Info Letter No. 2

Measurement Transformers in three-phase networks (Part 2)

Performance measurement in a balanced three-wire three-phase network with a two-pole insulated voltage transformer

In a symmetrically loaded three-wire three-phase network, a two-pole insulated voltage transformer can only be used for measuring performance if in the measuring equipment, the phase shift of the delta voltage versus the star voltage corresponding to the current is removed by a phase-rotating member. The required phase shift depends on the selected voltages.

For $\varphi = 0$:
Connection U_{12} *and* $I_1 \Rightarrow U_{12}$ *leads* I_1 *by 30°;*
Connection U_{13} *and* $I_1 \Rightarrow U_{13}$ *leads* I_1 *by 30°;*
Connection U_{32} *and* $I_1 \Rightarrow U_{32}$ *leads* I_1 *by 90°;*

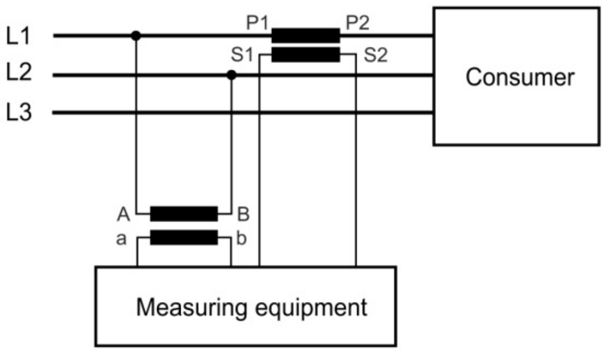

Figure 2.1 *Performance measurement with a two-pole insulated single-phase voltage transformer*

By using a single-pole insulated voltage transformer that is connected to the conductor and earth the star voltage can be measured. With the use of a two-pole voltage transformer, the difficulties associated with certain operating states are avoided.

Cyclic commutation with current connections in other external conductors

Normally the measuring equipment are provided for the connection of $\boldsymbol{I_1}$. If, however, the measuring equipment is supplied with the current $\boldsymbol{I_2}$ or $\boldsymbol{I_3}$ instead of the current $\boldsymbol{I_1}$, the voltage must also be changed cyclically.

Measurement of the currents in all three external conductors with two current transformers

From the two currents of any two external conductors, in a three-wire three-phase network

$$i_1 + i_2 + i_3 = 0$$

the current in the third external conductor can be determined exactly. The required circuit is shown in Figure 2.2.

To avoid an open secondary circuit of a current transformer, the wiring must be carried out with special care!

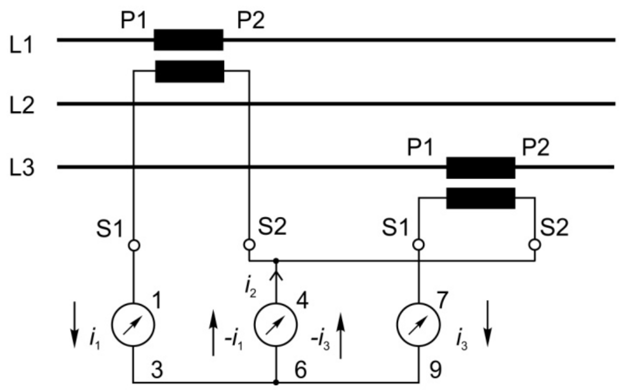

Figure 2.2 *Measurement of the current in the third external conductor*

Influence from an upstream measurement transformer

When connecting the measurement equipment instrument to the network via measurement transformers, their amplitude and angular errors must be noted.

Amplitude error of the measurement transformer

$$f_x = \frac{(X_2 \cdot K_n) - X_1}{X_1}$$

X_1 = Value at the primary winding,
X_2 = Value at the secondary winding

The amplitude error is calculated as positive, if the secondary value exceeds the setpoint.

Angular error of the measurement transformer

The phase shift of the secondary value against the primary value is referred to as the angular error of the measurement transformer. The angular error is given in *angular minutes*. The sign is positive if the secondary value leads with respect to the primary.

Effect on the measurement of the effective power with sinusoidal AC values

The percentage error F [%] caused by the errors of the current transformers and the voltage transformers during the measurement of $P = U \cdot I \cdot \cos\varphi$, is given by:

$$F\,[\%] = \left[f_u + f_i + \left(\frac{\cos\varphi - \cos(\varphi + \delta_i - \delta_u)}{\cos\varphi} \right) \right] \cdot 100\%$$

f_u = Amplitude error of the voltage transformer

fi = Amplitude error of the current transformer

δ_u = Angular error of the voltage transformer

δ_i = Angular error of the current transformer

The amplitude errors f_u and f_i and the angular errors δ_i and δ_u, with their signs, influence the result.

In table 2.2, the measurement errors caused by these differences in the effective power measurement for different values of the cosφ are given as examples for various differences of angular error

Table 2.2

δi - δu	cos φ = 0.9	cos φ = 0.5	cos φ = 0.1
0 ´	0	0	0
5 ´	0.07 %	0.25 %	1.45 %
10 ´	0.14 %	0.50 %	2.89 %
20 ´	0.28 %	1.01 %	5.79 %

From the values in the table it can be seen that a difference in the angular error has a non-linear effect on the value of cosφ and thus on the measurement value.
This effect clearly increases as the value of cosφ decreases.

Frequency error of the measurement transformer

Current transformers and voltage transformers with a nominal frequency of 50 Hz can be used without major limitations of accuracy and load range in a greater frequency range.

For current transformers this range is roughly between 15 Hz and 500 Hz. At values below 50 Hz, the available nominal power decreases in proportion to the frequency of the current. Likewise, the transmission error is greater. There are no restrictions on the function.

Voltage transformers with a nominal frequency of 50 Hz to 1000 Hz can be used without major restrictions on the accuracy and load in the range of 50 to 1000 Hz . At frequencies below 50 Hz, this is possible only with greatly reduced values of input voltage and lower rated power. The reason for this is the higher power consumption of frequency-dependent input resistance and exceeding the saturation limit of the iron core of the transformer. The transmission error is greater.

Effect of incorrect connection of the network voltage to the measurement equipment

The connection of the voltage and current paths to the measurement equipment and the required earthing on the secondary sides of upstream measurement transformers are specified in DIN 43807 for the respective measurement values, types of network and load types.

An incorrect connection of the voltage and/or the current paths to the measurement equipment can cause significant measurement errors during the performance measurement in three-phase networks. Practical experience shows that the probability of a false connection is relatively high. These effects on the measurement result are shown in the following example.

Example

At the voltage inputs of a measurement equipment for measuring the effective power in the **four-wire three-phase network**, the three-phase voltages can be connected in 6 different ways. All connections deviating from DIN 43807 cause incorrect measurement results.

The correlations should be made clear by displaying the measured single wire performance in the following example.

Given values

U1N	230 V	I1	1.6 A	cosφ 1	0.883
U2N	232 V	I2	2.8 A	cosφ 2	0.755
U3N	226 V	I3	2.4 A	cosφ 3	0.819

The displayed measurement values of the active power are listed in Table 2.4.

Table 2.4

Connection, continued	P1 [W]	P2 [W]	P3 [W]	Total	Ratio Pn : Pa
L1, L2, L3	324.9	490.3	444.3	1259.5	1.00
L2, L1, L3	-314.8	122.9	444.3	252.4	0.20
L3, L2, L1	-12.6	490.3	-500.3	-22.6	-0.02
L1, L3, L2	324.9	-598.3	48.5	-224.9	-0.18
L2, L3, L1	-314.8	-598.3	-500.3	-1413.4	-1.12
L3, L1, L2	-12.6	122.9	48.5	158.8	0.13

Checking the voltage connections to the measurement equipment

The correlations displayed can be used to check the connections. With measurement equipment that in addition to the total active power of the network also shows the effective power of all three phases simultaneously, incorrect connection of the measurement equipment can be recognized immediately due to the reversed sign of a wire power. All wire powers must have the same sign as the network power. If the measured value of one or two wire powers has an opposite sign, the connection is wrong and thus the value for the entire network power. With negative signs for *all* wire performances, there are two possibilities: either *only* the sign is wrong or the magnitude *and* sign.

Effect of incorrect connection of the network voltage to the measurement equipment

a) In the case of exchanging the wires

When the voltages are connected properly and with wrong connections of network currents with respect to the wires, the display of the effective power of the three-phase network has the same value as with incorrect connections of the network voltage.

(b) In the case of reversal of the polarity of S1(k) and S2(l)

Such an exchange can be easily be determined when the voltages are connected properly and reversal of S1(k) and S2(l) in the current path of one or two wires.

Current paths connected in the opposite direction change the angle φ to (φ + 180°), so that the sign of the associated wire performance is also reversed. By short-circuiting a current path (bridge between S1(k) and S2(l) at the connection terminals of the measurement equipment), the correct connection of the current path can be checked quickly and unambiguously.

With measurement equipment with a linear characteristic the displayed value of the network power decreases due to short-circuiting the current path when they are connected properly, with a wrong connection (inversion of S1(k) and S2(l)) the value increases. For other types of characteristics, their transmission characteristics must also be included!

Special feature of the Aron circuit

This behaviour occurs in the measurement of effective power in the three-wire three-phase network with measurement equipment that has two measurement stations (Aron circuit), is connected in accordance with DIN 43807 and φ_1 is less than + 60° and φ_3 is greater than - 60°.

If, however, at angle φ_1 or φ_3 the value of 60° is exceeded, the reverse applies. The sign of cos (φ_1 + 30°) is negative with φ_1 > 60° and also with φ_3 <- 60°. At φ = 60° the measured effective power of a measurement equipment is equal to zero (cos 90° = 0), so there is no change due to changing S1(k) and S2(l).

Extract from: H. Karger "Messungen in Netzen der elektrischen Energietechnik"

The series will be continued.
We will gladly supply missing Info Letters at any time!