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Multidimensional Relay Protection Architecture

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1 INTRODUCTION

As the years go by, microprocessor based protection terminal storage expands, and the number of information sources of system state increases enormously. In this situation relay protection accrues experience of intelligent observer, i.e. becomes capable of obtaining abilities for recognition, matching and self-training. The report focuses on the self-learning process resulting in setting relay protection operate areas and blockings, summarizing settings calculation algorithm. Theoretically tessellation route known from computational geometry is possible, i.e. to construct the operating area in multidimensional space. But in current practice another route sensitive to feasibility of teaching algorithms is believed more expedient. Subspace aggregate - real or complex signal planes each reflecting one of the measurements generated in protection terminal is applied instead of multidimensional space. [1].

Opposing conditions concept (monitored, α conditions and alternate, β conditions) plays a key part in the relay protection information theory [2]. Protection is intended to operate in α -conditions, while in all without exception β -conditions it is expressly prohibited. The opposition implies that the second condition contradicts the first one, limiting protection sensitivity to α -conditions. That's exactly why it is unreal to set out protection to operate in all α -conditions without exception. We have to be satisfied with softer approximation condition of protection ability to recognize α -conditions. [3]. Recognizability is a physical property of the object under observation, it becomes more or less apparent upon a number of varying parameters of object simulation models, as well as the size and the type of relay protection information base as its observer.

The report proposes to teach the protection using unconventional approach to data conversion and overcoming opposition of α - and β -conditions. On the one hand these are conditional depiction approaches of the supervised conditions [4], and on the other hand – it is a method of separating opposing condition groups into elementary oppositions. According to conditional depiction approaches α -conditions reproduced by corresponding simulation models (α -model), in the course of their conversion are not restricted by any condition, while β -conditions depictions are strictly limited resulting in the notable increase of protection sensitivity at constant information base. The following examples show the possibilities of each of the two conditional depiction modifications designed: sequential, when measurements participate in the teaching process in turn, and parallel where measurements with their planes form a common teaching group. In all cases simulation models of the protected object are playing the role of teachers.

Opposing condition groups mentioned in elementary opposition approaches may be either natural or artificial. In the first instance the problem of recognizing states occurring in a few α -

conditions and not occurring in some β -conditions should be settled. In the second instance α -and- β -conditions parameter definition areas are split into segments – subareas – determining different types of α -and/or β -conditions. Elementary opposition takes place between each type of α - and each type of β -condition. Elementary opposition overcoming results in information picture of the observer.

2 CONTIOTIONAL DEPICTIONS

Object simulation model parameters in α - and β -conditions are set by m_α and m_β -dimensional vectors of $\mathbf{x}_\alpha \in G_\alpha \subset C_\alpha$, $\mathbf{x}_\beta \in G_\beta \subset C_\beta$ parameters where G_α and G_β – are parameter definition areas in C_α and C_β object spaces. The observer converts the simulation model parameters into $\mathbf{z}_i$, $i = \overline{1, n}$, measurements – two-dimensional vectors with coordinates z_{i1} and z_{i2} , depicted on A_i measuring planes.

Parallel and sequential conditional depictions are different. Parallel conditional depiction affects only β -conditions, and the sequential one affects even α -conditions. Parallel depiction algorithm includes operation for unconditional depiction of G_α object plane onto all n of A_i planes leading to generation of $S_{\alpha i}$ planar figures. Then G_β area conditional depiction within $S_{\alpha i}$ figures is observed. Depictions falling into all $S_{\alpha i}$ areas without exception are only recorded.

$$\mathbf{z}_{\beta i}^{\text{cond}} \in S_{\alpha i}, i = \overline{1, n}. \quad (1)$$

Many depictions meeting n conditions (1), form blocking areas $S_{\alpha\beta}^{\text{cond}} \subset S_{\alpha i}$. In case each of $S_{\alpha i}$ planes performs permission function then $S_{\alpha\beta i}$ subarea aggregate performs opposite function of the relay protection blocking. Figure 1 shows two configurations of parallel recognition module. In one of them condition (1) is fulfilled, and in the other one – not fulfilled, but anyway from the standpoint of the observer, it should be checked during the teaching process. Therefore the observer reserves the right to play the key role in this process.

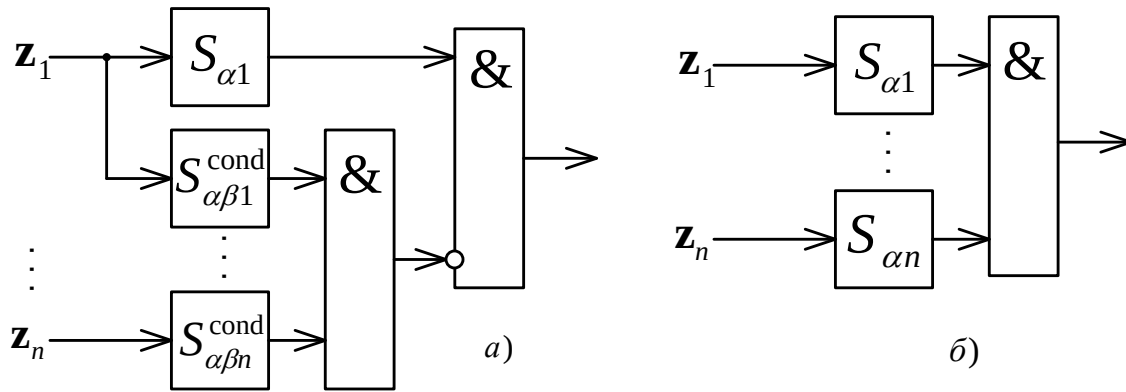


Fig. 1: Parallel recognition module configurations

a – in case condition (1) for any value of $\mathbf{x}_\beta \in G_\beta$ is fulfilled,

b – in case condition (1) along the whole G_β area is not fulfilled.

3 SEQUENTIAL CONDIONAL DEPICTIONS

In this case teaching process is performed in n strict consecutive hierarchic stages (fig. 2). The first stage reveals unrecognized condition area

$$S_{\alpha\beta 1} = S_{\alpha 1} \cap S_{\beta 1}, \quad (2)$$

where $S_{\beta 1}$, as well as $S_{\alpha 1}$, – are unconditional depiction of G_α and G_β areas. These depictions become conditional at the second stage. At i -stage G_α area $\mathbf{z}_{\alpha i}^{\text{con}}$ depiction is recorded when $(i-1)$ condition is fulfilled

$$\mathbf{z}_{\alpha 1} \in S_{\alpha\beta 1}, \quad (3)$$

$$\mathbf{z}_{\alpha k}^{\text{cond}} \in S_{\alpha\beta k}^{\text{cond}}, k = \overline{2, i-1}, \quad (4)$$

$$S_{\alpha\beta k}^{\text{cond}} = S_{\alpha k}^{\text{cond}} \cap S_{\beta k}^{\text{cond}}. \quad (5)$$

G_β area $z_{\beta i}^{\text{ycn}}$ depiction is recorded under the same number of corresponding conditions

$$z_{\beta 1} \in S_{\alpha\beta 1}, \quad (6)$$

$$z_{\beta k}^{\text{cond}} \in S_{\alpha\beta k}^{\text{cond}}, \quad k = \overline{2, i-1}. \quad (7)$$

Operations (3)-(7) perform A_i measuring plane recurrent link with preceding planes $A_k, k = \overline{1, i-1}$.

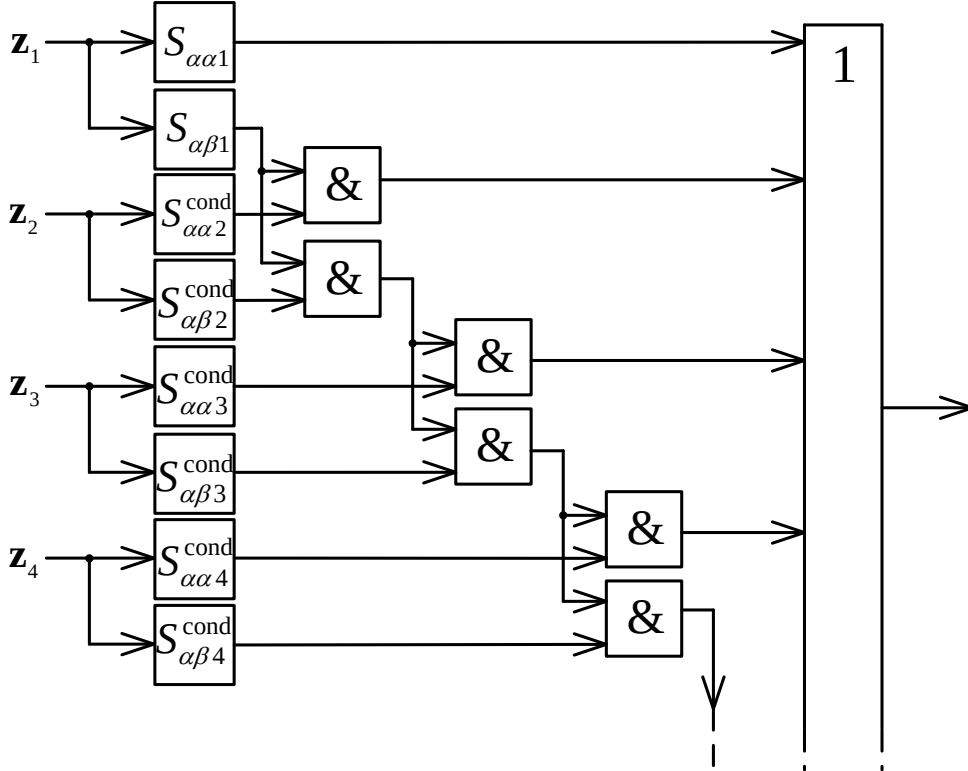


Fig. 2: Sequential type recognition module configuration

4 ELEMENTARY CONDITION OPPOSITIONS

To illustrate procedure of separation for elementary opposition and construction of recognition configuration informational picture we take an example of natural complex condition opposition according to Fig. 1 and 2. Suppose, it is necessary to solve a problem of phase selection in case of ground short circuits. It is required to recognize one of the power system phase fault, let's say A. Complexity is conditioned by probability of existence of three various types of α -condition: single-phase short-circuit $K_{A\alpha}^{(1)}$ and two-phase $K_{AB\alpha}^{(1,1)}$ and $K_{CA\alpha}^{(1,1)}$ short-circuits, as well as three different-type β -conditions: single-phase $K_{B\beta}^{(1)}$ short-circuit, $K_{C\beta}^{(1)}$ and two-phase $K_{BC\beta}^{(1,1)}$ short-circuits. As may be seen, complex opposition in this example consists of nine elementary oppositions. Each elementary opposition on fig. 3 is specified by type $K_{A\alpha}^{(1)} | K_{B\beta}^{(1)}$. In the configuration recognizing the galvanic coupling of A phase with ground elementary opposition is solved by self-contained module and all nine modules are grouped in threes by AND operation. The group generates a signal of possible phase A involvement into corresponding type of short-circuit but does not ensure recognition of the fault type, as for this moment simultaneous operation of two or all three module groups included into the configuration per fig. 3.

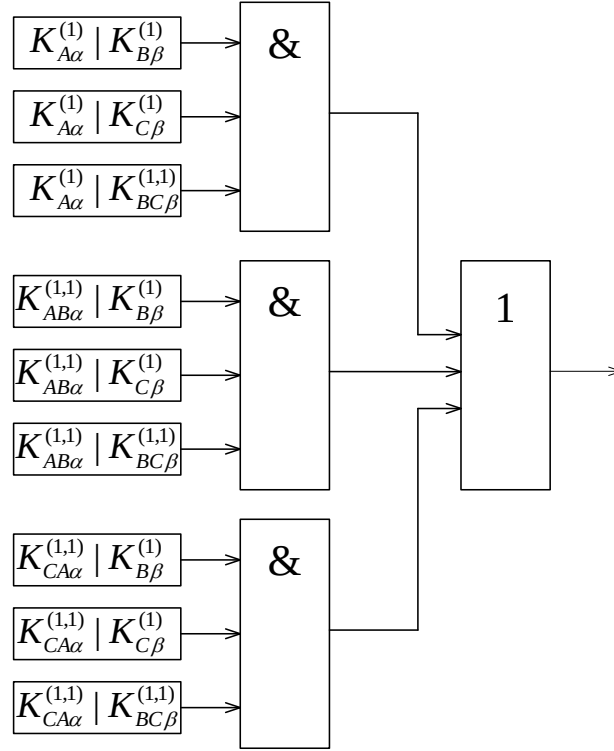


Fig. 3: Configuration recognizing phase A galvanic coupling with ground

5 OBSERVER INFORMATION PICTURE

The following problem can be solved by building informational picture. Simulation models of the object under observation (e.g. transmission line) in α - and β -conditions are given (fig. 4). Definition area of variable parameters G_α and G_β of simulation models are set by each parameter variation ranges (Table 1). α - and β -conditions elementary oppositions are revealed, therefore the observer configuration is built as per the type shown in Fig. 3.

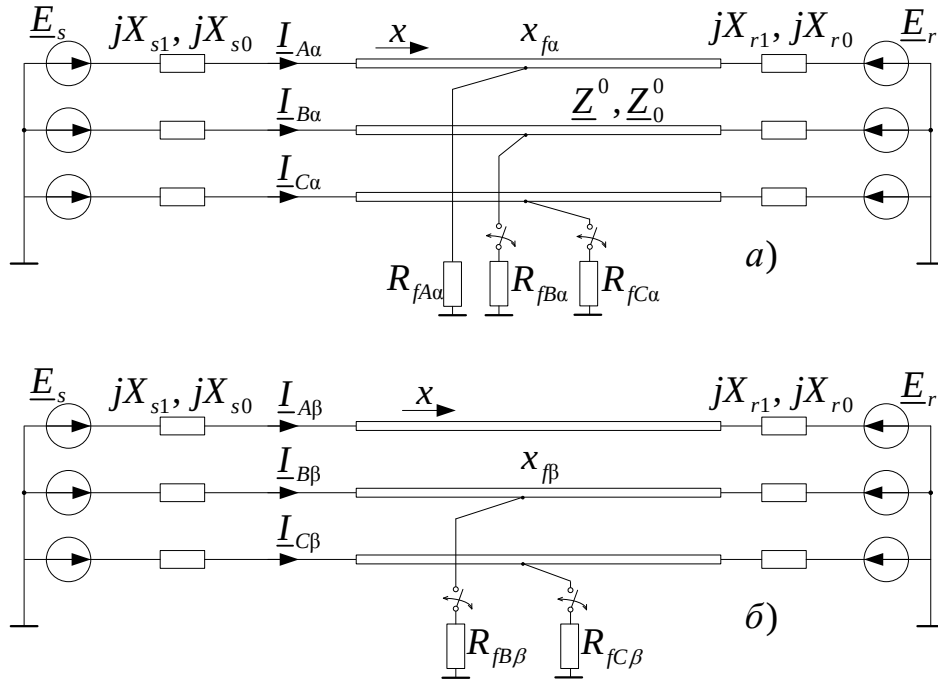


Fig. 4: Transmission simulation model in α -conditions (a) and in opposite β -conditions (b)

Table 1: Simulation model variable parameters as per Fig. 4

α - and (or) β -model parameters	Variable range
$X_{f\alpha}, X_{f\beta}$	$0 \dots l$
$R_{fA\alpha}, R_{fB\alpha}, R_{fC\alpha}$	$0 \dots R_{\text{пред}}$
$R_{fB\beta}, R_{fC\beta}$	$0 \dots \infty$
$\delta = \arg(\underline{E}_s / \underline{E}_r)$	$-60^\circ \dots 60^\circ$
X_{s1}	$140 \dots 160 \, \Omega$
X_{r1}	$100 \dots 110 \, \Omega$
X_{s0} / X_{s1}	$0,4 \dots 0,5$
X_{r0} / X_{r1}	$2,5 \dots 3,0$

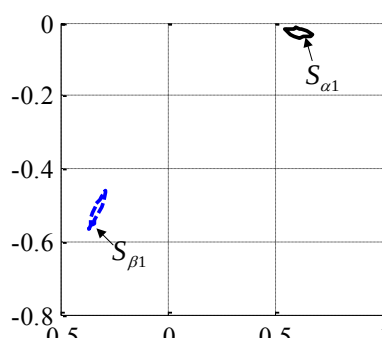
Each of the constituent modules solves one of the elementary opposition. The modules are taught by conditional depiction approaches. It is required to find out what number of these modules and at which measuring planes help us solve each elementary opposition.

Suppose that the observer information base in this example (its information models are given in fig. 4) consists of three currents of the current transmission mode. Note that in case of two-phase ground short-circuits one more transient resistance is variable than in case of single-phase short-circuits. The following supply voltages are recorded: $E_s = E_r = U_{\text{ph.nom}} = (500 / \sqrt{3})$ kV, transmission line length is $l = 278,6$ km, positive and zero sequences primary parameters of the line in Ohm/km: $X_1^0 = 0,302$, $R_1^0 = 0,12$, $X_0^0 = 0,696$, $R_0^0 = 0,27$. Losses in transmission and receiving systems are not considered, that impairs recognition of disturbances. Transient resistance limiting value R_{limit} in α -conditions was determined from the recognition conditions of the whole set of conditions G_α .

Observer information picture is given in table 2-4. Each table is the result of one stage of its construction. First stage revealed measurement in the form of relation between negative and zero-sequence currents $\underline{I}_2 / \underline{I}_0$, which by itself solves four elementary oppositions (Table 2). The five left required one more measuring plane and conditional depiction transition to be introduced. The second stage revealed the second measurement $\underline{I}_1(\underline{I}_2 + \underline{I}_0)$ in the form of mutual complex power of two signals: positive sequence current $\underline{I}_1$ and the sum of negative and zero sequence currents $\underline{I}_2 + \underline{I}_0$. The use of sequential conditional depiction approach to the group of two measurements allowed solving the rest elementary oppositions (Table 3). Thus we obtained R_{limit} limiting value of 47 Ohm.

Parallel conditional depiction approach is used at the final third stage to increase the observer sensitivity characterized by R_{limit} value (Table 4). R_{limit} was 55 Ohm.

Table 2: Condition opposition solved in one plane

Conditions		Measurement
α	β	$\underline{I}_2 / \underline{I}_0$, o.e.
$K_A^{(1)}$	$K_B^{(1)}$	

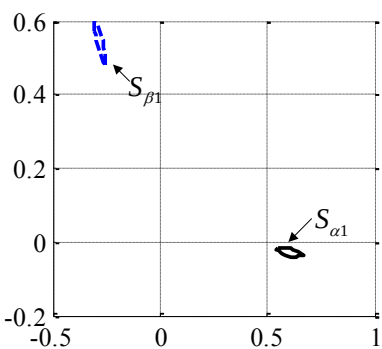
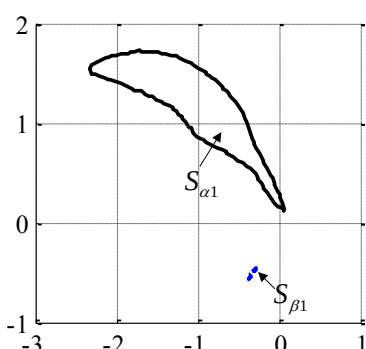
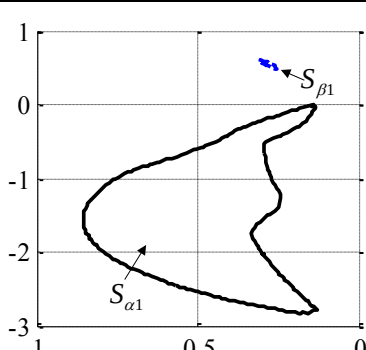
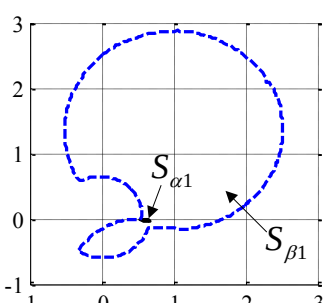
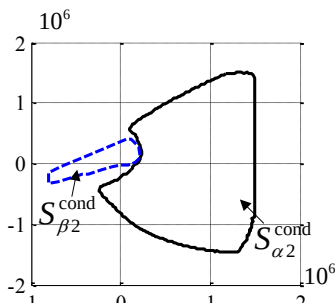
$K_A^{(1)}$	$K_C^{(1)}$	
$K_{AB}^{(1,1)}$	$K_B^{(1)}$	
$K_{CA}^{(1,1)}$	$K_C^{(1)}$	

Table 3: Sequential conditional depictions on two planes

Conditions		Measurements	
α	β	$\underline{I}_2 / \underline{I}_0, \text{ o.e.}$	$\underline{I}_1^* (\underline{I}_2^* + \underline{I}_0^*), \text{ A}^2.$
$K_A^{(1)}$	$K_{BC}^{(1,1)}$		

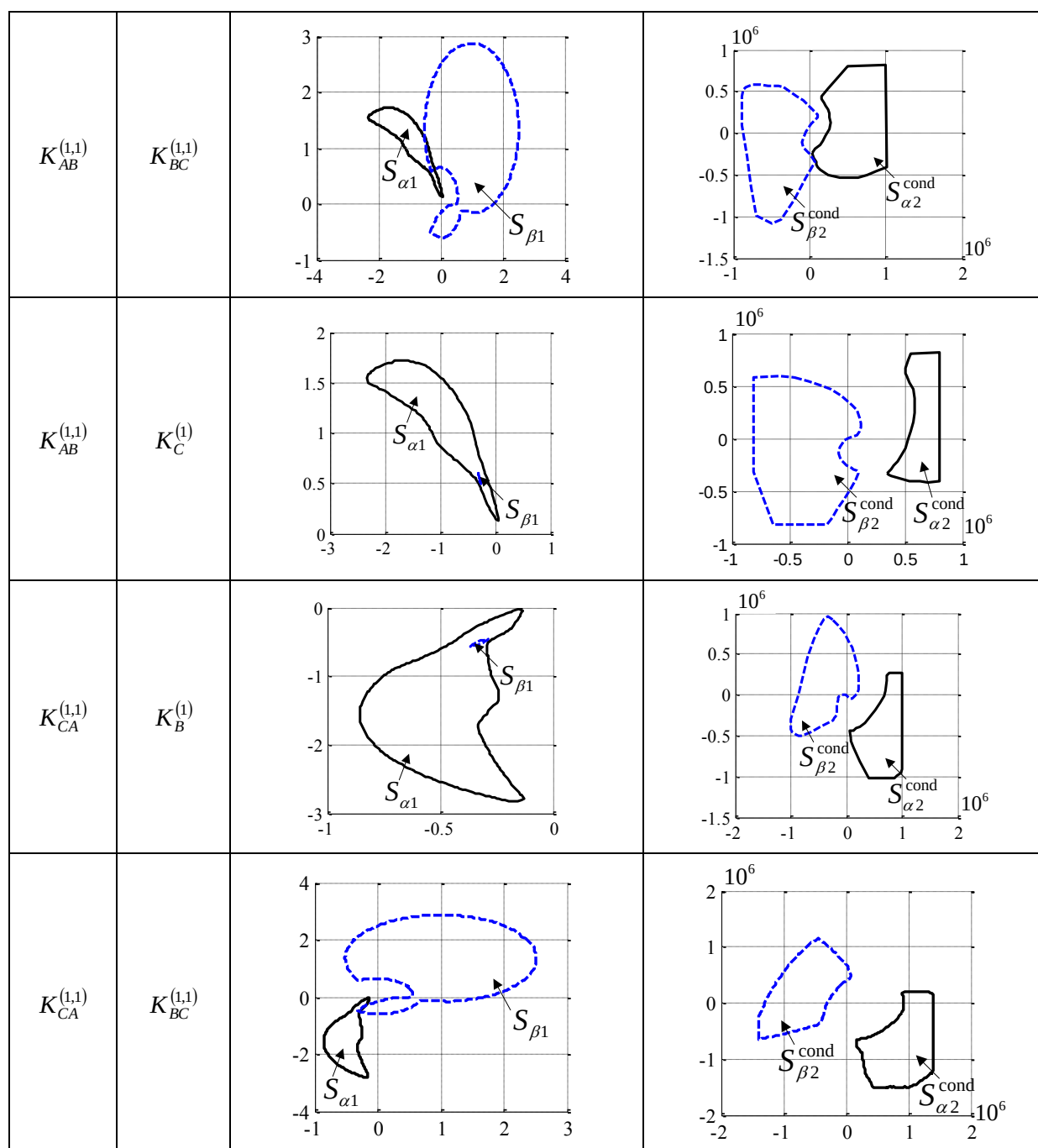
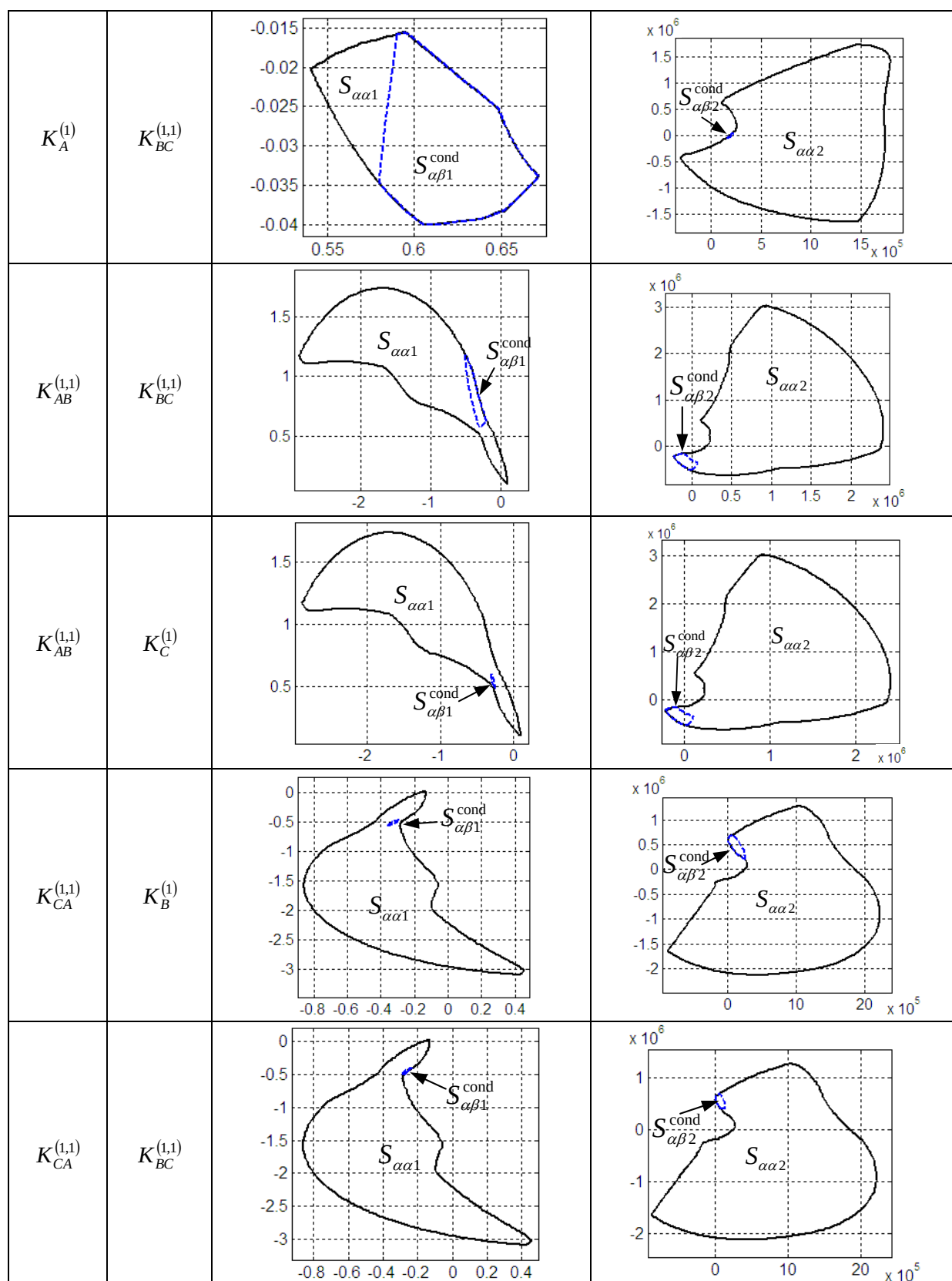


Table 4: Parallel conditional depictions on two planes

Conditions		Measurements	
α	β	$\underline{I}_2 / \underline{I}_0$, o.e.	$\underline{I}_1 \left(\begin{smallmatrix} * \\ \underline{I}_2 + \underline{I}_0 \end{smallmatrix} \right), A^2$.



6 CONCLUSION

Relay protection interpretation as a trained observer of opposite α - и β -conditions turned out effective in a number of aspects. As a natural result, it involved concept of signal simulation model conditional depiction into the process of relay protection training, concept

concerning separation of complex opposition between all β - and α -conditions into elementary oppositions between one-type β -condition and one-type α -condition, concept for construction of information picture depicting monitored condition recognition problem to be solved separately for each elementary opposition. In summary, it can be noted, that use of conditional depiction approach and separation of complex oppositions into elementary oppositions lead to unusual “atomization” of relaying mission problem. Herewith the role of each measurement is determined not heuristically but according to preset precise rules.

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