MOD.x190

SINGLE PHASE TRANSFORMER

MOD.x195

THREE PHASE TRANSFORMER

(X MEANS THAT THIS MANUAL IS VALID FOR ALL MODELS 0.1.2.3.4.5.6.7.8.9)

INSTRUCTION MANUAL

COMPANY
WITH QUALITY SYSTEM
CERTIFIED BY DNV
=ISO 9001/2000=

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ENX190MN	Rev.1-2003	Made in Italy

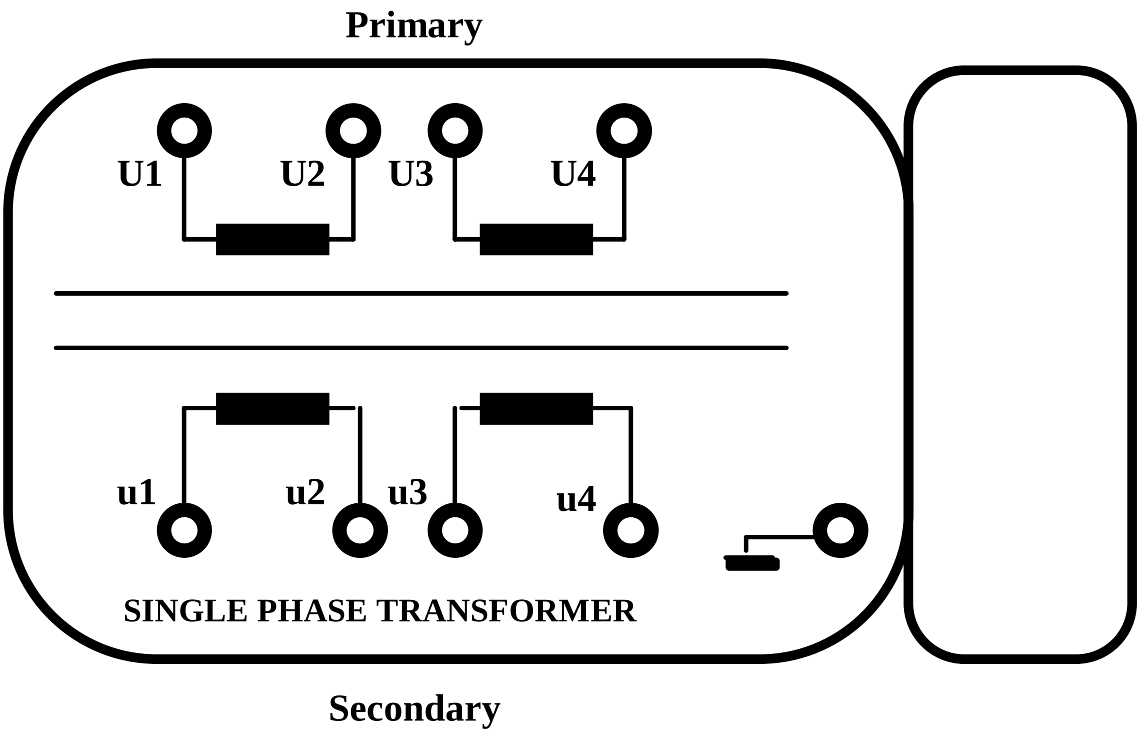
INDEX OF ASSIGNMENT

SINGLE PHASE TRANSFORMERS

Technical specifications:

MOD.3190	Power 0,3kW	Primary 220V (U1-U2: 110V + U3-U4: 110V) Secondary 110V u1-u2: 55V + u3-u4: 55V
MOD.4190	Power 1kW	
MOD.5190	Power 2kW	
MOD.6190	Power 3kW	

See current indication on the label on the transformer

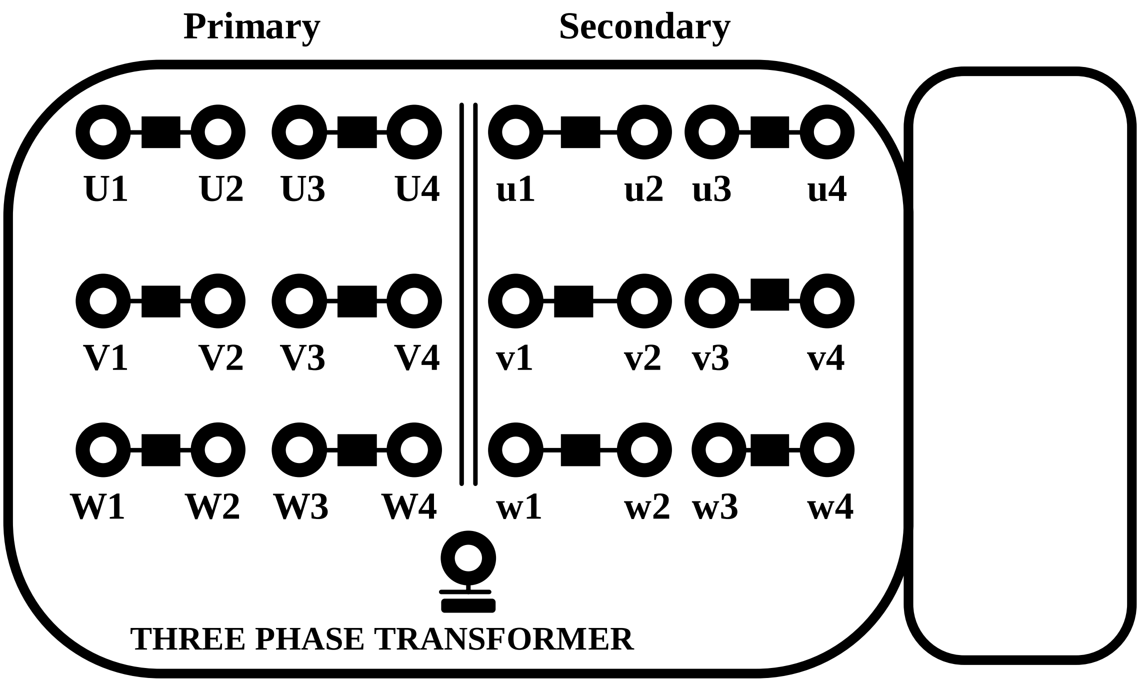


THREE PHASE TRANSFORMERS

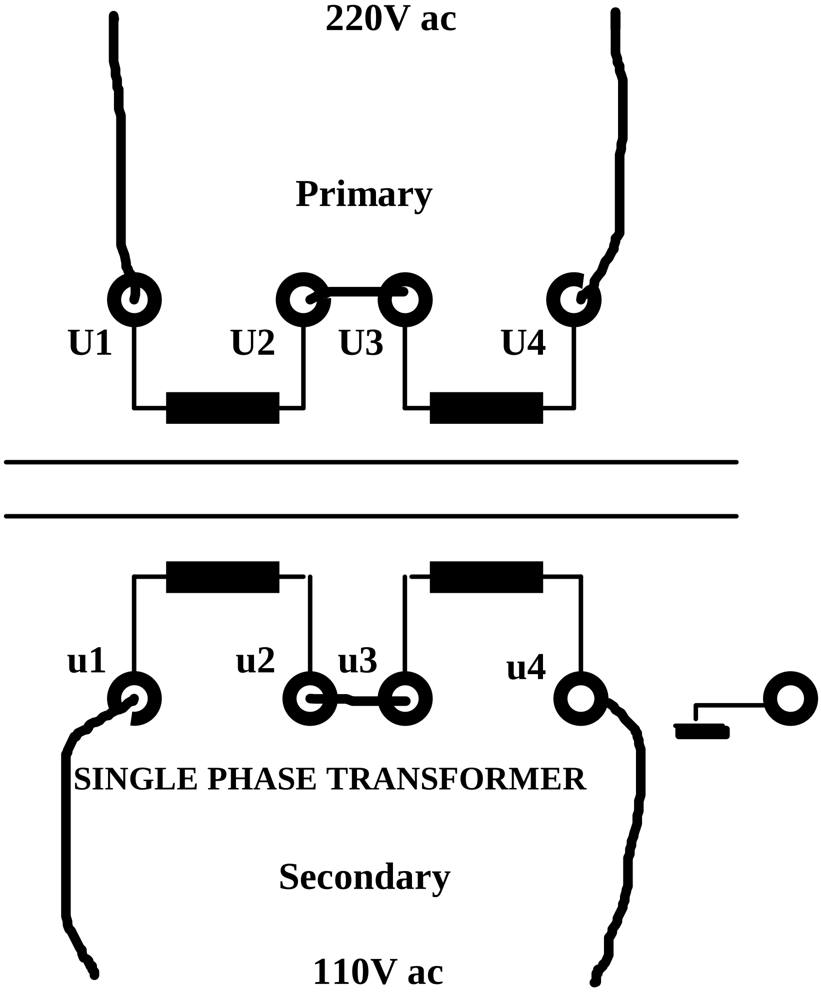
Technical specifications:

MOD.3195	Power 0,3kW	Primary: 380V STAR U1-V1-W1 (190V + 190V)
MOD.4195	Power 1kW	220V DELTA U1-V1-W1 (110V + 110V)
MOD.195	Power 2kW	Secondary: 220V STAR u1-v1-w1 (110V + 110V)
MOD.6195	Power 3kW	127V DELTA u1-v1-w1 (63,5V + 63,5V)

See current indication on the label on the transformer



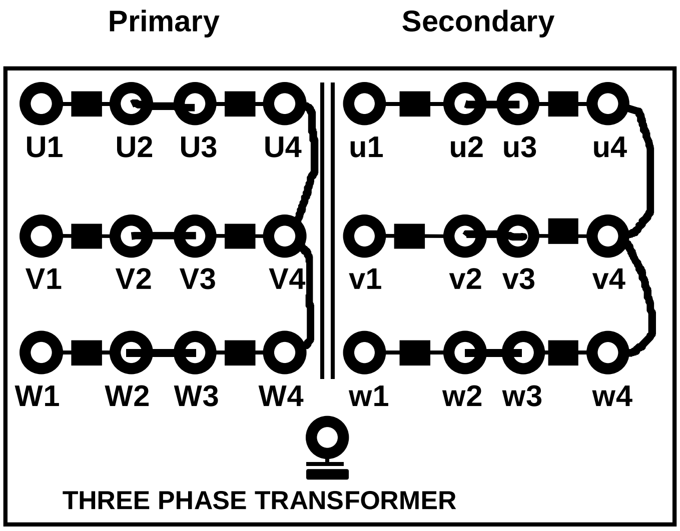
CONNECTION SCHEME OF THE SINGLE PHASE TRANSFORMER



CONNECTION SCHEME OF THE THREE PHASE TRANSFORMERS

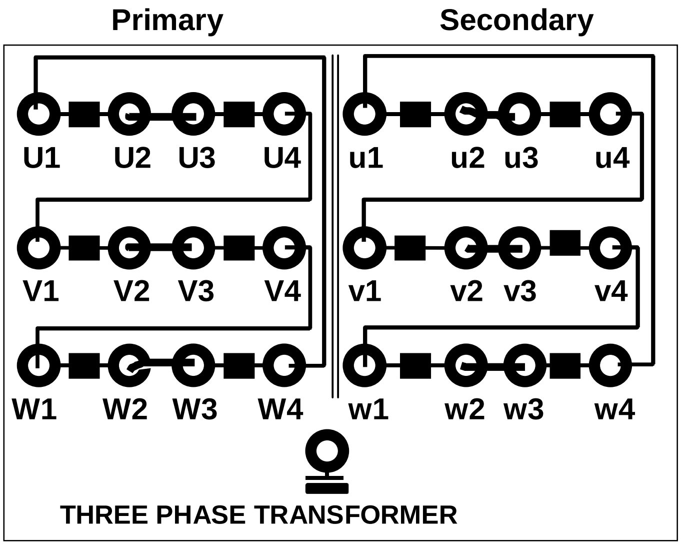
380/2210V STAR/STAR CIRCUIT

U1-V1-W1 Primary input: 380V
u1-v1-w1 Secondary output: 220V



220/127V DELTA/DELTA CIRCUIT

U1-V1-W1 PRIMARY INPUT 220V
u1-v1-w1 Secondary output 127V



ASSIGNMENT 1
NO-LOAD TEST OF SINGLE PHASE TRANSFORMER

This test tends to underline some necessary parameters for the study of the machine behaviour under different aspects: the determination of the equivalent circuit and the calculation of efficiency.

Now we are studying the equivalent circuit of a transformer considering the load it can represent towards the line

The circuit is supplied at the nominal voltage and with open secondary terminals. (Fig.1)

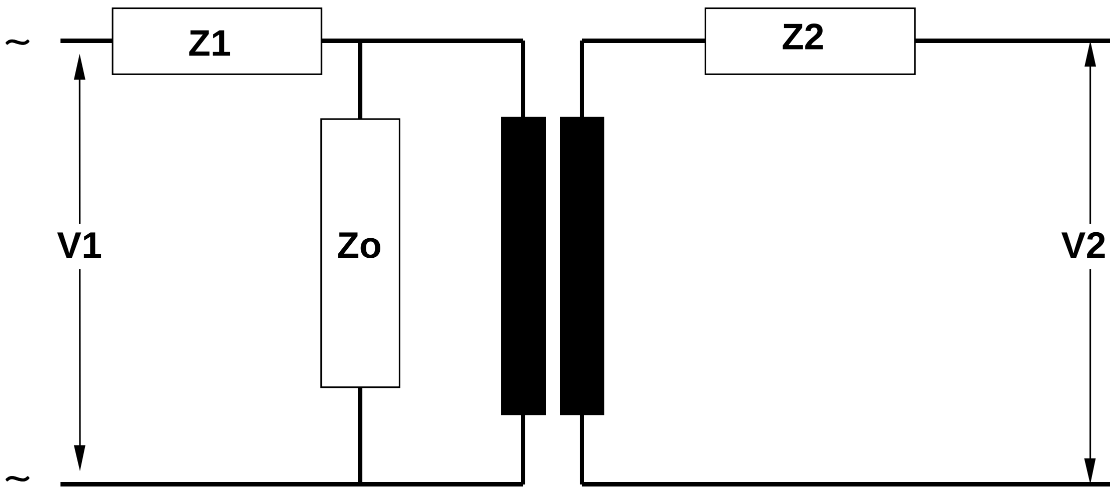


Fig.1. a) equivalent circuit of a single-phase transformer
b) equivalent scheme of Zo

The circuit appears as the series of the two impedance Zo + Z1.

The impedance Z1, concerning the primary winding is absolutely negligible in comparison to the impedance Zo. What the normal transformers are concerned, the ratio between the two impedance is about 1 : 500.

Consequently, without any doubt, only Zo can be considered existent; in fact after the no load test the derivation parameters will be established, in other words the equivalent elements to the iron nucleus will be studied.

The same conclusion can be drawn by some energetic considerations: the power no load absorbed by the transformer is essentially leaked power in the nucleus iron, this leak is caused by the phenomenon of hysteresis and that of the eddy currents

The leaks in the primary copper can also be overlooked because they are caused by the square of current. In fact for a 5% no load current of the nominal current, the leaks are 0.25% of the load leaks; consequently these leaks are insignificant.
This is also valid for the scattered reactive power, in comparison to the magnetising power.

For the no load proof we create a circuit by a suitable converter, which allows the regulation of voltage (Fig.2).

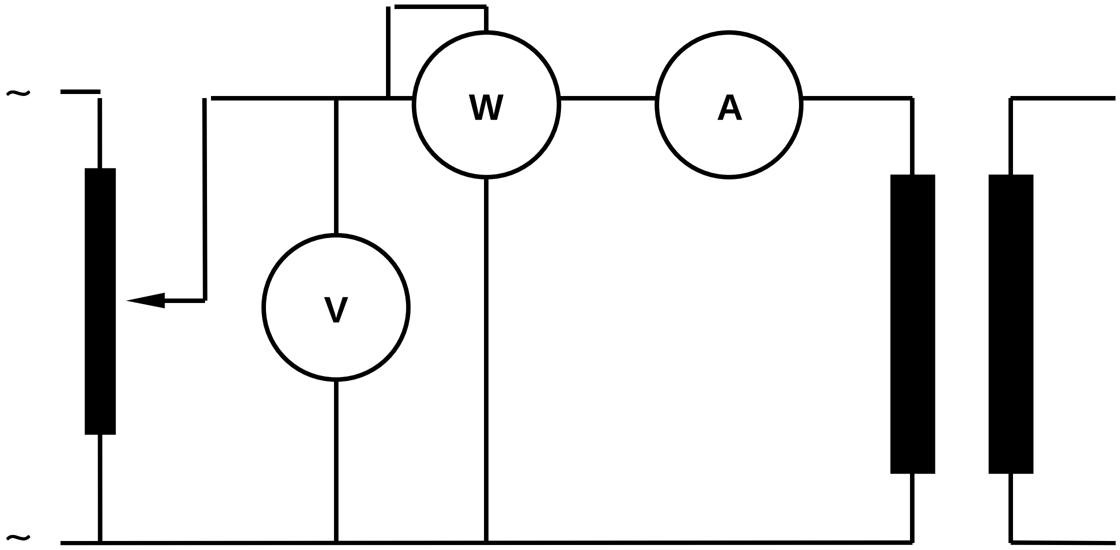


Fig.2 - No load proof of a single-phase transformer.

In the circuit the following instrument have to be used:
- a frequency meter
- a voltmeter for alternating current with higher load than the nominal value
- an ammeters for alternating current with 5~10% load of the nominal current (the highest value for small transformers)
- a watt-meter with loads with reference to the previous ones.

The circuit absorbs a very shifted current on voltage, because of the prevalence of the magnetising element; consequently a watt-meter with a low factor of power must be used.

As the circuit has a high impedance, the connection of the voltmetrics upstream the ammetrics is needed, in order to make the mistakes of the instrument self-consumption insignificant.

The no load proof must be generally carried out on the low voltage side if it is included in values that allow the use of instruments with suitable loads.

Supplying the transformer at nominal voltage and frequency, the following values van be read:

- **Vn nominal voltage**
- **f nominal frequency**
- **io no load current**
- **Po no load power**

RESULTS

As already explained, the absorbed no load power coincides with the leaks in the iron of the machine; therefore, without any doubt, the result is as follows:

$$\mathbf{Po - Pf;}$$

and in percentage:

$$Pf\% = 100\ \frac{Pf}{Sn}$$

Sn where Sn is the nominal power of the machine.

The no load current can also be evaluated by the calculation of the percentage value:

$$io\% = 100\ \frac{Io}{In}$$

Thanks to this percentage values you can already have a first idea of the transformer good quality. Consequently other interesting data can be obtained:

- **the factor of no load power cos φ - Po.VIo**
- **the magnetising power Au = Po tg φ o**
- **the magnetising current Iu = Io sen φ o**
- **the active current Ia = Io cos φ o**

and the parallel parameters of the equivalent admittance to

$$Yo = \frac{Io}{Vn}; \qquad Go = Yo \cos\varphi o; \qquad Bo = Yo \operatorname{sen}\varphi o;$$

or the parallel parameters of the equivalent impedance:

$$Zo = \frac{Vn}{Io}; \qquad Ro = \frac{Zo}{\cos\varphi o}; \; Xo = \frac{Zo}{\operatorname{sen}\varphi o}$$

NO-LOAD CHARACTERISTIC

A complete no load proof of the machine must take place at a voltage variable from O to a higher value than the nominal voltage in order to underline the machine behaviour by the obtained characteristics

The no load characteristics drawn according to the voltage are:

- **power** **Po = f (V)**
- **current** **Io = f (V)**
- **power factor** **cos φ o = f (V)**

Power Po = f (V)

This characteristic has a nearly parabolic course (Fig.3).

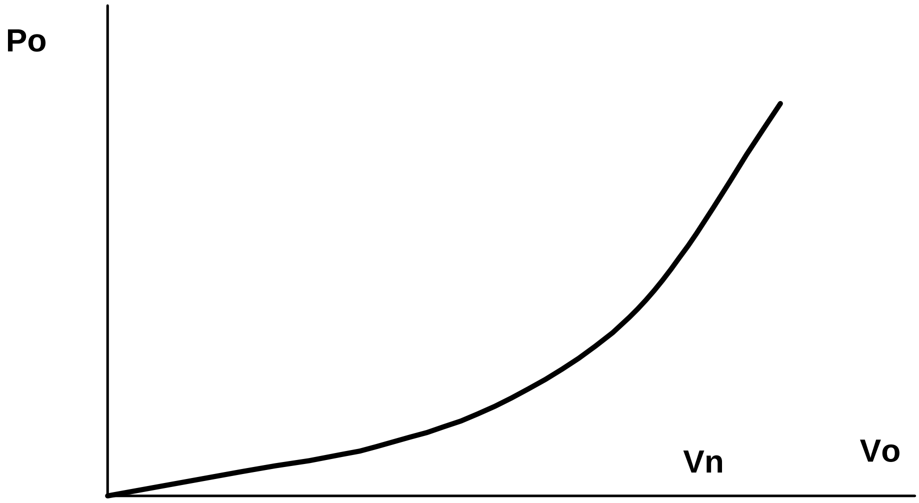


Fig.3 - Characteristic of the no load power of a single phase transformer Po = f (V)

In fact the no load power is practically the same of the leaks for hysteresis and those for eddy currents; the two leaks are dependent with a certain approximation for the Steinmetz exponent of the induction square

As in a transformer the voltage corresponds to the induction in the linear proportionality according to the formula E = 4,44 fNbmax A, there is a quadratic dependence between no load power and voltage

Current Io = f (V)

The no load current underlined by the proof of the transformer, is the sum of the magnetising component and the active component; the last one is caused by the leaks in the iron

Anyway, considering the priority of the magnetising current In, the characteristic Io - f (V) will repeat the course of a magnetising characteristic where the usual axes have been changed (Fig.4)

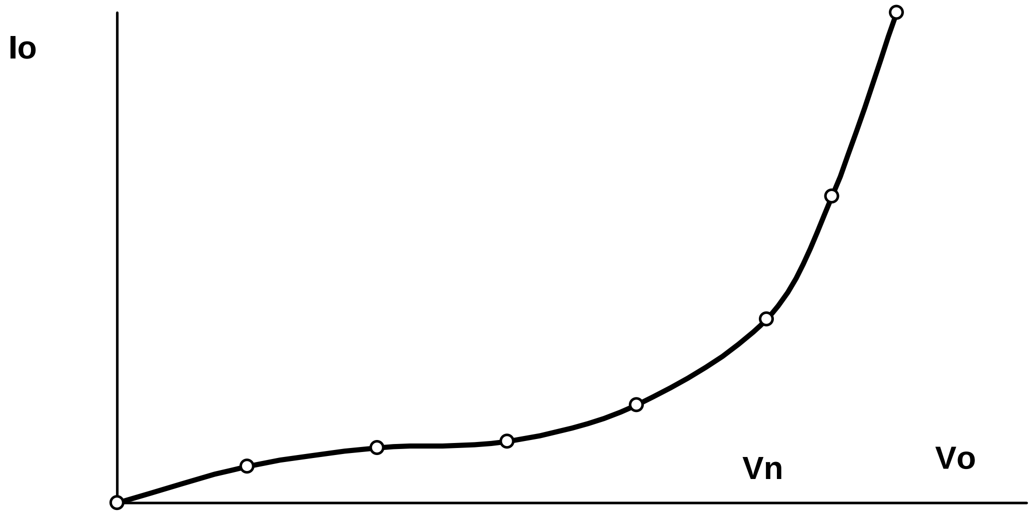


Fig. 4 - Characteristic of no load current of a single phase transformer Io = f (V)

In fact the magnetising current is proportional to the current of he magnetising field H and the voltage depends on the induction.

Therefore the current will be slightly growing with the voltage for low values and it will grow more rapidly than the nominal value of voltage because of the approaching saturation.

The knee of the characteristic will be less marked when the air gap, equivalent to the magnetic nucleus will result greater

Observing the, no load current, it presents a big deformation for high voltages and the instrument must be better electro-dynamic. A mobile iron instrument is less suitable, even if it could give some reliable measure

You absolutely have to any load the use of the instrument with coil and rectifier; the rectifier is sensible to the middle value Therefore it can give some completely wrong result because the factor of form changes by the wave

Power Factor cos φ = f (V)

The factor of no load power has a variable value and growing where the voltage grows (Fig.5

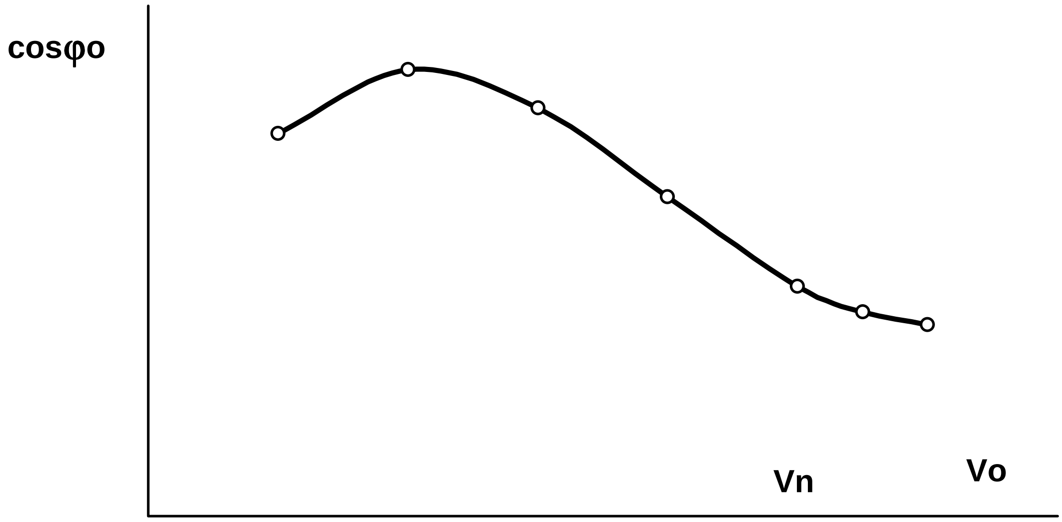


Fig.5 - Characteristic of the factor of no load power
of a single phase transformer cos φ o = f (V)

This is due to the progressive and gradual iron saturation causing a great growing of the magnetising component of current; this growing is higher than the more moderate growing of the active component.

As:

$$\mathrm{tg}\ \varphi\ o = \frac{Iu}{Ia}$$

the highest growing of numerator creates a corner growing and a consequent reduction of the factor of power.

For voltage values near to zero, the factor of no load power could reduce again if the material has a lower knee, sensible in the magnetisation, which the current has a higher incline than the following piece for.

Considering the change of the corner characteristic o, the derived equivalent parameters Ro and Xo aren't constant, but they change differently and according to the voltage.

Therefore they must be calculated considering the nominal voltage, as already done

ASSIGNMENT 2
NO-LOAD TEST OF A THREE-PHASE TRANSFORMER

The no load test of three-phase transformers has the same purposes of that of single-phase transformers. By this proof the derived equivalent parameters are established, but first of all the leaks in the iron of the machine.
The transformer is supplied by a three-phase converter.

As it is a symmetric three-phase voltage, the connection of a voltmeter between two threads is enough to measure of the line voltage. In order to work with more precision, three voltmeters are connected the three phases; the middle value of the three readings is considered valid.

The three-phase transformer is the case of unbalanced load because of the three different magnetic circuits.

Therefore three ammeters must be employed, each one on each phase (Fig.6)

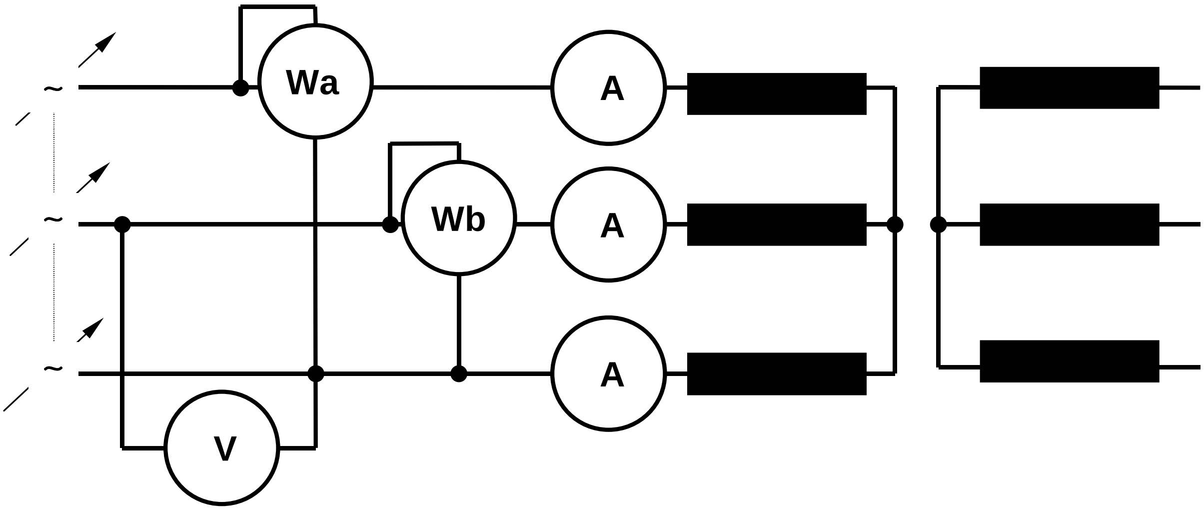


Fig.6 - No-load test of a three-phase transformer.

If the three ammeters are not available, one commutable ammeter can be connected on the three phases. In order to establish the power and the factor of void power - as it is the case of unbalanced power - you have to follow the method of the three readings or that of the four readings.

By the method of the three-phase readings, the active power is calculated:

$$Po = A + B$$

The reactive power of the formula:

$$Qo = \frac{A - B + C2}{\sqrt{3}}$$

Consequently the factor of power:

$$\text{Cos } \varphi \text{ o} = \text{cos arc tg } \frac{Qo}{Po}$$

By the method of the four readings the active power is also calculated:

$$Po = A + B$$

and the reactive power:

$$Qo = \frac{A - B + 2(B' - A')}{\sqrt{3}}$$

Consequently the parameter:

$$X = \frac{A + 2B + A' - B'}{2A + B - A' + B'} \qquad \text{and cos } \varphi \text{ o}$$

Practically the unbalance of the three phases is especially of modules, rather than of corner and the transformer acts as a balanced load with middle void current between the currents of each phase.

Consequently the ARON connection is often realised in order to obtain the active power:

$$Po = A + B$$

then the arithmetical mean of the void currents is calculated as follows:

$$Io = \frac{I' + I'' + I'''}{\sqrt{3}}$$

The factor of power will be:

$$\cos \varphi o = \frac{Po}{\sqrt{3VIo}}$$

This establishment even theoretically no correct, offers enough reliable values of factor of power.

Now suppose that the middle current Io has only the purpose of allowing the establishment of the factor of power; consequently the idea that the currents of a no load three-phase transformer are three and very different, is still valid.

According to the kind of connection (Fig.7) the magnetic unbalance causes:

- for a star connection, the current concerning the central phase is lower than the other two currents;
- for a delta connection, the current corresponding to the overhand knot of the two lateral phases is higher than the other two currents.

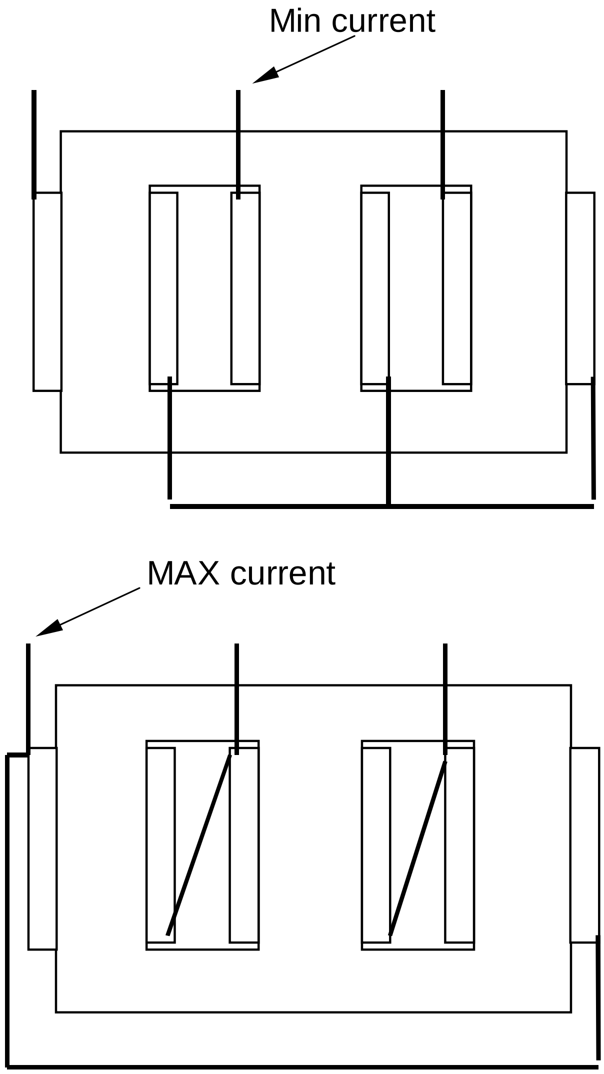


Fig.7 - Connection of the phases of a three-phase transformer.

In order to reduce the connection mistake, for the three-phase transformer, you have also to connect the voltmetrics over the ammetric.

The derived equivalent parameters can be obtained; they refer to the equivalent star circuit by the following formula:

$$Zo = \frac{V}{\sqrt{3Io}} \qquad Ro = \frac{Zo}{\cos\varphi o} \qquad Xo = \frac{Zo}{\mathrm{sen}\,\varphi o}$$

This case also refers to the middle value of no load current obtaining the impedances of a balanced transformer.

In order to be able to control completely the, the following characteristics must be drawn also for the three-phase transformer:

$$Po = f\ (V) \qquad Io\ =\ f\ (V) \qquad \cos\varphi\ o\ =\ f\ (V)$$

The obtained diagrams are similar to these already analysed for the single-phase transformer.

ASSIGNMENT 3
SHORT-CIRCUIT TEST OF A SINGLE PHASE TRANSFORMER

The short circuit test of a transformer has the purpose of vaulting the losses in the copper and establishing the equivalent series parameters.

The short circuit test is realising stalling in short circuit the secondary terminals of the transformer and supplying the primary by a voltage allowing the passage of a current corresponding to the nominal value. The values of this Voltage, called short circuit voltage, are 5-8% of the nominal voltage. For the machine reversibility the test can be carried out supplying one side.

This high voltage side is usually supplied and the low voltage side is stalled in short circuit, because the supplying voltage low in percentage - has values allowing the use of suitable instruments (Fig.8)

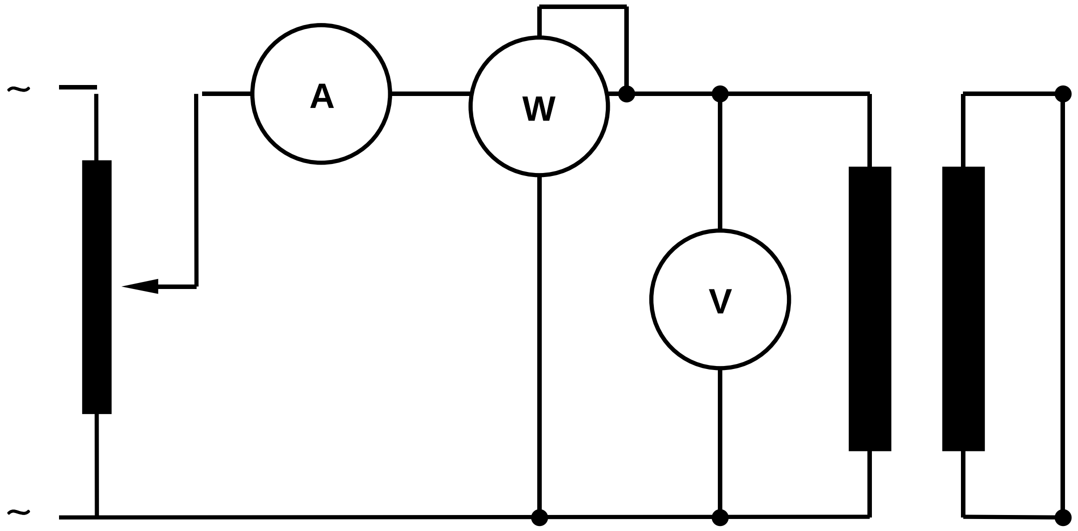


Fig.8 - Short circuit test of a single-phase transformer

You have to realise carefully the short circuit at the secondary, if interested by very strong currents, it must represent absolutely negligible contact resistance.

The instruments connected on the supplying circuit are:
- a frequency meter to verify the nominal frequency
- an ammeter with a load suitable to the nominal value of current
- a voltmeter with a load referring to a voltage 5-8% higher than the nominal voltage; for the most powerful transformers, lower values are valid
- a power-meter with loads referring to the previous ones
- a thermometer for the measure of the room temperature.

The instruments must be connected with the voltmetrics down the ammetric because it is a low impedance circuit. In fact the transformer in short circuit presents an impedance at the supply corresponding to the equivalent impedance series.

This can be established by the equivalent diagram: here the closing in short circuit of the secondary terminals corresponds to the parallel between the derived impedance Zo and the secondary impedance series referred to the primary Zz Kz (Fig.9)

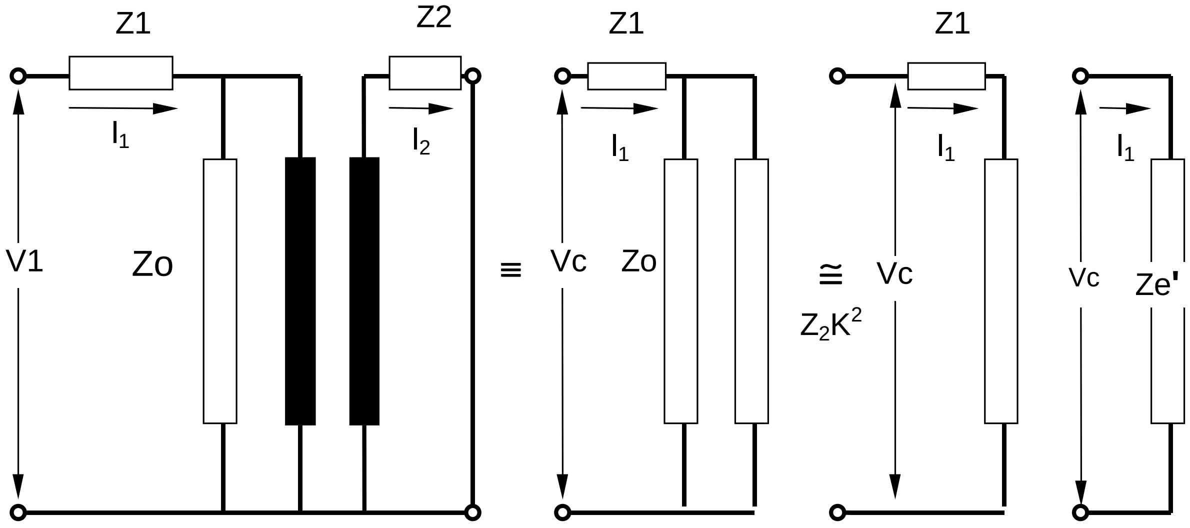


Fig.9 - Equivalent circuits of a single-phase transformer

As this secondary impedance series is about 500 times smaller than the first one, Zo can be disregarded and the equivalent primary impedance series Ze remains as total impedance.

The same conclusion can be drawn by energy considerations. In fact in the short circuit test, for the small impedance offered by the transformer, the application of a very low voltage is sufficient to allow the passage of nominal current.

Therefore the losses in the iron of the machine, depending on the machine square, for Vcc = 5% become 0.25 of the value at load, absolutely negligible.

The conclusion is that the absorbed power of the transformer in short circuit is the same of the losses on the copper.
The test indicates the following values:

- In = nominal current;
- f = nominal frequency;
- Vcc = short circuit voltage;
- Pcc = short circuit power

RESULTS ANALYSIS

As it has already been said, the losses in the copper are the same of the short circuit power:

$$Pcu \cong Pcc$$

In order to be able to calculate the equivalent parameters series, the factor of power must be calculated:

$$\cos\varphi\ cc = \frac{Pcc}{Vcc\ \ In}$$

Therefore:

- the equivalent impedance series $Ze = \frac{Vcc}{In}$
- the equivalent resistance series $Re = Ze \cos\varphi\ cc$
- the equivalent reactance series $Xe = Ze \operatorname{sen}\varphi\ cc$

or:

- the equivalent resistance series $Re = \frac{Pcc}{In2}$
- the equivalent reactance series $Xe = \sqrt{Ze2 - Re2}$

The parameters concern the supply side.

In order to bring them to the other side, you have to divide them by the square of the turns ratio.

$$Re'' = \frac{Re'}{K2} \qquad Ze'' = \frac{Xe'}{K2} \qquad Ze'' = \frac{Ze'}{K2}$$

SHORT-CIRCUIT CHARACTERISTIC

In order to study completely the machine, you have to obtain the behaviour characteristics changing the absorbed current assuring the role of variable parameter.

The characteristic curves are:

• voltage	**Vcc = f (I)**
• power	**Pcc = f (I)**
• factor of power	**cos φ cc = f (I)**

Voltage Vcc = f(I)

The supply voltage changes linearly when the current absorbed by the transformer in short-circuit changes; therefore the function is a straight line passing from the origin (Fig.10)

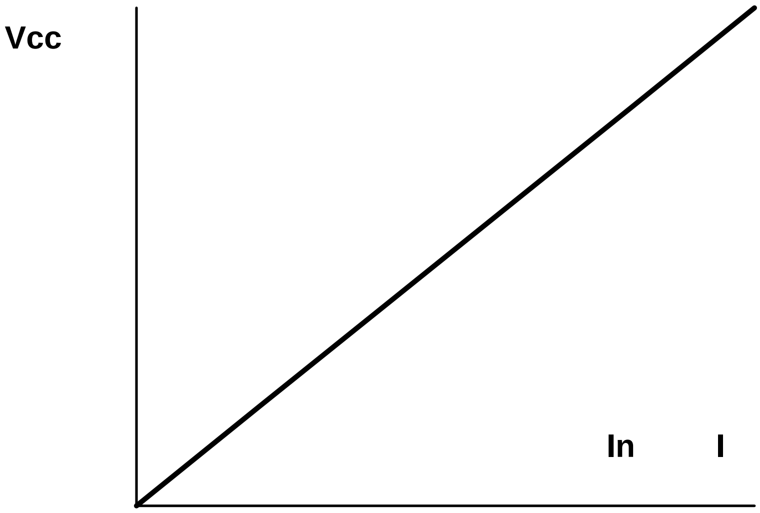


Fig.10 Characteristic of the short-circuit voltage of a single-phase transformer Vcc = f(I)

This happens because the two quantities are linked by the relation:

$$Vcc = Ze\,I$$

where Ze is the equivalent impedance series. It is constant because the ohmic component Re and the inductive component Ze are constant.

Here a possible temperature variation is not taken into consideration; it would change the measure because it produces a variation of the resistance value.
Pay attention that the windings don't overheat during the test.

Consequently the test of the high current value must begin.
The loss reactance is also constant because the induction values are not near to the saturation:

Power Pcc = f(I)

Changing the current the power absorbed by the transformer is a parabolic function (Fig.11)

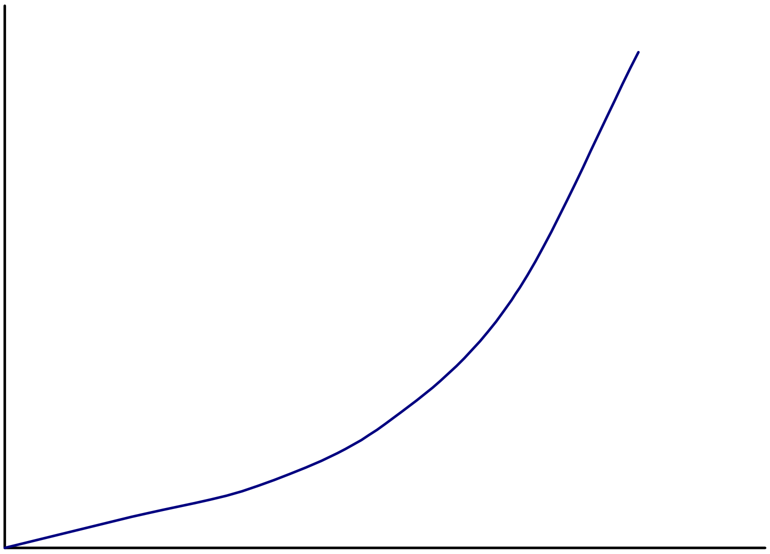


Fig.11 - Characteristic of the short-circuit power of a single-phase transformer.

This is caused by the fact that this power practically represents the only loss in the copper of the machine, being proportional to the current square

$$Pcu = Re\ I^2$$

Drawing the characteristic by the abscissa axis at the quadratic scale, the function becomes a straight line (Fig.12)

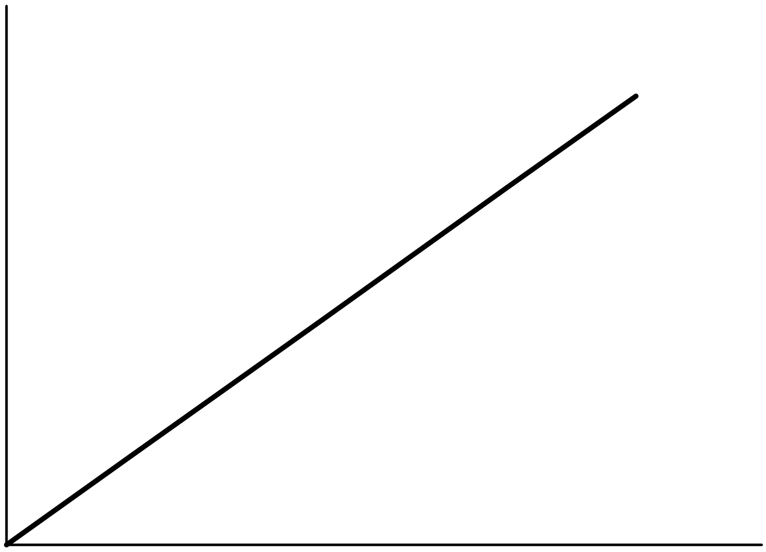


Fig.12 - Characteristic of the short-circuit power of a single phase transformer Pcc = f (I2)

Factor of power cos φ cc = f (I)

The factor of power of short-circuit is constant (Fig.13) because it depends on the parameters series of the machine, being constant

$$\cos\varphi \quad cc = \frac{Re}{Ze}$$

The constancy of the factor of power indicates that the measure is reliable and that during the test the windings are not very heated.

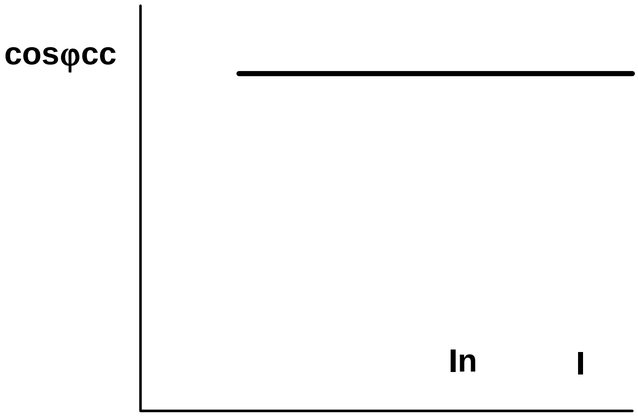


Fig.13 - Characteristic of the factor of power of short-circuit of a single-phase transformer cos φ cc = f (I)

ASSIGNMENT 4
SHORT-CIRCUIT TEST OF A THREE-PHASE TRANSFORMER

For the three phase transformers the test in short-circuit is carried out like for the single-phase transformers and following the already explained principles.

The terminals of a side must be blocked in short-circuit and the transformer on the other side must be supplied at the reduced voltage in order to make the nominal current flow in the windings.

For the measure of voltage in short-circuit, the connection of only one voltmeter between two threads is sufficient, as the supply is symmetric (Fig. 14

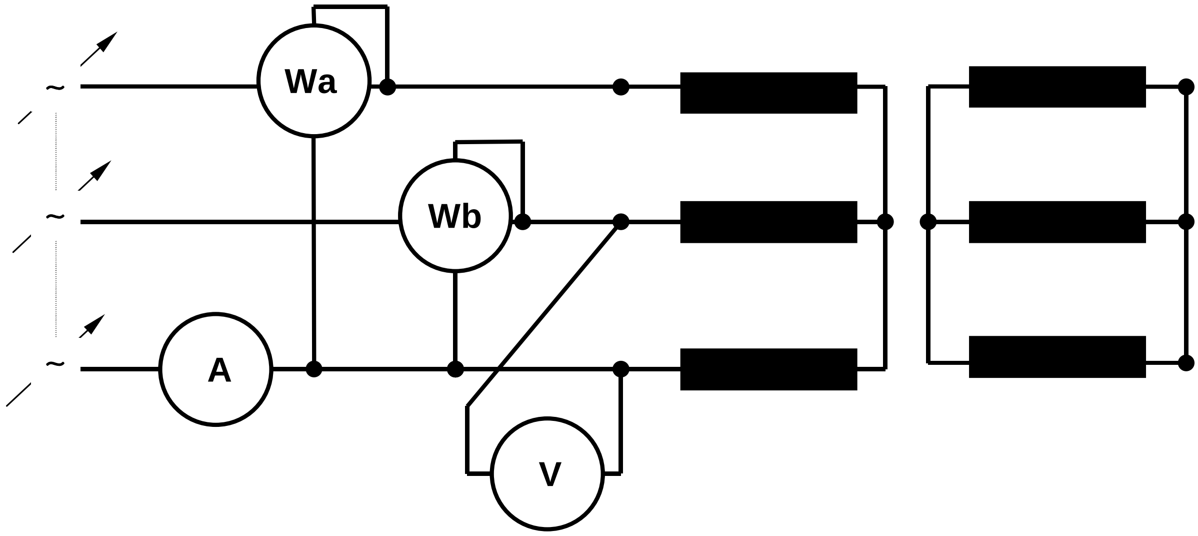


Fig.14 - Short-circuit test of a three-phase transformer.

For security reasons, you can also use three voltmeters, connected to mark the three line voltages, or only one commutable instrument on the three phases, this is usually not necessary.

The current measure consists in connecting an ammeter on one of the three threads.

This indication is sufficient as the three phase transformer in short-circuit is a balanced load created by the windings of each phase, clearly the same.

You could also connect three equal ammeters on the three threads and realise the middle one of the three indications.

This is generally not necessary.

The power absorbed by the transformer is indicated by two power meters, ARON connected; in other words

$$Pcc = A + B$$

8y the indications of the two power meters, the factor of power can be obtained by:

$$x = \frac{B}{A} = \cos \varphi \, cc$$

You obtain the value of the leak in the copper, that is the same of the absorbed power

$$Pcu \cong Pcc$$

The equivalent star-parameters can be calculated:

$$Ze = \frac{Vcc}{\sqrt{3} \quad x \quad 1}$$

$$Re' = \frac{Pcc}{3 \quad I\string^}$$

$$Xe = \sqrt{Ze2 - Re2}$$

where:

$$Re' = Ze \times \cos \varphi \, cc; \quad Xe = Ze' \; sen \, \varphi \, cc.$$

The parameters refer to one measure side. If you want them to refer to the other side, you have to divide them by the square of the turn ratio:

$$Re'' = Re'/KZ; \quad Xe" = Xe'/KZ; \quad Ze" = Ze'/K2$$

The transformer can have any connection, not necessarily a star connection; anyway the parameters established by the above explained formulae refer to a transformer (equivalent to the given transformer) having the star-connected phases.

Given the total equivalence of the method, the obtained results are correct.

We generally refer to the star-connection being more convenient, as the phases are directly interested by the line currents; these currents are those indicated by the read instruments.

ADDITIONAL LEAKS

By the proof in short circuit of a transformer, the additional leaks of the machine can be also established. After having calculated the windings resistance indirect current by a voltammetric method or an equivalent, the power leaked in the windings can be established by the following formula:

$$P_{ohm} = R_m I^2; \qquad \text{or,}$$

for three-phase and without considering the machine connection :

$$P_{ohm} = 1{,}5\ R_m I^2$$

You can observe that the ohmic leaks in windings aren't the same of the leaks in the copper given by the proof in short circuit of the machine.

The difference between the two leaks gives the value of the additional leaks:

$$\text{Add. leak} = P_{cc} - P_{ohm}.$$

They can't be established exactly individually and they include all the energetic dissipations that aren't direct part of the leaks of the principal magnetic and electric materials.

Their influence in the machine working is not very important and it is not taken into consideration for machines with a low power. For high powers these leaks can be more important; consequently they must be separated by the leaks in the copper.

They change inversely; they decrease when temperature increases.

ASSIGNMENT 5

ESTABLISHMENT OF CONVENTIONAL EFFICIENCY AND VOLTAGE VARIATION

The indirect proof on the transformer has the purpose of giving the necessary elements judge the machine quality and efficiency; these qualities are underlined by the values of efficiency and the voltage variation according to the distributed current.

We have spoken of voltage variations, not of the external characteristic, because by indirect test the voltage variation can be immediately established anyway if you don’t want to obtain the external characteristic of the machine 7 you have only to subtract the voltage variation from the no load voltage value:

$$V2 = V\,20 - \Delta V.$$

To comply with the CEI regulations, the two above mentioned characteristics

$$\eta = f(I);\ \Delta v = f(I)$$

must refer to the most unfavourable condition of working, consequently to the 75 C conventional temperature.

These two characteristics are also necessary for the factor of power 1 and 0.8

PARAMETERS EQUIVALENT T0 75' C

When the temperature changes the value of the ohmic resistance also changes according to the following formula:

$$Kt = \frac{309{,}5}{234{,}5 + t}$$

being t room temperature.
Now the two cases of transformers of low and high power are considered.

LOW POWER TRANSFORMERS

In this case the additional leaks are small and merged with those in the copper, established by the proof in short-circuit. By the proof in short-circuit, for the room temperature, the following parameters were calculated:

-equivalent resistance Re;
-equivalent reactance Xe.

For the temperature of T=75°C an increase in the resistance will take place in the ratio Kt:

$$Rt = Kt . Re;$$

the reactance remains the same:

$$Xt=Xe$$

Consequently the impedance increases to the value:

$$Zt = \sqrt{RT2 + Xe2}$$

The values of voltage and power of short-circuit change too.

-for the single phase:

$$VccT = ZTIn; \quad PccT = RT\ In^2 = Kt\ Pcc$$

-for the three-phase:

$$VccT = \sqrt{3}\ ZT\ In; \quad Pcct = 3RT\ In^2 = Kt\ Pcc.$$

HIGH POWER TRANSFORMERS

The separation of additional leaks is necessary before doing the 75° C deduction.
By the proofs in short-circuit and the direct measure of the ohmic resistances of the machine, the additional leaks could be calculated:

$$\text{Add.Lea.} = \text{Pcc} - \text{Pohm.}$$

The ohmic leaks are carried over at 75°C directly with the temperature coefficient:

$$\text{PohmT} = \text{KtPohm.}$$

On the contrary the additional leaks change inversely.

$$\text{Add.Lea.T} = \text{Add.Lea.} / \text{Kt}$$

If you add the ohmic leaks and the additional ones, you get the short-circuit leaks at 75° C

$$\text{PccT} = \text{PohmT} = \text{Add.Lea.T}$$

The conclusion is as follows:

For the single-phase:

- **the equivalent resistance $RT = P.cc\ T / In^2$**
- **the equivalent impedance $ZT = RT^2 + Xe^2$**
- **the power factor $\cos \varphi\ ccT = RT / ZT$**
- **the short-circuit voltage $VccT = ZT\ In$.**

For the three-phase:

- **the equivalent resistance $RT = .Pcc\ T / 3In^2$**
- **the equivalent impedance $ZT = RT^2 + Xe^2$**
- **the power factor $\cos \varphi\ ccT = RT / ZT$**
- **the short-circuit voltage $VccT = ZT\ In$**

CALCULATION OF EFFICIENCY

The conventional efficiency of a transformer must be calculated by the following formula:

$$\eta = \frac{\mathbf{Pr}}{\mathbf{Pr} + \boldsymbol{Pp}}$$

For a single-phase transformer the given power is obtained by:

$$\mathbf{Pr = Vn = I \; x \; cos}\ \varphi$$

and the leaked power must be calculated adding the leaks in the iron and those in the copper:

$$\mathbf{Pp = Pg + Pcu = Pf + RT \; x \; I^2}$$

Substituting, the result is:

$$\eta = \frac{Vn \quad \cos\varphi}{Vn \quad I\cos\varphi \; + Pf \; + \; RT \quad I\hat{}}$$

The formula is generally expressed according to the relative lead, in other words according to the relation between real current and nominal current

By " α " = I/In the result is I = x In and, substituting the efficiency is:

$$\eta = \frac{Vn \cdot In \cdot \cos\varphi}{Vn \cdot In \cdot \cos\varphi + Pf + \alpha \cdot RT \cdot I^2} = \frac{\alpha \cdot Sn \cdot \cos\varphi}{\alpha \cdot Sn \cdot \cos\varphi + Pf + \alpha^2 \cdot Pcu \cdot n}$$

where: Sn = Vn x In is the nominal power of the machine and

Pcu n = R x T x In2 are the leaks in the copper at 75 C obtained by the previous test and relative to the nominal current.

For a three-phase transformer the efficiency is:

$$\eta = \frac{\sqrt{3} \cdot Vn \cdot I \cdot \cos\varphi}{\sqrt{3} \cdot Vn \cdot I \cdot \cos\varphi + Pf + \sqrt{3} \cdot R \cdot T \cdot I^2} = \frac{\alpha \cdot Sn \cdot \cos\varphi}{\alpha \cdot Sn \cdot \cos\varphi + Pf + \alpha^2 \cdot Pcu \cdot n}$$

where Sn = $\sqrt{3} \cdot Vn \cdot In$ and $Pcun = 3 \cdot RT \cdot In^2$

Consequently, in order to calculate the efficiency you have to consider:

- the nominal power Sn
- the leaks in the iron Pg
- the leaks in the copper at full load Pcu n at 75° C

For Cos φ= 1 and cos φ = 0,8 to the value some fixed fractions must be assigned:

O 1/4 2/4 3/4 4/4 5/4
or:
0 0,25 0,5 0.75 1 1,25

By the obtained values of efficiency you can draw the diagram of the efficiency according to the distributed current, or the distributed power, or the load quarters (Fig 15)

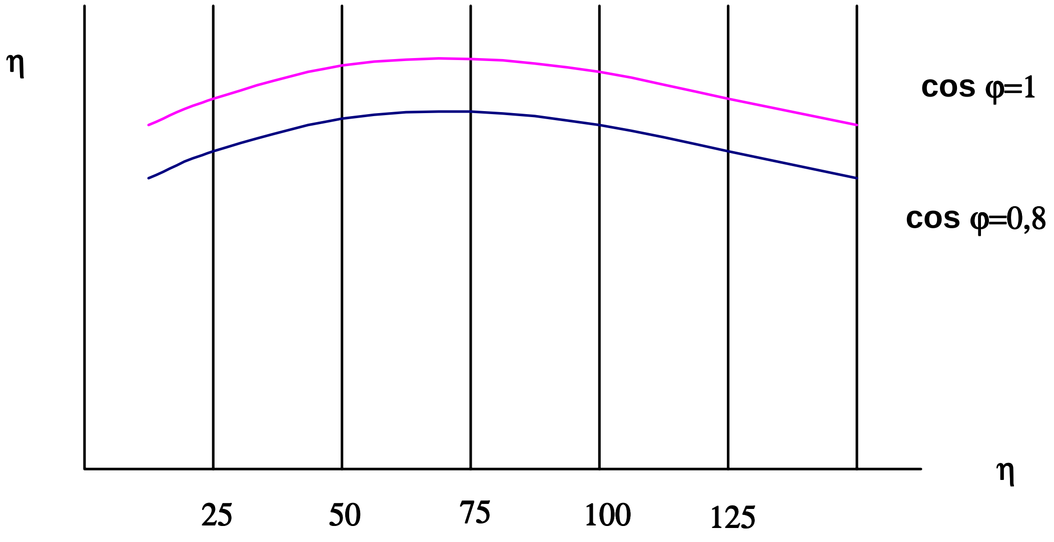


Fig.15 - Characteristic of the conventional efficiency of a transformer $\eta = f(\alpha)$.

CALCULATION OF THE VOLTAGE VARIATION

The formula giving the voltage variation in the limits of its principal term - here sufficient - can be:

- for the single-phase:

$$V = I\,(RT \cos\varphi + Xe \operatorname{sen}\varphi) = \alpha\, In\,(RT \cos\varphi + Xe \operatorname{sen}\varphi)$$

- for the three-phase:

$$V = \alpha \sqrt{3}\, In\,(RT \cos\varphi + Xe \operatorname{sen}\varphi)$$

where:

- RT is the resistance carried over at 75°C
- Xe is the equivalent reactance;
- In is the nominal value of current

Substituting the known values with $\cos\varphi = 1$ and $\cos\varphi = 0.8$, the result is the voltage variation at the load quarters (Fig.16).

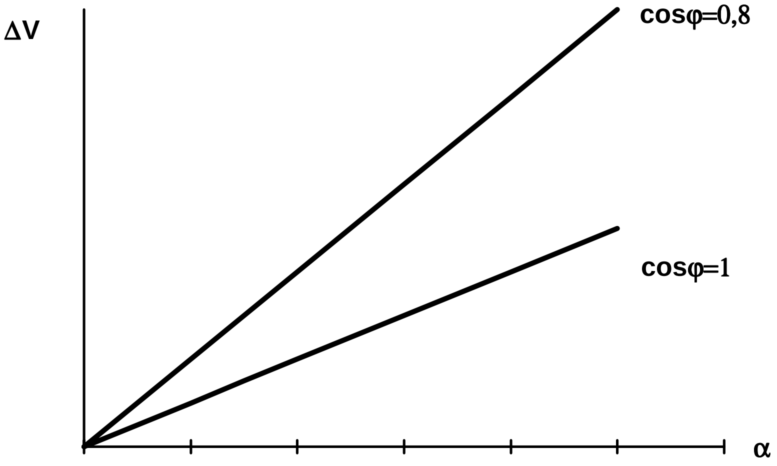


Fig.16 - Characteristic of the voltage variation of a transformer V = f (α)

The written formula of the voltage variation is linear function of the load; therefore the characteristic is linear.

The value of the voltage variation often refers to the nominal voltage as relative value in percentage; therefore you have to calculate at 4/4 of load:

$$\Delta V\,\% = 100\,\frac{\Delta V}{Vn}$$

ASSIGNMENT 6
DIRECT TEST OF A TRANSFORMER

The direct test of a transformer underlines the efficiency and the external characteristic of the machine applying a real load to the transformer.

The electric circuit of measure must be supplied by a suitable source at constant voltage and the same of the nominal one. The instrument connected in short circuit must be (Fig.17)

- on the primary: a frequency meter to measure the applied voltage a volt-meter to verify the applied voltage an ammeter to measure the absorbed current a power meter to measure the absorbed power.

For the three-phase transformer an ARON connection is necessary.

- on the secondary: a volt-meter to measure the distributed voltage an ammeter to measure the distributed current a watt-meter to measure the power brought to the load.

For the three-phase transformer an ARON connection is necessary.

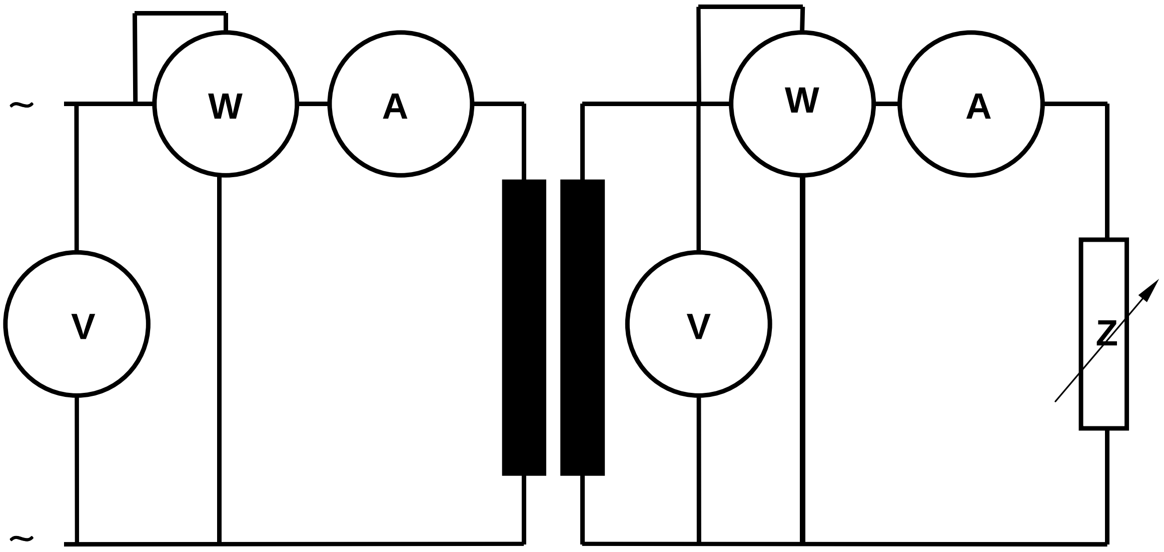


Fig.17 - Circuit for the direct test of a single-phase transformer.

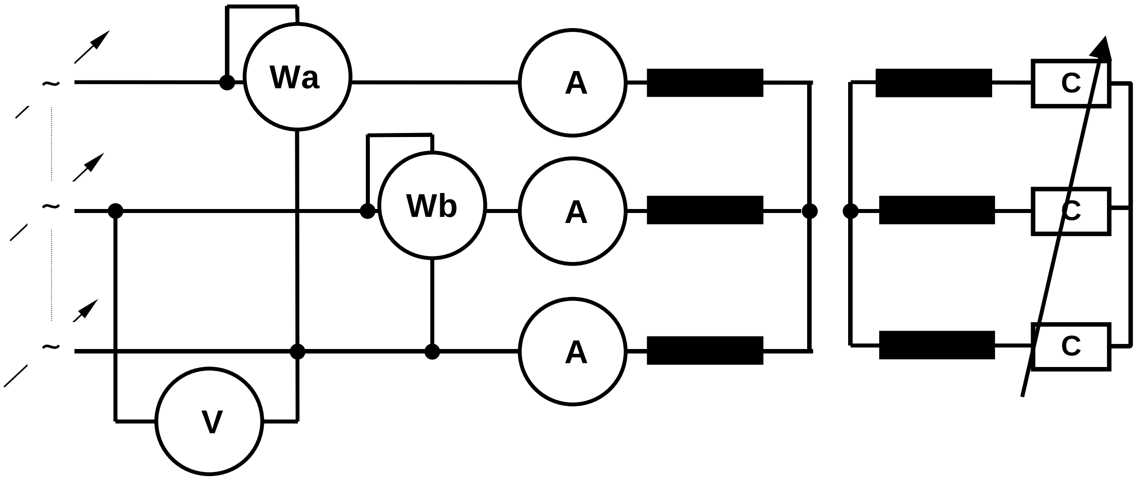


Fig.18 - Circuit for the direct test of a three-phase transformer.

All the instruments must be suitable to the alternating current and have a load corresponding to the nominal values of the machine.
The load connected to the transformer must have the possibility of regulation of values and phases.
This makes the direct test difficult, apart from the case of ohmic load, explained hereunder.
The test must be carried out with the machine under thermal condition, in order to avoid temperature variations during its realisation.

The primary voltage must be kept constant; the load must be changed so that the secondary ammeter assumes discrete current values corresponding approximately to the no load quarters till a overheating of about 20 - 25%.

For every current value it has to be observed:

- the distributed power Pr
- the voltage at the secondary V2
- the absorbed power Pa
- the current absorbed to the primary I1

By the above written values it has to be observed:
- the efficiency η = Pr/Pa
- the voltage variation ΔV = V20 - V2 with V20 no-load voltage

Consequently the characteristic demanded by the test:
- efficiency η = f (I2)
- external characteristic V2 = f (I2)

The two curves are drawn according to the distributed current.

In the direct test the assigned independent variable is the current; the power is also the function of this parameter.

The two quantities, power and distributed current can be considered proportional when the voltage drop causes a reduction of the voltage increase.

Anyway the difference is not important, because it reaches - at the worst - values of 5-6%.

The efficiency curve assumes a nearly flat course that is not very variable for great variation of load current, with maximum trend about 3/4 of the load (Fig.19).

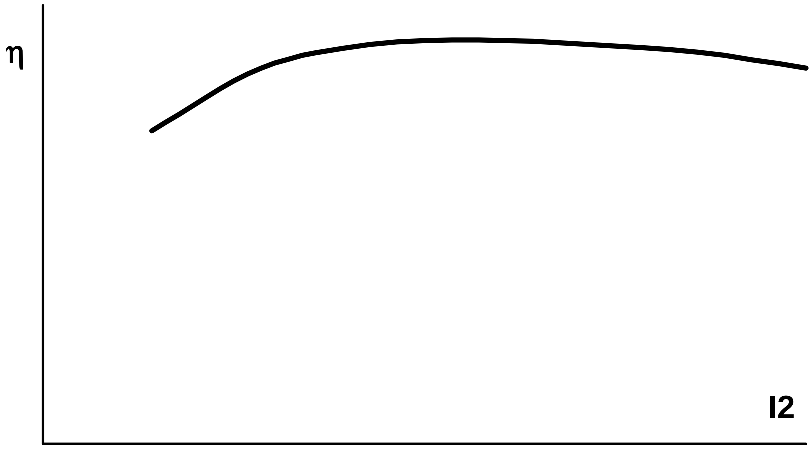


Fig.19
Diagram of the efficiency according to the load current.

The external characteristic, at ohmic load, is nearly linear. The voltage variation is measured directly by the complementary segment between V20 and V2 (Fig.20).

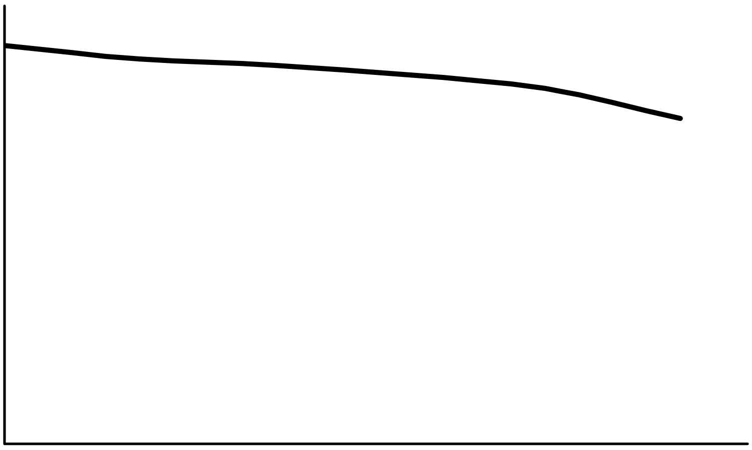


Fig.20
External characteristic of a ohmic load transformer.

At a 4/4 load, the voltage variation in percentage can be calculated; it gives an indication of the machine good quality:

$$\Delta V\% = 100\frac{\Delta V}{Vn}$$

In the test of the transformer the courses of the absorbed primary current and factor of power are not interesting; here they are not considered