Installation for Testing, Adjustment and Control of Three-Phase Low Voltage Automatic AC Circuit Breakers, with Dynamic Switching

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Abstract—**The paper refers to a new and original installation designed for testing, setting and controlling of single phase and three-phase automatic AC low-voltage circuit breakers, with dynamic switching, which are used, currently, in electrical power distribution, in industry field or research institutes. This installation can be extended to automatic AC low-voltage circuit breakers with static switching.**

This installation has the following structure:

- **a three-phase current source for testing the current components of circuit breakers to overcurrent;**
- **a single-phase voltage source to conduct tests on voltage components;**
- **fixed links, elastic and flexible connections;**
- **instrumentation for measuring and recording quantities of electricity, heat and time;**
- **toolbox for assembling-disassembling;**
- **other accessories as coaxial shunts, non-inductive voltage dividers.**

The paper presents some theoretical considerations which are necessary to achieve an efficient installation with properly operating qualities. There are also presented, some experimental data obtained with the three-phase current source.

Index Terms— **three-phase current source, single phase voltage source, coaxial shunts, voltage dividers, overcurrent.**

I. INTRODUCTION

The installation has a three-phase current source for testing, setting and controlling of the current components of single-phase or three-phase circuit breakers for overload and short circuit protection (overcurrent) in all cases: overload or single-phase, two-phase or three-phase short circuit.

Voltage source allows the study of the voltage components behavior to voltage variations for all rated voltages that are built.

The current source of the installation is transportable and the voltage source is portable (hand-held).

There are presented design requirements to obtain two performance sources for currents and voltages fields required.

The installation allows gross and fine setting of voltage and current. It also can operate on computer aided.

II. ELECTRIC CIRCUITS OF CURRENT AND VOLTAGE ADJUSTABLE SOURCES

II.1. The current source

Fig. 1 presents the principle diagram of the current source. This includes:

- the adjustable voltage source represented by a three-phase adjustable transformer, type “TUR”, TR, mains through a three-phase contactor, K, remotely controlled by a double-button control, I-O, the short-circuit protection being provided at the switchboard.

The adjustable transformer has a star connected primary winding, P, and a delta connected secondary winding, S, to avoid the third order current harmonic to reach the current source, TC.

In order to set the voltage, it was used a group of three rolls, r_1, r_2, r_3, that are moved in both directions, by a single-phase actuator to increase or decrease the voltage in 0-500V domain.

The technical data of the transformer are:

- S_n= 80kVA;
- f_n= 50Hz;
- primary unit – U_p= 380V, I_p= 121.5A;
- secondary unit – U_s= 0…525V, I_s= 88A.

- current source presented as a voltage-current power transformer with a special design that allows to obtain six levels of current, covering the current domain of three-phase low voltage automatic circuit breakers Schneider and Moeller type.
- automatic circuit breaker to test, IA, can be supplied as follows:
  - each current path from one phase of the current source secondary winding (a-x, b-y, c-z);
  - star connection of current source secondary winding supplies star connection of the circuit breaker;
  - delta connection of current source secondary winding supplies star or delta current paths connections of the circuit breaker.

The overcurrent tests require either to balance the three-phase currents or to create a three-phased and asymmetric currents system. To this end, independent setting components of current, on each phase, are necessary. These may be:

- adjustable controlled inductances;
- inductances with secondary current which is adjustable from 0 to a short circuit value;
- current-voltage transformers.

Practice shows that the most convenient solution is the last. This involves using, on each phase, of a single-phase voltage-current transformer, of small power (apparent power is 3-5% of phase apparent power). The rated voltage of the transformer is equal to the rated voltage of the phase on which it is mounted. Secondary winding is sized to the rated current of the primary circuit of the current source, the secondary voltage being greater than the voltage on one turn of the primary winding.

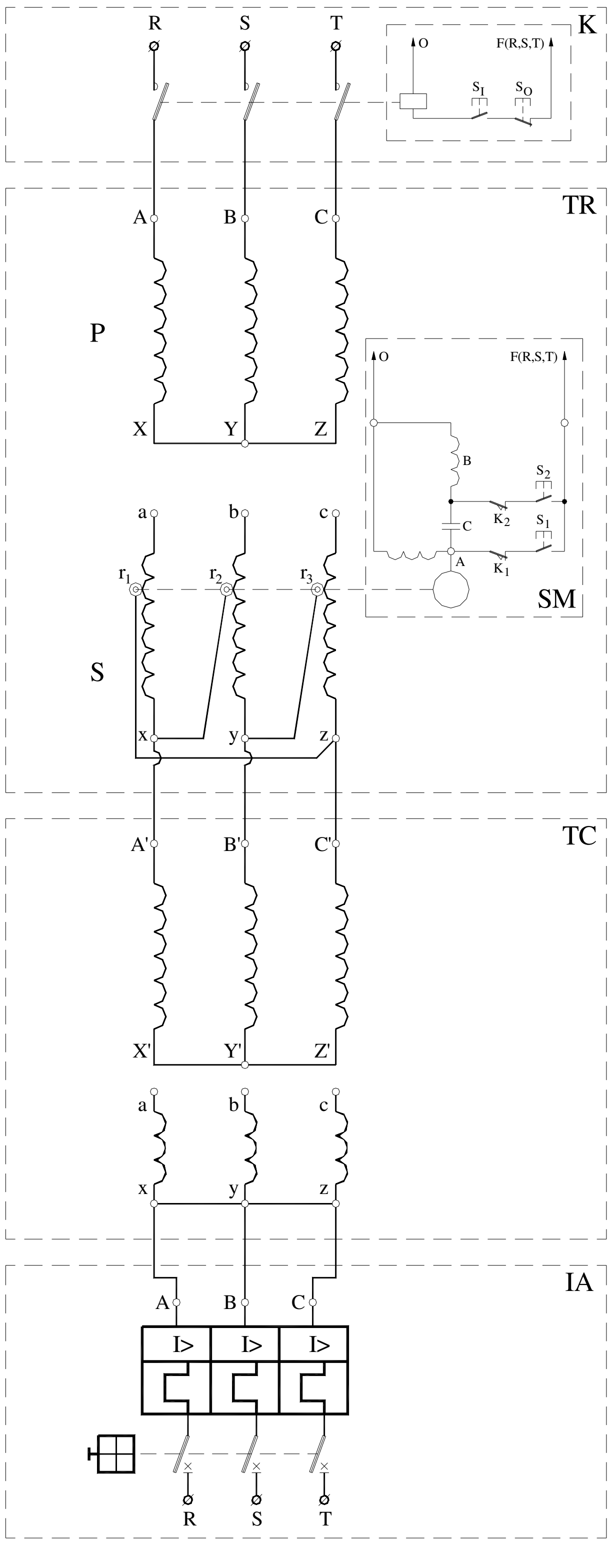

Fig. 1 The current source

This voltage may be added or deducted from the primary voltage, the supply being made with adjustable voltage between 0 ... U_{2n}, leading to a controlled increase or decrease of the phase current.

This allows obtaining a symmetric or asymmetric system of currents.

II.2. The voltage source

The voltage source was intended to have the wiring diagram shown in Fig. 2, in single-phase construction.

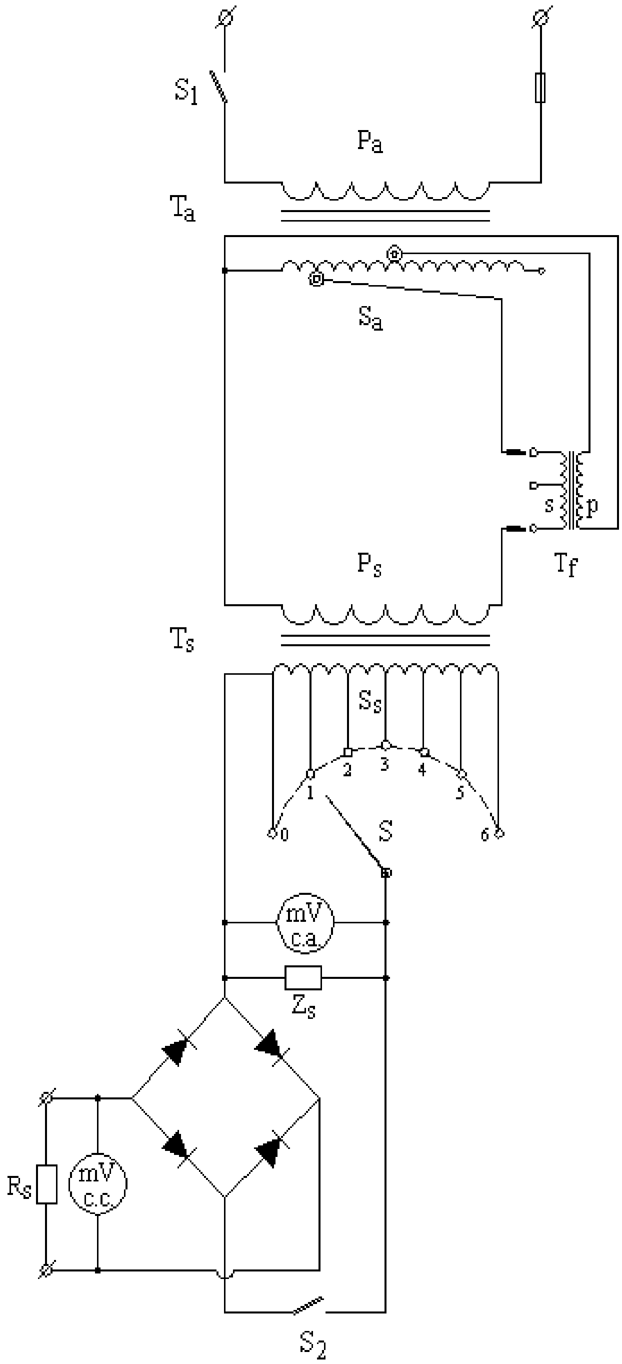

Fig. 2 The voltage source

The voltage source has a power transformer, T_a, with the primary unit, P_a, supplied with adjustable voltage between 0 ... $1.2U_n$ (U_n – phase voltage which is supplied). The transformer has an adjustable secondary unit, S_a, providing the variable output voltage U_2, which is transmitted to an additional transformer, T_s, which has the same power with T_a. Its primary P_s, has the same rated voltage of T_a, U_{2n}. The secondary is provided with DC and AC tappings, according to Table I. Alternative voltages are using the switch S_1, for all the levels mentioned. The adjustable voltage controlled with a voltmeter, mV, can be applied to voltage components (DT_m, DD, EA, Sm).

The DC tappings send the voltages, by the switch S_2, to a rectifier bridge, whose output voltages are applied to DC components (DT_m, DD, EA, Sm). Fine setting of voltage is obtained with autotransformer T_f, whose secondary s, it provides a voltage, U_{2f} , that can be added to U_2 voltage, but with fine variations obtained by the adjustable voltage, U_{1f}, applied to its primary p.

TABLE I. AVAILABLE OUTPUT VOLTAGES

U [V]	12	24	30	48	60
$U_{c.c.}$ [V]	x	x	x	x	x
$U_{c.a.}$ [V]	x	x		x	x
U [V]	100	110	125	127	130
$U_{c.c.}$ [V]	x	x	x		x
$U_{c.a.}$ [V]	x	x		x	x
U [V]	200	208	220	230	240
$U_{c.c.}$ [V]	x	x	x		
$U_{c.a.}$ [V]	x	x		x	x
U [V]	250	277	380	400	415
$U_{c.c.}$ [V]	x		x		
$U_{c.a.}$ [V]	x	x	x	x	x
U [V]	440	480	525	550	600
$U_{c.c.}$ [V]	x				
$U_{c.a.}$ [V]	x	x	x	x	x

III. THEORETICAL CONSIDERATIONS

Ferromagnetic parts of magnetic circuits of the current and voltage source components (transformer with adjustable secondary unit, adjustable autotransformer, current and voltage source transformer) must meet the following requirements:

- ferromagnetic materials should have an hysteresis cycle as narrow and a linear region of B(H) characteristic as extended, as if instrument transformers, in order to maintain the current waveform or test voltage closer to sinusoidal form;
- losses in iron as low in the operating field;
- construction with minimized number of parasitic air-gaps;
- apparent power of the installation appropriate and satisfactory for the series of automatic circuit breakers that will be tested.

Regarding the windings of the current source, is required:

- sizing the windings to equivalent current of intermittent duty adopted, rigorously within the range of insulation class with the highest temperature;
- the secondary must have a suitable number of windings to obtain the current levels that are necessary;
- the weight of copper in secondary close to that of primary;
- short-circuit voltage minimized.

The short-circuit percentage voltage of current source, for a transformer with two cylindrical windings, has two components:

$$u_k = \sqrt{u_k^2 + u_r^2}\ , [\%] \qquad (1)$$

where:

u_a is the active component, defined by:

$$u_a = \frac{U_a}{U_n}\cdot 100 = \frac{r_n \cdot I_n}{U_n}\cdot 100\, , [\%] \qquad (2)$$

that for a polyphase transformer, with m number of phases, becomes:

$$u_a = \frac{r_k \cdot I_n^2 \cdot m}{U_n \cdot I_n \cdot m}\cdot 100 = \frac{P_k}{S\cdot 10^3}\cdot 100\, , [\%] \qquad (3)$$

where:

P_k – short-circuit losses of the transformer, in [W];
S – apparent power rating, in [kVA].

Since the P_k and S parameters of three-phase transformers are standardized, this component already has an optimum value determined, so that reduction is not possible. Also, the active component is only a small percentage of short-circuit voltage (less than 2%).

Similarly, the reactive percentage component, u_r, of short-circuit voltage represents the ratio between the reactance voltage drop, $x_k I_n$, in response to rated current, that is:

$$u_k = \frac{x_k \cdot I_n}{U_n}\cdot 100\, , [\%] \qquad (4)$$

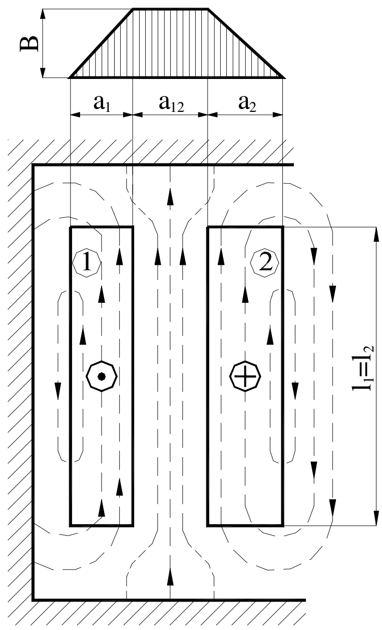

Fig. 3 Theoretical aspects at transformer windings

According to the general theory of the transformer, in case of two concentric cylindrical windings, with equal height columns, Fig. 3, the armature-leakage reactance is:

$$x_k = \frac{7.92 \cdot f \cdot N^2 \cdot \pi \cdot d_{12}}{l} \cdot a_r \cdot k_r \cdot 10^{-8},\ [\Omega] \qquad (5)$$

As a result, the reactive component becomes:

$$u_r = \frac{7.92 \cdot f \cdot N \cdot I \cdot \pi \cdot d_{12} \cdot a_r \cdot k_r}{U_{sp} \cdot l} \cdot 10^{-6},\ [\%] \qquad (6)$$

where U_{sp} – the voltage of one turn winding.

If it considered $\frac{\pi \cdot d_{12}}{l} = \beta$ and $N = \frac{U_n}{U_{sp}}$, then:

$$u_r = \frac{7.92 \cdot f \cdot S' \beta \cdot a_r \cdot k_r}{U_{sp}^2} \cdot 10^{-3},\ [\%] \qquad (7)$$

In our case, size a_r would be, Fig. 3:

$$a_r = a_{12} + \frac{a_1 + a_2}{3},\ [\mathrm{cm}] \qquad (8)$$

If it notes $\sigma = \frac{a_{12} + a_1 + a_2}{\pi \cdot l}$, the second factor, k_r, is calculated as it follows:

$$k_r = 1 - \sigma \cdot (1 - e^{-1/\sigma}) \qquad (9)$$

which has values in the range of 0.93 .... 0.98.

According to data presented, can be identified opportunities to minimize the percentage of short-circuit voltage by minimizing the reactive component, which may be obtained by acting on influence factors.

IV. EXPERIMENTAL DATA

The three-phase current transformer has the values for supply voltage $U_{A'B'}$, $U_{B'C'}$, $U_{A'C'}$, according to data from Table II, with appropriate representation in Fig. 4-a,b,c.

The results show that the current source has an approximately linear dependence between primary voltage and secondary current.

TABLE II. SUPPLY VOLTAGES AND CURRENTS

U_{AB} [V]	U_{BC} [V]	U_{AC} [V]	I_A [A]	I_B [A]	I_C [A]
4,9	0,8	4,6	0	0	0
14,5	9	12,6	200	240	180
18,4	14,4	17,1	372	400	256
25,7	22,4	24,9	520	600	384
31,6	28	30,4	640	772	464
39,8	35,9	38,4	800	992	592
47,8	44,4	46,5	952	1200	716
55,6	51,5	54,6	1100	1400	852
62,8	58,3	60,6	1232	1600	940
71,8	68,4	70,6	1400	1820	1080
79,9	76,9	79	1540	2000	1200
92,6	90,2	92	1780	2440	1460
105,1	101,5	103,5	2020	2800	1652

It is noted that it obtains an asymmetrical three-phase currents system due to different values of phases impedances. Therefore, to obtain a balanced current system, it is necessary a fine-setting of currents to allow their equalization.

If the primary voltage would achieve maximum value U = 500V, the secondary current could reach a value of approximately 10.000A per phase, which corresponds to the intended testing, required of low-voltage automatic circuit breakers, namely by their current components.

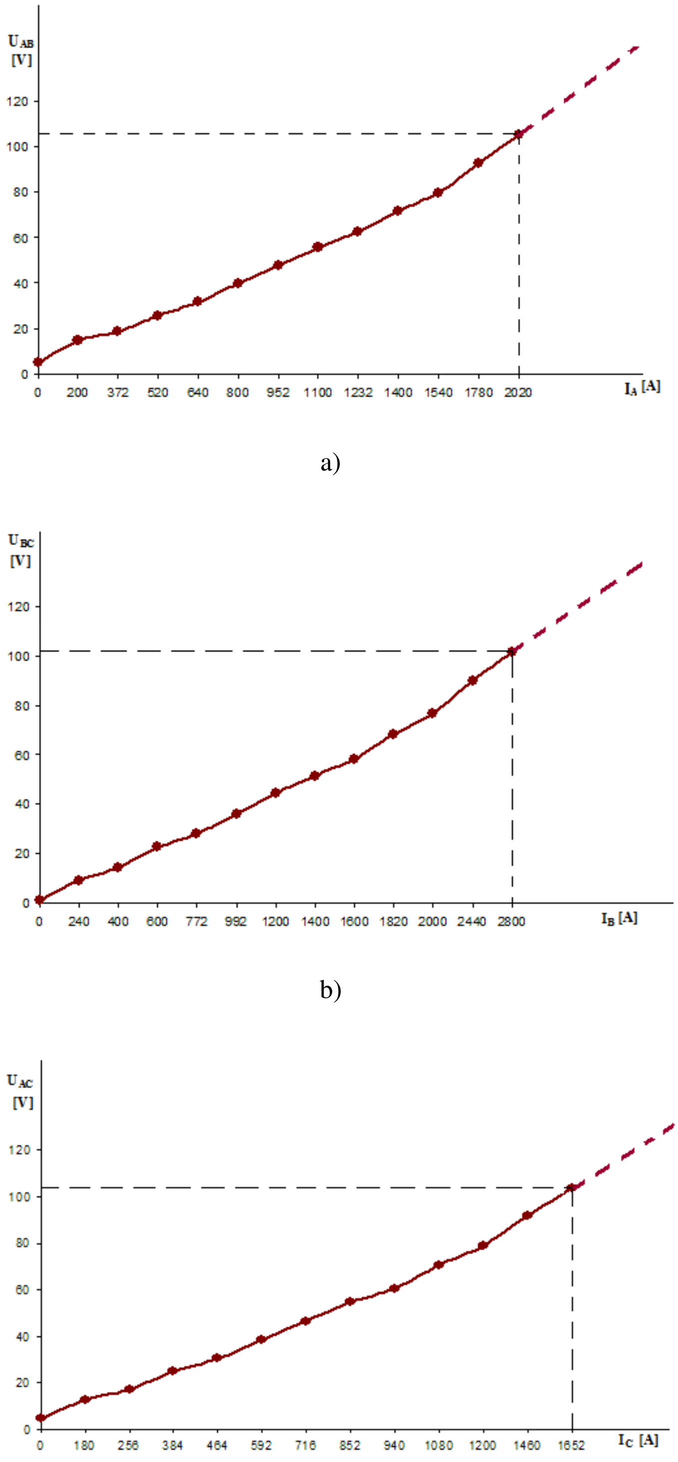

Fig. 4 Supply voltages vs. secondary current

In the oscillogram shown in Fig. 5 it can be seen the approximately sinusoidal shape of secondary currents of the current source.

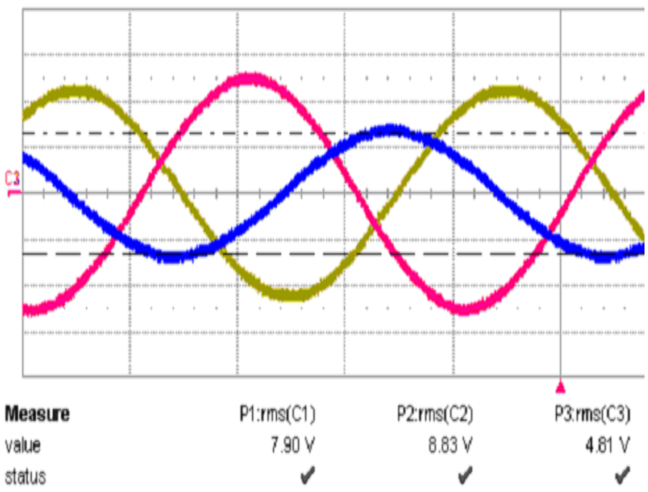

Fig. 5 Secondary current waveforms

V. CONCLUSION

From those presented the following conclusions can be deducted:

1. It highlights the opportunity to design an installation for testing, setting and control of three-phase low-voltage automatic AC circuit breakers, with dynamic switching, capable of performing the functions of current and voltage sources.
2. The behavior tests of the components for overcurrent protection (thermal and electromagnetic releases) may use a three-phase current source, specialized in low-voltage automatic circuit breakers, which allows correct choice of automatic circuit breakers for a given consumer and shaping of protection characteristics. Also, by using the current source, the installation can provide balanced currents on the three-phases or an asymmetrical current system for testing.
3. The installation also has a single-phase voltage source, for the rated values of voltage components (electromagnets to close/open the main circuits, the under-voltage release), which allows the study of their behavior to voltage variation between the prescribed limits for both AC and DC. The voltage source presents the possibility of a fine-setting of the test voltage.
4. It provides a convenient solution by designing the adjustable transformer and current source with the same magnetic circuit.
5. Tests for breaking capacity can only be modeled using the adjustable transformer in association with RLC components to ensure the load impedance at power factor imposed in the case.
6. The installation is equipped with original accessories for measuring and recording quantities in these tests.
7. The installation can operate computer aided.
8. This installation allows carrying out tests according to EU standards while having the possibility to model the measurement of breaking capacity, so it can be a means of preparing students in electrical field or advanced learners in specialized training programs and also, of training the operating personnel from maintenance field.
9. The installation has the necessary facilities for use in scientific research related to construction and operation of electrical equipments and apparatus.
10. The installation can be also used for technical support services as part of business enterprises, at their request, due to its modular construction and mounting, measuring and recording electrical quantities accessories that are available.

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