CONTRIBUTIONS TO THE DEVELOPMENT OF DEVICES TO INCREASE SAFETY IN OPERATION OF THE ON-LOAD –TAP-CHANGERS OF THE POWER TRANSFORMERS

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În lucrare se analizează influența polarității sau a succesiunii surselor de alimentare asupra stabilității servosistemelor. În vederea modelării matematice a polarității sau a succesiunii trifazate se adoptă noțiunea de "variabilă p" definită prin intermediul algebrei elementelor trivalente. Se studiază mai multe metode pentru contracararea influenței „variabilei p". Se obține modelul matematic al convertoarelor de valență şi se prezintă un stand experimental pentru studiul mai multor variante originale de discriminatoare de "variabilă p". Prin utilizarea acestor tipuri de relee se obține creşterea siguranței în exploatare a comutatoarelor de reglaj sub sarcină de la transformatoarele electrice de putere.

This paper examines the influence of polarity or sequence on the stability of supply sources servo-systems. In the mathematical modeling of polarity or three phase sequence is adopted the concept of "variable p" defined by the algebra of trivalent elements. Various methods to counter the influence of "variable p"are studied. Converters to obtain the mathematical model of valence and presents an experimental stand for studying several variants of the original discriminatory "variable p". By using these types of relays we achieve improvements of the safety in operation of the on-load-tap-changers of the electrical power transformers.

Keywords: on-load-tap-changer, safety in operation, the sequence phase, action device

1. Introduction

To determine the conditions to increase safety in operation of the on-load-tap-changers is necessary to study the factors and elements that can give indications about the technical situation at a time. These factors are mainly mechanical and electrical in nature and should be studied in the context of linking providers with recommendations proposed in technical books, for maintenance during operation. For example, recent studies at the University "Politehnica" of Bucharest [1] are based on vibration measurements, using an accelerometer and LabView program, to determine the level of wear of the on-load-tap-changer

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assembly. The on-load-tap-changer equips 96% of over 10 MVA transformers. Measurements for determining the level of wear or defects resulting on-load-tap-changer are as an opportunity because they are one of the major subassemblies of the transformers and auto-power transformers, of the substations and electrical networks, and statistical analysis of operational behavior indicates that the highest percentage of failure or damage of the transformers and auto-transformers, according to research from ICMET Craiova [2]. Power supply of the action devices of the on-load-tap-changer when the sequence is polarity reversed can cause damage in many cases, their situation being further addressed in this article.

2. Preliminary considerations

In Fig.1. it is presented schedule a typical three-phase motor equipped servo-system. It is noted that if a normal diet, when does BD button and turns 1K contactor C1 cam will move the race L1 limiter, which limits the range of adjustment will lead to the outbreak contactor 1K and thus block the functioning of the action device in the sense voltage ordered by the BD. Considering the same case, to supply the sequence of phases or incorrect polarity, if push BD to close contactor 1K, which incorrectly power supply, will cause by system down-multiplier rotating cam C1 to L2 limiter. But L2 limiter it isn't serial in 1K contactor coil circuit and cann't change its status. Therefore servo-system will not be stopped at the limit of travel controlled by BD button, which causes follow:
- breaking the noose kinematic elements (Fig. 2a);
- the cage of some portions of the regulating winding which will destroy the heat effect and due to electro-dynamic forces developed between turns, coils and windings (Fig. 2b);
- partial and sometimes total destruction contacts (Fig. 2c).

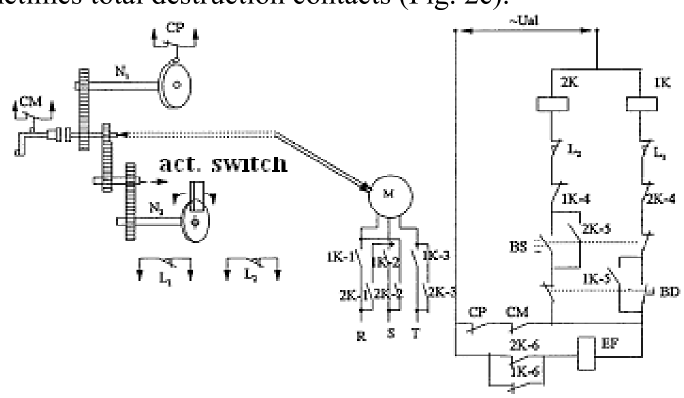
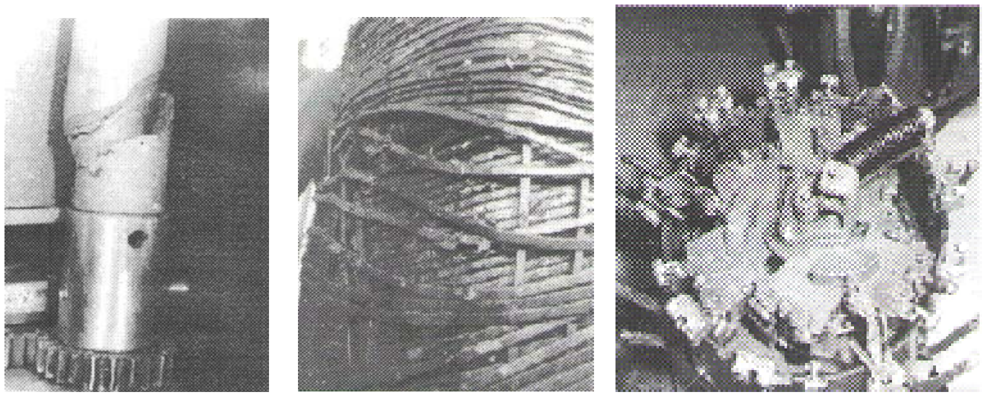


Fig. 1. Schedule a servo-system equipped with a three phase motor



a b c

Fig. 2. Damage to on-load-tap-changer [6]: a) Breaking rod drive; b) Effects of short circuit current on the windings; c) Destruction of resistors, and contacts broken

3. Contributions to the synthesis schemes provided with the opportunity to eliminate the influence of power supply on the correct operation of servo-systems

It's known that stability is determined by parameters and servo-systems structure for the linear systems and input parameters and the type size for the nonlinear systems [3]. Studies on servo-systems operation led to the finding that, especially for those mounted on mobile installations is conditional stability and polarity or three-phase sequence voltage power supply to action device. Adopt a polar or three phase sequence incorrect result in overrunning extreme operating range with sometimes serious consequences both for watching and for installation. With reference to the load switches tuning voltage of the power transformers, damage caused by the choice of three phase voltage polarity or sequence of annual rises to values in the millions of lei.

Mathematical modeling of three phase sequence of voltage polarity or power is achieved by adopting the following notion of "variable p" defined by the algebra of trivalent elements as follows:

$$p = \begin{cases} \Phi(p) = \Phi(1) = 1 & \text{- polarity or direct sequence} \\ \Phi(p) = \Phi(2) = 2 & \text{- polarity or reverse sequence} \\ \Phi(p) = \Phi(0) = 0 & \text{- power is interrupted} \end{cases}$$

Theoretically, the possibility of trivalent conversion of "variable p" is confirmed by the divalent Lagrange variable tri-valence [3]. In [4] were derived mathematical models of the six possible types of converter “variable p”, as follows:

$$\Phi_1(p) = \Phi_1(1) \cdot L_1(p) = 1 \cdot (2p^2 + 2p) \quad (1)$$

$$\Phi_2(p) = \Phi_2(2) \cdot L_2(p) = 1 \cdot (2p^2 + p) \quad (2)$$

$$\Phi_3(p) = \Phi_3(1) \cdot L_1(p) + \Phi_3(2) \cdot L_2(p) = p^2 \quad (3)$$

$$\Phi_4(p) = \Phi_4(2) \cdot L_2(p) = 2 \cdot (2p^2 + p) \quad (4)$$

$$\Phi_5(p) = \Phi_5(1) \cdot L_1(p) = 2 \cdot (2p^2 + 2p) \quad (5)$$

$$\Phi_6(p) = \Phi_6(p) \cdot L_1(p) + \Phi_6(2) \cdot L_2(p) = 2p^2 \quad (6)$$

Types of converters 3 and 4, modeled mathematically by functions $\Phi_3(p)$ and $\Phi_4(p)$are of great practical. These converters ensures the correct installation, even in terms of polarities or changing the sequence three phase power supply. If DC sources these converters are made on the basis of direct and reverse polarity selectors and for three phase source based on direct sequence and reverse filters.

❖ If DC source, the function of the two types of converters can be achieved by a Graetz bridge, although their structure is apparently different from that of converters type 3 and type 6 made in classic fashion. This paper aims to demonstrate that theoretically and practically, that a Graetz bridge recovery, can make a converter type $\Phi_3(p)$and $\Phi_4(p)$.

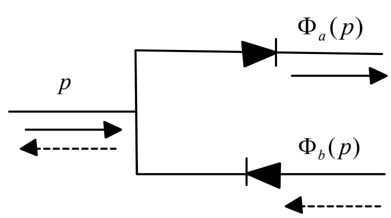


Fig. 3. Converter "variable p" done with rectifier diodes

Equivalence can be demonstrated experimentally found mathematically from the fact that the simple diode rectifier is a circuit, Fig. 3, one of valence converter, whose input size is the “variable p” associated with the tide at the entrance and exit where size is a function $\Phi_a(p)$, meaning that $\Phi_b(p)$ associated current output as shown in Table 1.

Table 1.

Values associated with "variable p"

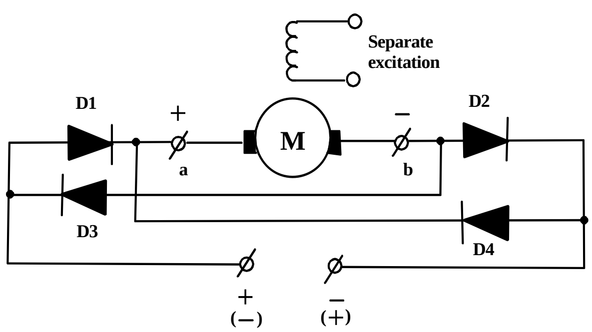
Meaning current	→	← - - -	Current
Value “variable p”	1	2	0
Value function $\Phi_a(p)$	$\Phi_a(1)=1$	$\Phi_a(2)=0$	$\Phi_a(0)=0$
Value function $\Phi_b(p)$	$\Phi_b(1)=1$	$\Phi_b(2)=2$	$\Phi_b(0)=0$

Starting from the possible values of the function $\Phi_a(p)$ and $\Phi_b(p)$ by applying the generalized formula of Lagrange interpolation is obtained:

$$\Phi_a(p)=\Phi_a(1)\cdot L_1(p)=1\cdot\left(2p^2+2p\right)=2p^2+2p \tag{7}$$

$$\Phi_b(p)=\Phi_b(2)\cdot L_2(p)=2\cdot\left(2p^2+p\right)=p^2+2p \tag{8}$$

Given the relations (1)-(6) that which $\Phi_a(p)=\Phi_1(p)$ and $\Phi_b(p)=\Phi_4(p)$ shows that a diode rectifier, depending on connection mode circuit, the converter can perform the functions of the valence converter of type 1 respectively type 4. In Fig. 4. is shown the principle scheme of a recovery Graetz bridge which is powered by a DC motor.



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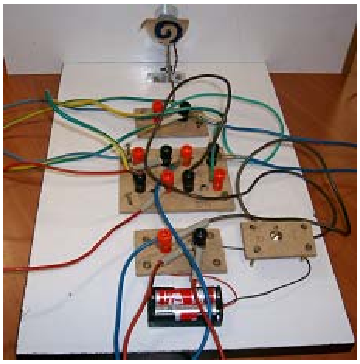

b

Fig. 4. Recovery Scheme Graetz: a) Schematic diagram; b) Experimental Stand

❖ If an automatic control system to power an electric motor three phase as “variable p” acts directly on the action device and its control scheme, study its influence has focused on these two items, which are used in any servo-systems. For analysis considers simplified scheme of Fig.7. extending the notion of stability of this scheme, the stability condition is limited to the existence of a perfect correspondence between order and effect. Electric engine status is shaped by trivalent variable Z defined as:

$$Z=\begin{cases} 0- & \text{engine idle} \\ 1- & \text{engine rotates to increase the size of the execution engine rotates} \\ 2- & \text{execution of decreasing size} \end{cases}$$

Engine status is a function of state contactors 1C and nC block model “variable y”; and as the “variable p”.

$$Y=\begin{cases} 0- & \text{1C and nC contactor triggered} \\ 1- & \text{1C plug, nC triggered} \\ 2- & \text{1C triggered, nC plug} \end{cases}$$

Block contacts status is subject to state control buttons BD and BC shaped by trivalent “variable b”; defined as:

$$b=\begin{cases} 0- & \text{when the transfer of energy to 1C and nC contactors coils is interrupted} \\ 1- & \text{when the transfer of energy to one of the contactors coils 1C or nC is by button or contact BC} \\ 2- & \text{when energy transfer to one of the contactors coils 1C or nC is made with button or contact BD} \end{cases}$$

The button or contact BC is to increase the size of the order of execution, and the BD for the purposes of this decrease. Status button can be modelled by BC bivalent variable $c = \{0;1\}$, and the state of BD by bivalent variable $d = \{0;1\}$, where value 1 corresponds to the state in which the two switches or contacts are driven. It notes that:

$$Z = f_z(p, y) \tag{9}$$

$$y = f_y(b) = b \tag{10}$$

According to previously established stability condition reduces to the relationship:

$$Z = b \tag{11}$$

Setting conditions imposed scheme of Fig. 5. leads to the next area of possible values of the function $Z = f_z(p, y)$

$$f_z(p,y) \rightarrow \begin{Bmatrix} f_z(1,1) = 1; f_z(1,2) = 2; f_z(1,0) = 0 \\ f_z(2,1) = 2; f_z(2,2) = 1; f_z(2,0) = 0 \\ f_z(0,1) = 0; f_z(2,2) = 1; f_z(2,0) = 0 \end{Bmatrix} \tag{12}$$

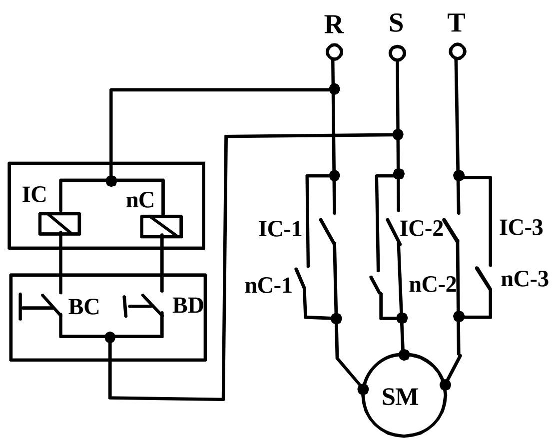

Fig. 5. Simplified scheme of a power servo-system

Applying the interpolation generalized formula of Lagrange:

$$f(x_1, x_2......x_n) = \sum_{\alpha_i = 0,1,2} f(\alpha_1, \alpha_2......\alpha_n) \cdot L\alpha_1(x_1) \cdot L\alpha_2(x_2) \cdot ......L\alpha_n(x_n) \tag{13}$$

where $f(\alpha_1, \alpha_2......\alpha_n)$is the possible values of function $f(x_1, x_2......x_n)$ and is the polynomial form of Lagrange:

$$\begin{aligned} &L_0(x_1) = 2 \cdot x_1^2 + 1; L_0(x_2) = 2 \cdot x_2^2 + 1; ....L_0(x_n) = 2 \cdot x_n^2 + 1 \\ &L_1(x_1) = 2 \cdot x_1^2 + 2 \cdot x_1; L_1(x_2) = 2 \cdot x_1^2 + 2 \cdot x_1; ...L_1(x_n) = 2 \cdot x_1^2 + 2 \cdot x_1 \\ &L_2(x_2) - 2 \cdot x_1 + 2 \cdot x_1; L_2(x_2) = 2 \cdot x_1^2 + 2 \cdot x_1; ...L_2(x_n) = 2 \cdot x_1^2 + 2 \cdot x_1 \end{aligned} \tag{14}$$

Obtain the following equation of state:

$$Z = f_z(p, y) = p \cdot y \quad (15)$$

Analyzing the equation of state (15) about the condition of stability (11) are found under the influence "variable p", stability can be achieved in two cases namely: - case I, when power supply is associated with a "variable p" bivalent defined on the field $p = \{0;1\}$; - case II, "variable p' " trivalent defined on the field $p' = \{0;1;2\}$ is substituted by a bivalent function of the form $\Phi(p) = p = \{0;1\}$, where equation of state becomes:

$$Z = f_z(p, y) = \Phi(p) \cdot y \quad (16)$$

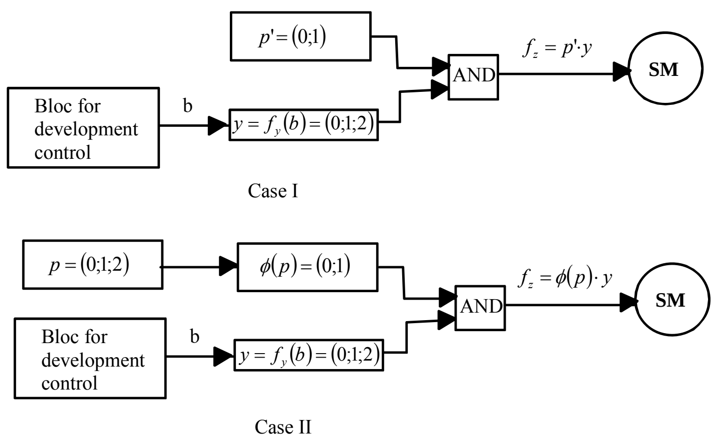

Fig. 6. Logical schemes for the two cases

The function $\Phi(p) = p$ is a physical model by converting the variable element in a trivalent $p' = \{0;1;2\}$ and bivalent variable $p = \{0;1\}$ is adopted the name of the converter valence tri-bivalent. Logical schemes for the two cases are presented in Fig. 6. With reference to case 1, the power sources, the only that support an association with "variable p" bivalent are the single phased sources in which case the "variable p' " is defined as:

$$p' \rightarrow \begin{cases} 0 - & \text{for lack of power supply} \\ 1 - & \text{for the presence of power supply} \end{cases}$$

4. Counter influence "variable p" using three-bivalent valence converters

It is noted that in relations (1)-(6), for trivalent "variable p", functions $\Phi_1(p);\Phi_2(p);\Phi_3(p)$ can take only 0 and 1 values while functions $\Phi 4(p);\Phi 5(p);\Phi 6(p)$ only values 0 and 2. For the problem considered, is practical important only the first three types of converters, whose state equations can be written as:

$$\Phi_1(p) = p \cdot [1 \cdot (2p+2)] = p[\delta_1 \cdot \varphi_d(p)] \quad (17)$$

$$\Phi_2(p) = p \cdot [2 \cdot (2p+2)] = p[\delta_2 \cdot \varphi_i(p)] \quad (18)$$

$$\Phi_3(p) = p \cdot [1 \cdot (2p+2) + 2(p+2)] = p \cdot [\delta_1 \cdot \varphi_d(p) + \delta_2 \cdot \varphi_i(p)] \quad (19)$$

Expressions (17)-(19) passing at the structural form:

$$\Phi_1(p) = p \wedge [\delta_1 \wedge \varphi_d(p)] \quad (20)$$

$$\Phi_2(p) = p \wedge [\delta_2 \wedge \varphi_i(p)] \quad (21)$$

$$\Phi_3(p) = p \wedge [(\delta_1 \wedge \varphi_d(p)) \vee (\delta_2 \wedge \varphi_2(p))] \quad (22)$$

A logical scheme which are shown in Fig. 7, Fig.8 and Fig.9. In the previous expressions δ are trivalent constant defined as:

$\delta \rightarrow$

- $\delta_1 = 1 -$ when shaping a portion of the circuit, the energy transferred without shape or polarity three phase sequence of voltage network
- $\delta_2 = 2 -$ when a portion of the circuit model, which transferred power without polarity or shape-phase sequence voltage network
- $\delta_3 = 0 -$ when a portion of the circuit is interrupted or when circulated homo-polar sequence currents

Considering the values and functions $\varphi_d(d)$ and $\varphi_i(p)$ for $p=1$ and $p=2$ obtain:

$$\varphi_d(1) = 1 \ ; \quad \varphi_d(2) = 0 \ ; \quad \varphi_i(1) = 0 \ ; \quad \varphi_i(2) = 1 .$$

Therefore it is concluded that the element shape function $\varphi_d(p) = 2p+2$ is a discriminating variable $p=1$, and the element shape function $\varphi_d(p) = p+2$ is a discriminating variable $p=2$. These are discriminating variable "P" simple action equipped with only one input and only one output control (Fig.8 and Fig.9).

Functions $\varphi_d(d)$ and $\varphi_i(p)$ no physical sense for $p=0$ a fact confirmed by practice. Analyzing the mathematical model of the converter type valence 3, that it is equivalent to two transducers of type 1 and 2 operating in parallel, which is expressed by:

$$\varphi_3(p)=\varphi_1(p)\vee\varphi_2(p) \tag{23}$$

The above equalliy is possible because of its properties of the Lagrange formula. for trivalent variable.

A type 3 converter can be achieved either by two separate discriminating in which one for variable $p=1$ and another for variable $p=2$ or acting with a discriminatory with combined action (equipped with only one imput and two output control), wich encompassing the functions of the two discriminating with a simple action (Fig.9).

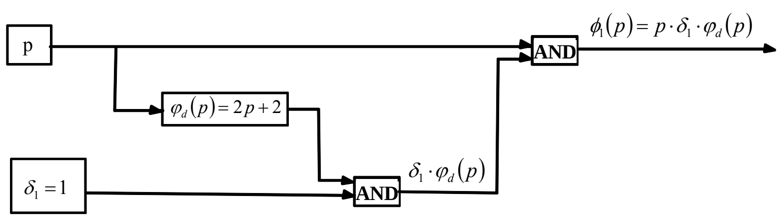

Fig. 7. Valence converter type 1

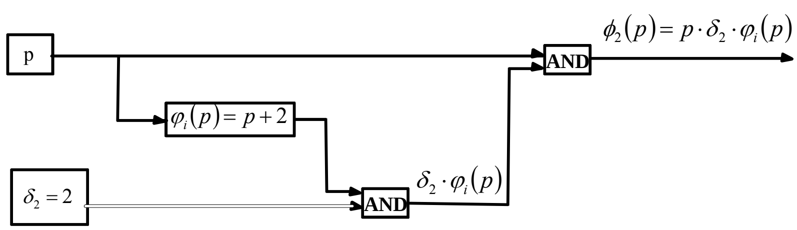

Fig. 8. Valence converter type 2

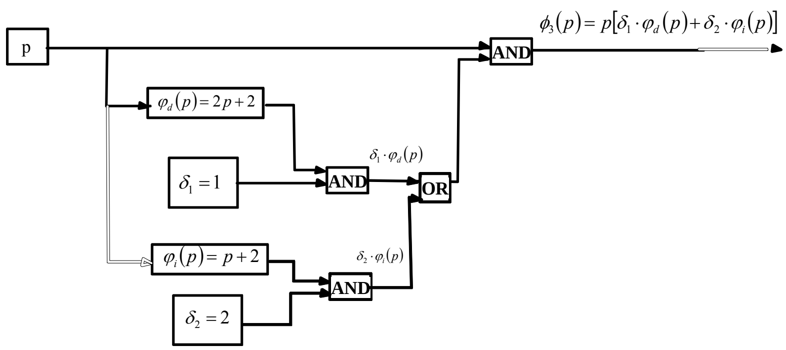

Fig. 9. Valence converter type 3

6. Conclusions

1. Recovery scheme Graetz connected between a DC power supply and DC motor ensure its correct polarity regardless of the fluctuation of power supply polarity.

2. In Fig. 10. is presented a servo-system equipped with relay for a correct three phase voltage supply, based on mathematical model of valence converter type 3 (logical scheme of Fig.9), which was conducted in laboratory EMAD of University "Ştefan cel Mare" Suceava [6]. There is an electromagnetic relay of "variable p" with action combined [7], that improves the simplified scheme of a power servo-system presented in Fig. 7. With this model, the direction of rotation, of the device

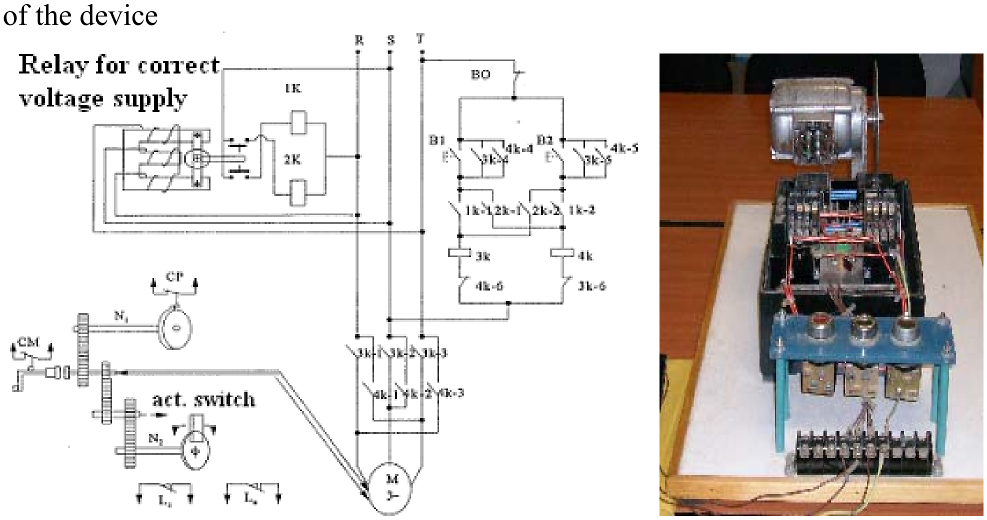

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Fig. 10. Servo-system equipped with relay for a correct three phase voltage supply:
a) Schematic diagram; b) Experimental Stand.

of the on-load-tap-changer of the power transformer, remains unchanged if the power supply three phase sequence change. We created and other models of the relays for a correct three phase power supply, for examples in [8] and [9]. Notice, making the electronic protection relay [9], we used, among other components, two triggers Schmitt because the output of the Schmitt trigger remains constant if the input stays below (or above) some critical threshold (thanks to *Otto Schmitt* an American scientist, he invented a simple electronic circuit) [10] and [11].

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