is to be supplied from a T connected transformer. Can a 15 kva transformer also handle 4 kva of lighting load between X2 and X0? The ratio of single phase load to total load is $\frac{4}{14}$ or .29. Curve 5 shows that the kva available exceeds .9 of 15 or 13. Hence, a 14 kva total load cannot be handled. However, curve 2 shows that a 15 kva rating will handle the load if it is placed on X3-X0.

Curve No.	Design	Single Phase Load
1	T-Connected	X2 to X3
2	T-Connected	X3 to X0
4	T-Connected	X1 to X2
5	T-Connected	X2 to X0
7	Delta Bank of 3–1 Phase Units	Line to Line
8	Wye Bank of 3–1 Phase Units	Line to Neutral



Available Kva for Mixed Single and Three Phase Loads

Sound Levels

Why Are Transformer Sound Levels Important?

With increased power demands, transformers must be located nearer to their loads for a more efficient power distribution. Transformer noise is receiving more attention as electrical loads increase in buildings where large groups of people are present such as hospitals, offices, schools, and apartment houses. The noise problem has been complicated by the growing use of hard light-weight construction materials which reverberate sounds rather than absorb them. For this reason, architects and engineers are now specifying lower audible sound levels for dry type transformers.

Nema industry standards specify 40 db noise level for transformers through 9 kva and 45 db for units rated 10 kva through 50 kva. For Westinghouse average values see section "Typical Performance Data".

What is Transformer Noise?

The main source of sound in a transformer is magneto-striction. This is the property of electrical sheet steel which causes it to elongate and contract in the presence of a magnetic field. These periodic mechanical movements produce sound vibrations in the core, having a fundamental frequency equal to twice the flux frequency. Due to a non-linear relationship between magneto-striction and flux density, a number of harmonically related higher frequencies are also produced. This results in a noise spectrum, composed on fundamental frequencies of 120 cycles per second and harmonics of 240, 360, 480, 600, etc.

The pulsations of the core also travel through other parts of the transformer, which have a tendency to vibrate at one or other of these same frequencies. These add to the overall sound level in the form of inter-laminar core and coil vibrations. The amount of this addition is dependent upon the surface area and resonant frequency of each component part.

How to Control Transformer Sound and Minimize its Transmission

The main source of transformet noise is magneto-striction and the effects of it are controlled by the designer to produce transformers having satisfactory sound levels.

Also contributing to sources of sound are the interlaminar core and gap vibrations and coil vibrations. These sources are due to the inherent structure and method of constructing the transformer core and coil assembly. Gap vibrations are kept to a minimum by controlling the pressure when banding the two core halves together. Interlaminar and coil vibrations are controlled by encapsulating the entire core and coil in epoxy resin. This assures a compact assembly with minimum sound amplification.

Dry type transformers of open construction need metal frames to secure the core and coil to the case. These frames not only provide paths along which sound produced by the core excitation can travel, but because of mechanical vibrations, they become a noise source. Since the core and coil of the encapsulated transformer is rigidly encased in a mechanically strong, sound deadening material, metal frames and other subassemblies are not needed.

Large surface areas of an enclosure produce noise and add to the overall sound level. Westinghouse designs keep this surface area to a minimum. This, together with rigid case material, results in minimum sound generation from the transformer enclosure.

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How to Minimize Transformer Hum in Installation

Transformer hum control in quiet production and office areas is a growing problem in today's modern plant. Reasons: (1) higher lighting levels call for more transformer power, and (2) managers are becoming more conscious of the disturbing effects of persistent, discordant sound.

Here are eight rules that will minimize trouble on transformer installations.

1 Fix transformer locations during design stages of a new plant building, whenever possible. If transformer is mounted in available spaces after the building is finished, expensive modification may be needed to correct noise problems.

2 Install transformers where noise will be least objectionable – in storerooms or low-occupancy areas, or near other noise-producing equipment. This point seems all too obvious, but it's often overlooked.

3 Avoid mounting transformers in areas where voices echo. Stay away from reflecting enclosures or objects that cause resonance. Places like stairwells and hallways can be trouble makers.

4 Mount transformers in a "free field away from tile, brick, concrete, or steel ceilings, walls, or floors. This way sound amplification by reflection is avoided. Second-best mounting is a flat surface. A corner mounting is least desirable. Reason: all sound is then concentrated in a single quadrant.

5 Use non-rigid conduit or flexible conductors to connect transformers. Core vibrations not isolated by internal damping can be transmitted to the building structure just as easily through rigid conduit as through the transformer mounting itself.

6 Don't mount transformers in areas of light mass. Walls, partitions, balconies, and upper floors should be taboo. If the weight of the mounting surface corresponding to the projected area of the transformer is equal to or greater than the transformer weight the chance of noise amplification through surface vibration is reduced considerably.

7 Don't mount transformers on surfaces that could cause distortion of the transformer assembly. Wherever a surface is obviously uneven, use shims or compressible material (such as neoprene) at the point of mounting.

8 Wait until the new building is finished and functioning at regular capacity before taking steps to correct hum. Very often normal industrial noises will mask transformer hum, and make corrective measures unnecessary. Also inhabited buildings furnish further damping through draperies, furniture and personal clothing.

Designation of Voltage Ratings of Windings

General: A long dash (—) shall be used to separate the voltage ratings of separate windings. A slant (/) or X shall be used to separate voltages obtained by delta or wye connections, by the use of taps, or by series-parallel connection in the same winding as explained in the following paragraphs.

Delta-wye: A single or three phase winding designed for either delta or wye operation shall be designated by the delta-voltage rating, followed by a slant and the wye voltage rating. Example: 120/208Y signifies that the windings may be connected for 120 volts delta or 208 volts Y.

Three Phase Y: A three phase winding designed only for wye connection, with the neutral of the winding brought out, shall be designated by the wye voltage rating followed by a slant and the voltage from line to neutral. Example: 208Y/120 signifies a winding suitable for 208 wye connection with 120 volts available from line to neutral.

Series-Parallel or Three Wire: A single or three phase winding designed for series-parallel or three wire connection shall be designated by the parallel voltage rating followed by a slant and the series voltage.

Example: 120/240 signifies a winding suitable for 120 volt parallel connection, or 240 volt series connection, or 240/120 volt three wire connection. Note that 120/240 will appear on the instruction plate. Three wire connections are discussed in terms of 240/120 which means that 240 volt loads and 120 volt loads can exist simultaneously and the 120 volt load does not have to be equal. The only criteria for successful loading is that the current rating of either 120 winding not be exceeded which is determined by dividing rated kva by 240.

Series-Parallel Only: A single or three phase winding designed for both series and parallel connection shall be designated by the parallel voltage rating followed by an x and the series voltage rating.

Example: 240 x 480 signifies a winding suitable for 240 volt parallel connection or 480 volt series connection, but not for 480/240 volt three wire connection.

Three Wire Single Phase: A winding having a mid tap and designed for one half rated kva at one half the voltage on either side of the mid tap shall be designated by the full winding voltage followed by a slant and the voltage from line to midpoint.

The ability to operate with three wire connections means that the coil sections are properly interleaved to operate with unbalanced loads on either side of the mid tap without excessive voltage regulation.

Example: 240/120 signifies a 240 volt full winding with mid tap for one half rated kva at 120 volts, 240/120/480 signifies a winding suitable for connection for either 240 or 480 volts, the 240 volt connection having a mid tap for one half rated kva at 120 volts.

Output and Voltage Ratings and Primary Taps for Single-Phase General-Purpose Transformers

Voltage Rating of Transformer, Volts	Output Rating, Kva														
	0.250	0.500	0.750	1	1.5	2	3	5	7.5	10	15	20	25	37.5	50
Transformers															
240-120	X	X	X												
120 x 240-120/240				X	X	X	X	X	X	X	X		X	X	X
480-120	X	X	X												
480-120/240				A	A	A	A	A	A	A	A		A	A	A
240 x 480-120/240				X	X	X	X	X	X	X	X		X	X	X
600-120	X	X	X												
600-120/240				XA	XA	XA	XA	XA	XA	XA	XA				
120 x 240-32	X	X	X	X	X	X	X	X					XA	XA	XA
120 x 240-12 x 24	X	X	X	X	X	X	X								
Autotransformers															
240/120	X	X	X	X	X	X	X	X	X	X	X	X			

Output and Voltage Ratings and Primary Taps for Three-Phase General-Purpose Transformers

Voltage Rating of Transformer, Volts	Output Rating, Kva						
	3	6	9	15	30	45	75
480-208Y/120	XA	XA	XA	XA	XA	B	B
600-208Y/120		X	X	X	X	B	B

X designates a transformer having no primary taps.
A designates a transformer having two 5-percent full-capacity primary taps below rated voltage.
B designates a transformer having four 2½ percent full-capacity primary taps below rated voltage.
From ASA std. C89.1-1961.

Specialty Transformers
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Overload and Intermittent Rating

Overload capacity is not deliberately designed into transformers as the objective is to come within the allowable rise with nameplate loading. Therefore, overloads result in "over-temperature", the affect on life being a function of time and temperature. The heat storage ability of a transformer permits overloads and repetitive overloads of a cyclic nature. As heat storage is involved, the overload capacity is proportional to the weight of active material. Transformer temperature increases with overload but the actual temperature attained depends upon prior load history. If the overload temperature exceeds rated temperature for only a short period of time (2 – 4 hours), no measurable shortening of insulation life results.

It is difficult to state the overload capacity of EP transformers as this varies with duration and amount of overload. It also varies with the size of transformer. With this in mind, the general statement is made that type EP and EPT will deliver 200% load for 15 minutes, 150% load for ½ hour, and 125% load for 2 hours without being damaged. If this is a point of concern, the factory should be consulted and the desired operation described in detail.

The more frequent the cycles of "overload followed by reduced load" the less fluctuating will be the temperature swings and the increase in temperature. Advantage can be taken of this to get more than nameplate rating out of a transformer.

The rating of a transformer for intermittent duty may be found by the equation:
Equivalent Continuous Rating =

$$\frac{1}{\sqrt{1 + \frac{\text{Time Off}}{\text{Time On}}}} \times \text{Load}$$

This equation is most accurate when the "time off" plus "time on" is less than 1 hour. It is obvious that long periods (2 to 4 hours) result in a transformer approaching a steady state temperature condition.

Definition of Enclosures, Non-Ventilated (Based on NEMA Standards)

Type 1 General Purpose: An enclosure intended primarily to prevent accidental contact with the enclosed apparatus. Serves as protection against dust, light, indirect splashing, but is not dust tight.

Type 2 Drip Tight: Enclosure intended to prevent accidental contact with the enclosed apparatus and is constructed to exclude falling moisture and dirt. Suitable for application where condensation may be severe, such as cooling rooms and laundries.

Type 3 Weather Resistant (Weatherproof): Intended to provide suitable protection against specified weather hazards. Suitable for application outdoors on ship piers, canal locks, and construction work and for application in subways and tunnels. The enclosure shall be constructed to exclude beating rain. Standard EP and EPT construction comply with types 1, 2 and 3.

Type 5 Dust Tight: Provided with gaskets or their equivalent to exclude dust. Suitable for application in steel and cement mills where it is desirable to exclude dust. Standard EP and EPT cases are not dust tight.

Type 6 Submersible: Suitable for application where submersion may occur, as in quaries, mines, and manholes. The design of the enclosure will depend upon specified conditions of pressure and time. Standard EP and EPT transformers are not submersible transformers.

Type 7 (A, B, C, or D) Hazardous Locations – Class I: These enclosures are designed to meet the application requirements of the National Electric Code for Class I hazardous locations. Class I locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitible mixtures. See Chapter 5 of N.E.C.

Type 9 (E, F, or G) Hazardous Locations – Class II: These locations are those which are hazardous because of the presence of combustible dust. See Chapter 5 of N.E.C. Standard EP and EPT cases do not comply with type 7 and 9 requirements.

Type 12 Industrial Use: Designed for use in those industries where it is desired to exclude such materials as dust, lint, fibers, flyings, and oil or coolant seepage. Standard EP and EPT cases do not meet type 12.

General

Type EP cases, single phase, 3 to 10 kva inclusive, are listed by Underwriters' Laboratories as weatherproof type 3. The lower kva ratings are listed as indoor, the only difference being one less primer coat. The 15 kva and larger single phase cases are of similar construction but at present U.L. does not list these ratings or 3 phase ratings.

The core and coils are definitely dust tight but dust can enter the terminal compartment as the joints are not completely flanged or gasketed.

Although EP and EPT are not represented as being submersible, they will come through an occasional flooding in good operating condition. Where flooding can occur, the installation position must be such that terminal compartments will readily drain.

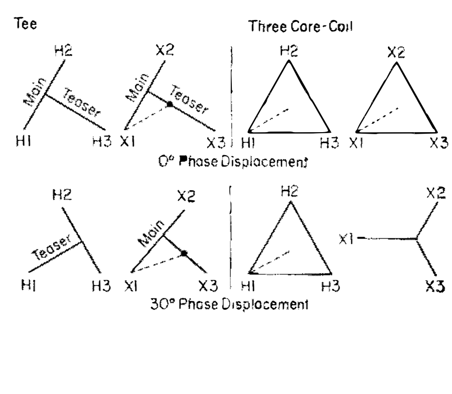
Tee-Connected Three Phase Transformer

This transformer consists of two single phase core and coils interconnected in an arrangement simulating a "T" for transforming 3 phase to 3 phase. The two core and coil assemblies are placed side by side in a case.

Tee connected 3 phase transformers are different because two core and coil assemblies accomplish the voltage transformation. This is in contrast to three core and coils or three coils on a 3 legged core type magnetic circuit. The T is nothing more than a simplification of the commonly accepted "Scott" connection for 3 phase to 2 phase transformation. It is obvious that if two core and coils will accomplish 3 phase to 2 phase transformation then two core and coils will transform 3 phase to 3 phase.

The vector relationships are shown below and compared with △-△, etc. vectors:

The vector relationships between the three phase primary and secondary is a function of the winding arrangement on the two single cores. If both main windings are on one core, and both teaser windings on the other, there will be no phase displacement between pri-



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Tee-Connected Three Phase Transformer (Continued)

mary and secondary. If each single core has one "main" winding and one teaser, the phase displacement will be 30°C.

A phase displacement of 0° simulates the wye-wye or delta-delta arrangement of conventional three phase transformers. A 30° displacement simulates wye-delta or delta-wye.

One end of the teaser winding on both primary and secondary is internally connected to the mid point of the corresponding main. The neutral point on all windings is on the teaser one third of the distance electrically from its connection to the main.

An important object in the design of a T connected winding is to insure that the mid point of the main is electrically midway between the two ends of the winding throughout the full range of anticipated loading. This is accomplished by careful balancing of both the resistance and reactance in the two halves of the main winding. Any current flowing in one half of the winding will induce an equal current in the opposite direction in the other half of the same winding or in another winding on the same core. The mid-point of the main and consequently the neutral point, which is closely associated with it, is quite firm in its relationship to line voltages.

Winding Arrangements

The T connection has different exciting current and neutral current characteristics from delta or wye connections but gives equal performance. It has been common practice to specify one of the four standard delta or wye connections to get the exciting current and neutral current flow desired and this in turn determined the phase shift from high to low. The T connection has the same exciting current and neutral current characteristic regardless of phase shift; so a customer should specify that a zero phase shift is desired only when it is necessary for paralleling purposes and in all other orders, the 30° phase shift should be supplied since it is easier to manufacture and gives better impedance values. The terms "zero phase shift" and "30° phase shift" should be used rather than "Delta-Delta" or "Delta-wye".

Standard high voltage tap arrangements and series – parallel low voltage connections are possible with T as is done on delta and wye; but a transformer to work on two different systems with voltage in the ratio of the $\sqrt{3}$ is not possible. This is because coils cannot be re-connected for this ratio change.

Either a low voltage lighting tap or a low voltage neutral can be brought out of a T connection and it is theoretically possible to bring out both although limited space makes this highly undesirable. A neutral should not be used with a series-parallel low voltage for economic reasons. Neither should series-parallel high and lows be specified.

Third Harmonic Currents

The T connected transformer has two exciting currents instead of three. The third harmonic components are not in phase but in quadrature. One core and coil of the two will be connected directly across one pair of lines. The exciting current for the other unit will flow from the third line and divide equally at the midpoint of the first unit and add vectorially to the exciting current of the first unit in one of the first two lines and subtract in the other. Therefore, the vector sum of the exciting currents in the three lines is zero. Consequently, the third harmonic components of the exciting current are not suppressed and the neutral does not shift as in a Y-Y transformer with isolated primary neutral.

Current and Voltage Balance

The impedance of the T design is of the same order as a single phase transformer of one half the kva. The impedance of three core and coil designs is of the same order as single phase transformers of one third the kva. As impedances increase inversely with ratings, the T transformers can be expected to have better voltage regulation than three core and coil transformers. The result is that differences in regulation between phases are negligible. In 30° phase shift units, a 5 to 10 percent difference in regulation is common, but the result is .1 to .3 percent difference in voltage which is hardly detectable with industrial meters. The zero phase shift transformer may have 25 percent difference in regulation between phases and although this would not produce appreciable effects, it points out the desirability of the 30° phase shift connection.

Parallel Operation

A T connected 3 phase unit can be paralleled with another 3 phase unit if the usual paralleling requirements are met (equal voltage ratios, equivalent vector diagrams, and regulation within ± 7½%). There are considerable problems in designing to meet these requirements and it is more economical to limit paralleling to duplicate designs.

Equivalent Y-Y Connection

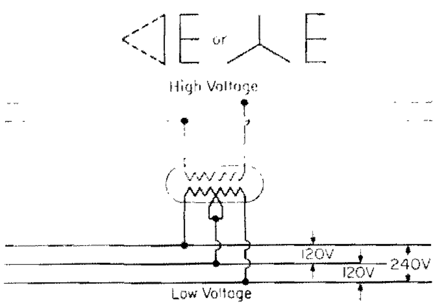
With the T connection, it is not necessary to bring out the primary neutral and connect it to the source neutral to provide a path for the third harmonic exciting current to avoid neutral shift. It must be emphasized that with the T connection, it is not only unnecessary but highly undesirable for the primary neutral to be connected to source neutral. If this is done the T connected unit will act as a conventional Y with its primary neutral connected to the system neutral and the transformer will try to balance the three line to neutral voltages for the whole system. It could seriously overheat from this cause without the secondary being loaded. The low voltage material may be brought out and either grounded or used for line to neutral loading without introducing an unfavorable operating condition.

Primary Open Circuit

In many 3 phase connections an open circuit in a primary line can cause trouble to the transformer or the load. Wye-wye core type transformers tend to overheat when a supply line is open. Other bank connections do not show trouble in themselves but motors fed from the low voltage will overheat due to an open primary. The 30° phase shift T connection is partly self-protecting under this condition. If the open circuit is on the lead connected to either end of the main unit, the whole load is lost and no overheating of motors can occur. This is not true if the other primary connected to the teaser winding is the one with the open circuit, but the bank is not endangered It should be pointed out that proper safety for this condition depends on proper relaying.

Specialty Transformers
5000 Volts and Below

Standard Transformer Connections
Single Phase Connections
Single Phase Three-Wire Secondary (Series Connection)

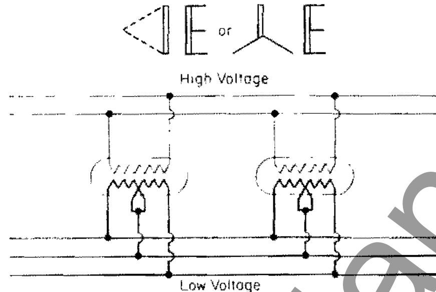


The most commonly used connection for small distribution transformers is that where a three-wire secondary is supplied at 120/-240 volts. A similar connection may be used for 240/480 volt transformers. The primary may be supplied from a single-phase line, two wires of a three-phase line or one line wire and a neutral of a three-phase line.

The 120-volt loads should preferably be balanced in order that both halves of the low-voltage winding will be equally loaded. It would not be desirable with this connection to draw more than 50 percent of the transformer rated load from either half of the low-voltage winding, as by so doing that half of the winding would be overloaded.

Although most of the following diagrams show two-wire (per phase) secondary systems, many of these connections can be used to supply a single-phase three-wire system by using the mid-point of the secondary winding. In many of the following diagrams it is also possible to supply combined two or three-phase and single-phase (2 or 3 wire) loads. In such cases it may be desirable to use unequal kva ratings for the different transformers in order that all transformers carry the same percentage of rated load.

Single Phase Parallel Operation of Two Single Phase Units



The parallel operation of transformers having the same high-voltage and low-voltage ratings is often utilized in those cases when it is necessary to increase the total bank capacity and a single unit of the correct capacity is not available.

Economically it is not efficient to operate two transformers in parallel where a single unit could be used, as by so doing the losses of two units in parallel will be greater than the losses of a single unit of the same equivalent capacity.

When the ratio of reactance to resistance is about the same for both transformers the maximum safe bank capacity may be obtained as the smaller of the two values obtained from the following two formulae:

Bank capacity (based on not overloading transformer no. 1)

$$= \frac{C_1 Z_2 + C_2 Z_1}{Z_2}$$

Bank capacity (based on not overloading transformer no. 2)

$$= \frac{C_1 Z_2 + C_2 Z_1}{Z_1}$$ where C_1 and C_2 are nameplate kva ratings and Z_1 and Z_2 are nameplate percentage impedances for transformers no. 1 and no. 2, respectively.

Transformer as Booster

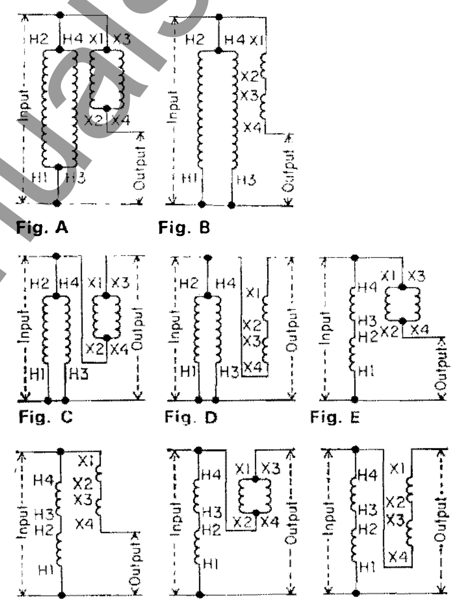


Fig. A Fig. B Fig. C Fig. D Fig. E Fig. F Fig. G Fig. H

Nominal Circuit Voltage	Transformer Function	Percent Change of Circuit Voltage	Fig. No.	Kva Output ① in Terms of Nameplate Rating
120	Boost	10	A	10 times
	Boost	20	B	5 times
	Buck	10	C	10 times
	Buck	20	D	5 times
240	Boost	5	E	20 times
	Boost	10	F	10 times
	Buck	5	G	20 times
	Buck	10	H	10 times

① If actual voltage differs from nominal, multiply kva output by ratio of actual voltage to nominal.

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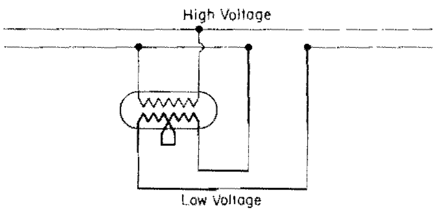
Standard Transformer Connections

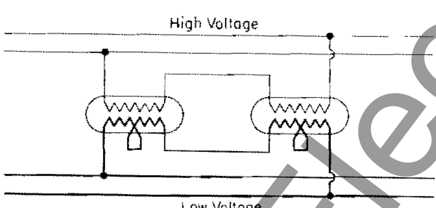
Transformer as Booster, Cont'd

The purpose of a booster transformer is to raise the voltage of the circuit from which the transformer is excited. The primary winding is connected in multiple and the secondary winding in series with the line. By reversing the secondary winding its action can be changed from boosting to bucking. In this connection the low-voltage winding is subjected to the overvoltages of the high-voltage circuit. Transformers specially designed for booster operation are insulated to take care of these voltages. Caution should be used, therefore, in applying standard two-winding transformers as boosters. However, if this connection is used on such transformers with 1.2 kv class secondaries, it is recommended that one end of the secondary winding be grounded.



Consideration should also be given to the reduction in effective transformer impedance when connected as a booster. This may involve the addition of series impedance to limit short circuit currents to permissible values.

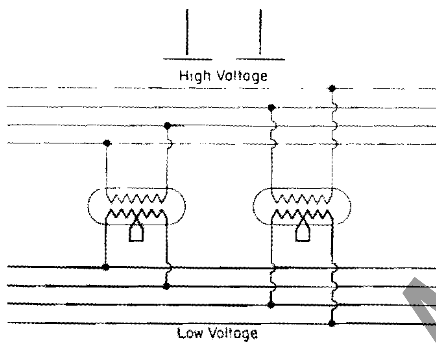
60 Cycle Transformers on 25 Cycles



When using a 60-cycle transformer on a 25-cycle circuit, a transformer rated at approximately double the voltage of the circuit would be required to prevent magnetic saturation of the iron core. The same result can be accomplished by connecting two transformers of the same voltage in series.

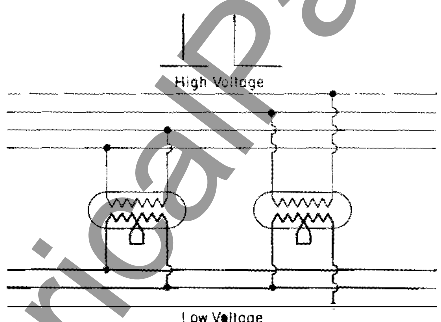
Two Phase Connections

Two Phase, Four Wire



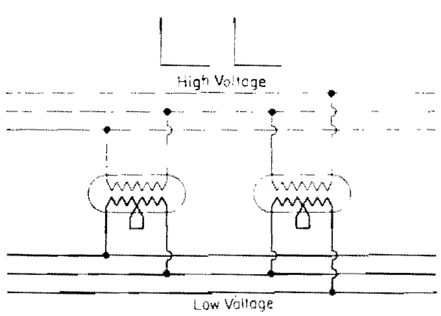
In this connection two phase, four wire is transformed to two phase, four wire of a different voltage with no connection between the two phases.

Two Phase, Four Wire to Two Phase, Three Wire



The two phases on the low-voltage side are electrically tied together. The common third wire is sometimes grounded. With balanced load the current in the common wire is $\sqrt{2}$ times that in the outside.

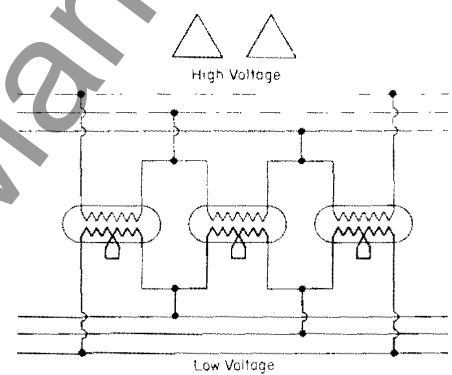
Two Phase, Three Wire Interconnected



In this connection the two phases are electrically tied together by the common third wire. This is permissible in certain cases and not in others. This third or common wire is sometimes grounded. With balanced load, the current in the common wire is $\sqrt{2}$ times that in the outside wires.

Three-Phase Connections

Three Phase Delta-Delta

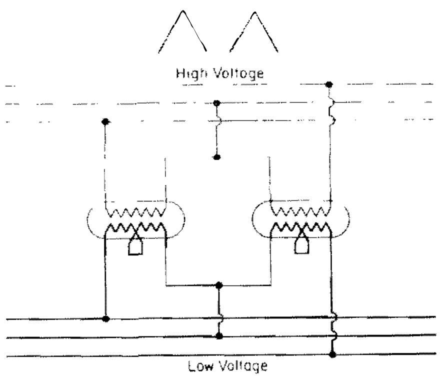


In the delta-delta connection, a multiple path is provided between any two lines, in both primary and secondary, and so it exhibits some properties of a parallel circuit. The voltages are determined by the source but the division of current among the phases depends upon the internal characteristics of the transformers. For a balanced load, the division of current among the phases is equal only when individual transformers have equal impedances. Delta-delta connections are very sensitive to off ratio conditions because resultant voltage drives a circulating current around the delta. It is evident that transformers of identical voltage rating should be used for delta-delta banks.

The dependence of current division between phases upon the impedance values of individual transformers gives a flexibility of operation to the delta-delta bank, for connection of different kva ratings in the delta is possible, since a phase having the smaller rating can be expected to have the higher impedance and, thereby, takes a smaller share of the load. By this property delta-delta banks are operated when made up of transformers having different ratings and, in fact, with one phase entirely omitted as in open delta.

Specialty Transformers
5000 Volts and Below

Three Phase, Open Delta



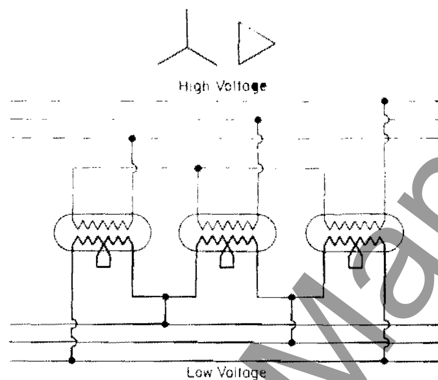
Three to three phase may be transformed by the use of two similar transformers in open delta. In this connection the units will transform 86 percent of their rating, i.e., two 100 kva units in open delta transforming three phase, 2300 volts to three phase 230-115 volts will have a bank capacity of 172 kva.

In the open delta connection it is not necessary that the impedance characteristics be the same, although it is preferable when it becomes necessary to close the open delta bank with a third unit.

The open delta connection is often used as a temporary expedient pending a contemplated increase of load and offers a very simple means of handling this matter. By adding a third 100 kva unit in the above mentioned example the resultant bank capacity will be increased from 172 to 300 kva.

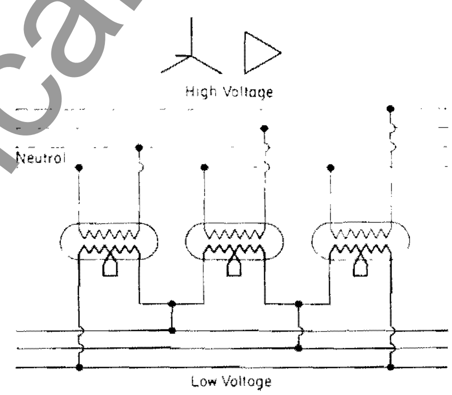
The regulation of an open delta bank is not as good as a closed delta bank. The drop across the open delta is greater than across each of the separate transformers.

Three Phase, Star Three Wire – High Voltage; Delta Three Wire Low Voltage



When three transformers are operated with their high voltage-windings in star the incoming line voltage is the $\sqrt{3}$ or 1.732 times the transformer winding voltage. This connection is very popular and presents a very convenient way of boosting the transmission voltage without purchasing additional transformers.

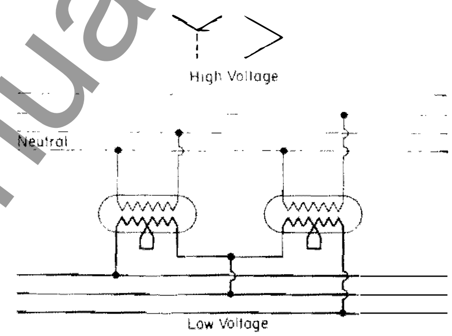
Three Phase, Star Four Wire – High Voltage; Delta Three Wire Low Voltage



This connection permits three phase power to be transmitted at the star voltage. At the same time single-phase power may be taken from the mains by connecting the transformer between the neutral and any of the three phase wires. In this connection it is not necessary that the impedance of the three transformers be the same. The high-voltage neutral is usually grounded.

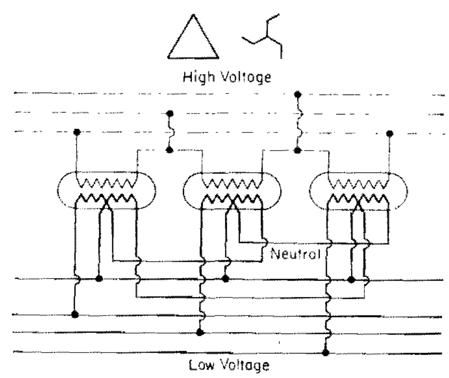
Miscellaneous

Three Phase; Star Four Wire One Leg Out – High Voltage; Open Delta Three Wire – Low Voltage



This is similar to a V connection. The primary of each transformer is connected between the neutral and one of the three-phase wires. The secondaries are connected to the secondary mains, the same as for the delta connection, except that the third transformer is not used. (The secondaries are in open delta.) The two transformers will provide 86.6 percent of their combined rated capacity.

Three Phase; Secondary Star Inter-Connected



The primary side of this group may be connected either in star or in delta. Each half of the secondary winding of each transformer has a voltage of 57.7 percent of the interconnected star voltage. A bank of transformers designed for connection in this manner must have a capacity 7½ percent greater than the kva to be transformed. The purpose of the interconnected star winding is to permit the unbalanced d-c current from the third wire of the three-wire circuit of a rotary converter to get back into the alternating-current system feeding the converter. Since this d-c current divides into two equal parts in each transformer and also these parts

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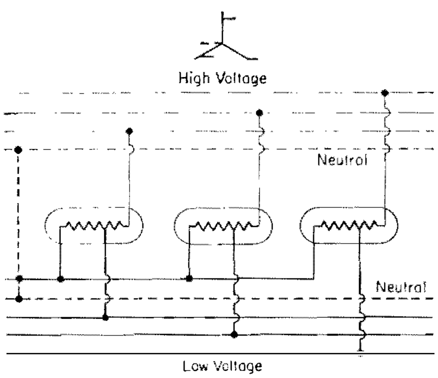
Three Phase; Secondary Star Inter-Connected (Continued)
flow in opposite directions magnetically in the two parts, the d-c current does not magnetize the core. If this current would flow in one direction through the winding, the d-c magnetic flux would add to the a-c flux and perhaps saturate the core.

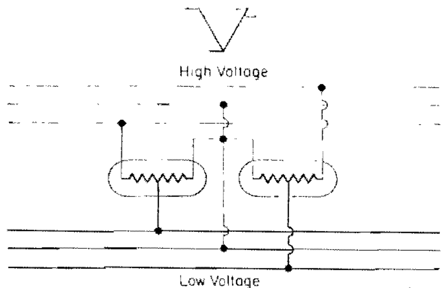
A star interconnected autotransformer can be used to provide a stable ground for an isolated three phase supply, the interconnected winding being used with half-wave rectifiers to prevent saturation of the magnetic circuit.

Three Phase; Three or Four Wire Star-Star with Autotransformers



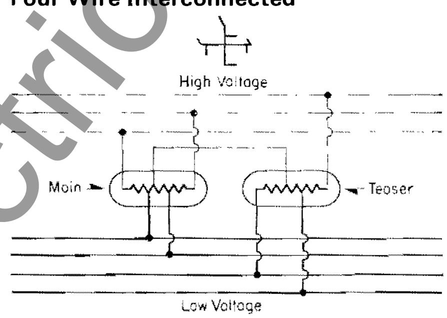
In this connection the high and low-voltage windings are electrically connected together, and for this reason the low-voltage side and connected apparatus will under fault conditions be subjected to the voltage of the high voltage circuit. The material in the autotransformer is less than that in a two-winding transformer, transforming the same power. The saving in material is quite large when there is but a small difference in the primary and secondary voltages, and the saving becomes less and less as the difference between the primary and secondary voltages increases.

Three Phase; Three Wire Open Delta with Autotransformer



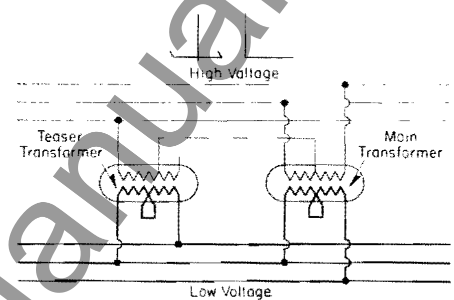
In this connection the high and low-voltage windings are electrically connected together, and for this reason the low-voltage side and connected apparatus will under fault conditions be subjected to the voltage of the high-voltage circuit. The material in the autotransformer is less than that in a two-winding transformer, transforming the same power. The saving in material is quite large when there is but a small difference in the primary and secondary voltages, and the saving becomes less and less as the difference between the primary and secondary voltages increases. This connection requires 17 percent larger transformer capacity than the star-star autotransformer connection.

Autotransformers for Phase Transformation; Three Phase to Two Phase Four Wire Interconnected



When a phase transformation is desired without any considerable stepping up or down of voltage, the autotransformer is the most simple and cheapest arrangement. The connection shown has the windings on the two-phase side electrically connected together at their middle point.

Phase Transformation, Scott; Two Phase Three Wire to Three Phase Three Wire or Scott; Three Phase Three Wire or Two Phase Three Wire

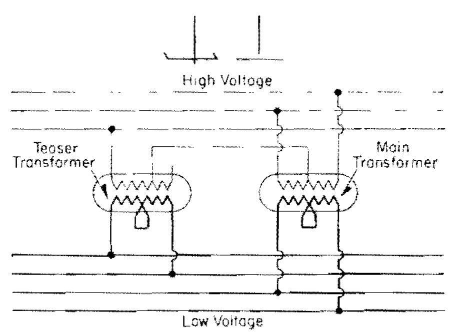


This is a phase transformation from three phase to two phase, or from two phase to three phase. Either the primary or secondary side may be made three phase. The three phase side must have special taps to make this transformation. One unit must have an 86.6 percent tap, and the other unit a 50 percent tap. A three-wire circuit is used on the two phase side. This is formed by merely joining together two of the wires forming the two phases. In this manner the two phases are electrically connected together.

Dry-type transformers are ordinarily designed so that the full rated capacity of the bank can be utilized without exceeding normal temperature rises.

If the transformers are to be used with motors interconnected at mid-points, the connection shown at the left cannot be used and four-wire connection illustrated in figure 19 is recommended.

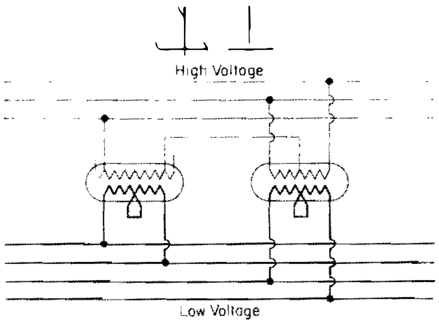
Phase Transformation, Scott; Three Phase Three Wire to Two Phase Four Wire or Scott; Two Phase Four Wire to Three Phase Three Wire



This connection is exactly the same as the previous one except the two-phase side is made four-wire. In this manner the two 2-phase circuits are electrically separated.

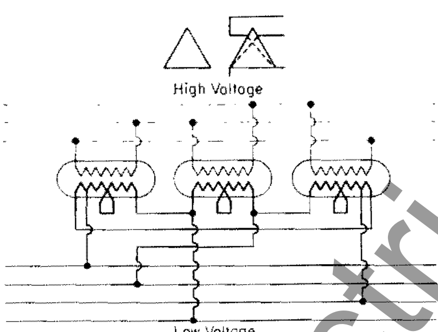
Specialty Transformers
5000 Volts and Below

Scott Transformation; Standard 10 to 1 Ratio Used



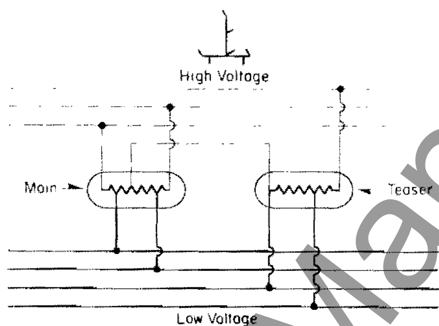
If a Scott transformation is desired, and a transformer having an 86.6 percent tap is not available, a unit having a 10 percent tap or two 5-percent taps may be used to give approximate results. With this arrangement the two-phase voltages will be unbalanced by about 4 percent.

Phase Transformation; Fortesque Connection



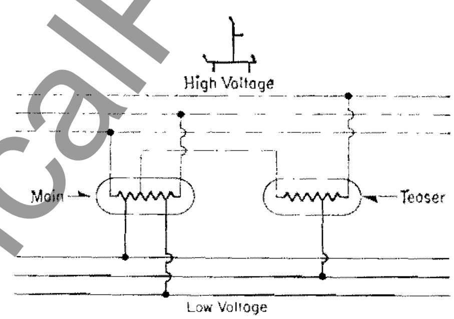
This is a transformation from three phase to two phase by the use of three transformers, one of which is standard and the other two have special taps on the low-voltage side. One advantage of this connection is that both two and three phase current may be delivered at the same time. The sum of the power delivered at two phase and at three phase must be somewhat less than the normal rating of the transformers, in order not to overload the transformers.

Autotransformers for Phase Transformation; Three Phase to Two Phase, Four Wire



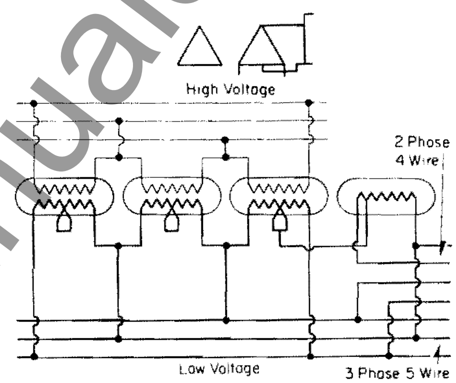
This connection is the same as the one shown previously except that the windings on the two-phase side are not connected together at their middle points, but the end of one phase is connected to the middle of the other phase.

Autotransformers; Three Phase to Three Phase, Three Wire



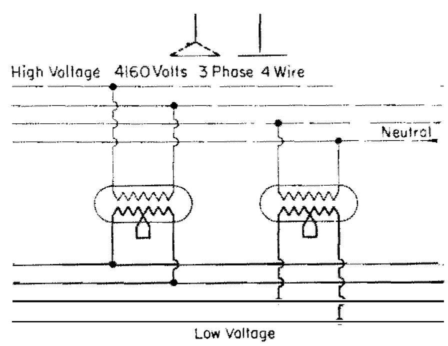
Where the voltage change from primary to secondary is small, the use of an autotransformer for a voltage transformation is cheaper than the use of two-winding transformers. The primary and secondary windings are tied together electrically, which may be an objection in some cases.

Phase Transformation; Three Phase to Two Phase Using an Autotransformer



This shows how two phase voltages may be taken from a delta bank by the simple application of an autotransformer. The auto is connected between the apex of the delta and the mid-point of the opposite side. This gives a 1 to 1 ratio which means that the two phase and three phase voltages on the low-voltage side are equal. The high-voltage winding of the bank may be connected star or delta. The two phase and three phase loads may be taken off simultaneously. If no load is drawn off at three phase, approximately 75 percent of the bank rating may be taken off at two phase.

Phase Transformation Using Standard Transformers of Different Voltage Ratings



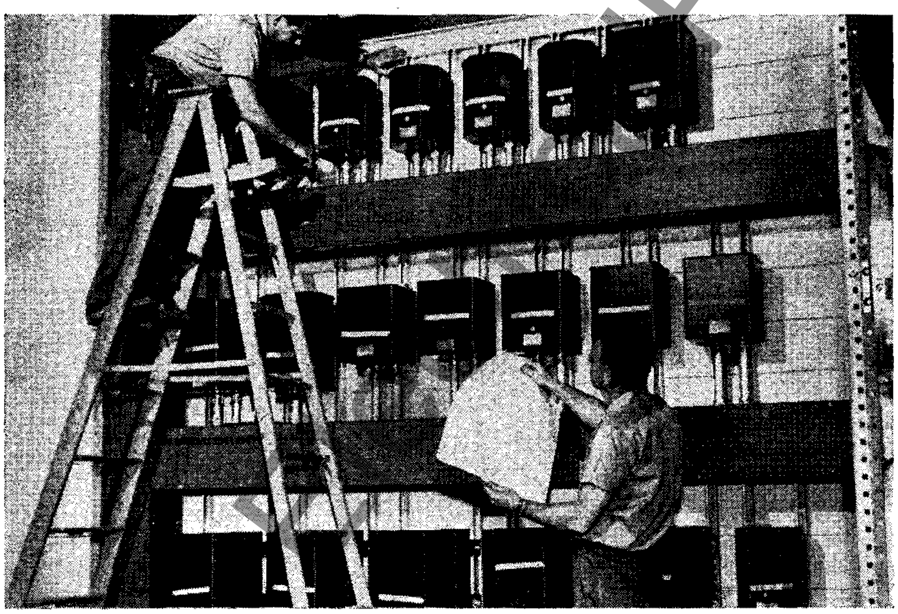
This is a phase transformation from three phase to two phase employing standard transformers. Transformer No. 1 is rated 4160 volts to 240/120 volts. Transformer No. 2 is rated 2400 to 240/120 volts. Each transformer will have a rating equal to one-half the two-phase load.

Specialty Transformers
5000 Volts and Below

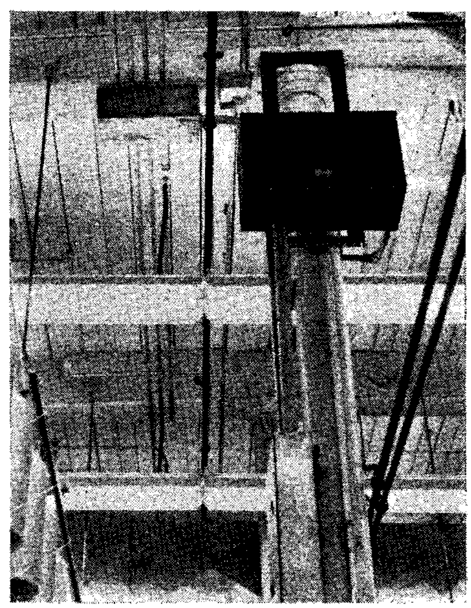
Typical Performance Data
Values are measured at 100°C NEMA reference temperature except for 15, and 25 Kva single phase and all three phase units which are measured at 135°C reference temperature

Kva	Losses (Watts) No Load	Losses (Watts) Full Load	% Imp.	% Regulation 1.0 PF	% Regulation .80 PF	Efficiency Full Load	Efficiency ¾ Load	Efficiency ½ Load	Efficiency ¼ Load	Temp. Class Deg. C	Sound Level (DB) Avg.	Sound Level (DB) Max.
Single Phase												
¼	13	36	9.24	9.20	8.00	87.5	85.0	82.0	80.0	80	33	40
½	20	45.4	5 12	5.07	4.54	91.8	91.6	90.5	85.2	80	33	40
¾	21	54	4.44	4.14	3.33	93.3	93.5	92.8	89.1	80	34	40
1	11	52	4.18	4.09	3.62	95.1	96.0	96.0	95.2	80	34	40
1½	17.1	74.4	3.7	3.83	3.6	94.3	95.1	95.5	94.5	80	35	40
2	20	84	3.42	3.18	3.30	96	96.4	96.5	95.4	80	35	40
3	31	104.4	3.0	2.5	2.96	96.6	96.9	96.75	95.5	80	36	40
5	29	139	2.31	2.22	2.20	97.3	97.6	97.75	97.2	80	36	40
7½	48	176	1.85	1.75	1.90	97.7	97.9	97.9	97.1	80	37	40
10	56	200	1.41	1.44	1.60	98	98.2	98.1	97.4	80	37	45
15	72	329	1.85	1.71	1.80	97.8	98.1	98.15	97.6	115	40	45
25	144.5	437	1.65	1.18	1.63	98.4	98.4	98.3	97.5	115	40	45
Three Phase												
3	44	162	5.8	4.0	5.7	94.9	95.4	95.3	93.6	115	36	40
6	82	252	3.3	2.85	3.25	96.0	96.25	96	94.2	115	36	40
9	84	290	2.96	2.28	2.83	96.9	97.15	97.1	95.95	115	36	40
15	106	450	2.8	2.3	2.8	97.10	97.4	97.5	96.6	115	38	45
20	166	455	2.75	1.5	2.50	97.8	97.85	97.7	96.5	115	38	45
30	229	681	2.14	1.51	2.12	97.8	97.9	97.8	96.7	115	40	45

Further Information
Prices: PL 46-820
Description: DB 46-850



Single Phase, Type EP Installation



Three Phase, Type EPT Installation

Westinghouse Electric Corporation
Specialty Transformer Division; Greenville, Pa.
Printed in USA