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Automatic Control of the Structure of Dynamic Objects in High-Voltage Power Smart-Grid

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Abstract

The control and protection algorithms for the considered class of dynamic facilities with a tunable structure are considered. Their relevance follows from the concepts of the development of the electric power industry—*smart grid*, *digital substation* and *outsourcing services*. The properties of this class of dynamic objects are spatial distribution, many options for changing the structure and motion in vibrational circuits at natural frequencies from ultra-high to ultra-low. The input coordinate of the dynamic objects is the vector of the change in the structure of the object. The output coordinate is the power of a special semantic signal about the state of the facilities. Their management is carried out as part of the stabilisation system of the normal operation of the facility. Stabilisation is achieved by the criterion of the minimum deviation of the power of the semantic signal from the ‘normal mode’ setting of operation. Executive bodies rebuild the structure of the dynamic facility in a pulsed, programmatic way, using the possibilities of self-healing and resource reservation. If stabilisation is not possible, the damaged area is excluded from the facility. The problem of the stability of the system turned out to be the lack of sufficient information about the state of the object and the similarity of the structure and significance of unrecognisable semantic situations to the main situations. Control algorithms are synthesised by the developed structural-informational (SI) method of dynamic pattern recognition.

Keywords: relay protection, automation, Petersen’s coil, smart grid, protection against single-phase earth faults, structural-informational method, modelling

1. Introduction

Generalised and developed solutions to the problems of synthesis and ensuring the stability of the operation of automatic control and protection algorithms for a class of objects with a tunable internal structure. At the present stage of development, it is necessary to operate with information flows at a higher level of abstraction than traditional methods of building networks. The concept of information flow refers to a set of demodulated signal parameters from transient signals (transients) in an object. Connected network elements are considered as dynamic facilities (objects) of the control and protection (OCP). Within the framework of the smart grid concept, all the necessary algorithms for relay protection and automation (RPA) devices are in the foreground, and the equipment that controls the operation of the OCP (**Figure 1**) is at the second level. It implies the possibility of describing the properties of OCP

electrical circuits through control algorithms [1–9]. Such a structural-informational (SI) method is developed by the author further [8–15]. The methods of applying the available results of the SI method to describe the internal structure of high-voltage equipment of the OCR network are shown.

In the traditional construction of networks, a great deal of experience has been gained in describing and calculating OCP [6–7]. Usually it is enough to indicate the established terminology and mathematical description of the OCP in the technical literature [15–18]. A method is necessary for describing the transient process in the OCP from the place of formation to the resulting text messages at a more abstract level, without loss of information and with the possibility of engaging the achievements of the traditional description. This allows a compact description of the problem and a focus on control algorithms [9–11].

The task was posed in a series of published works [7–11], based on the results achieved by improving recognition algorithms in devices for protection against single-phase earth faults in networks with a Petersen's coil. Studies show [8–13] that, for example, to maintain the stability of the operation of RPA device algorithms in distribution networks with a voltage of 6–35 kV, the amount of input information is insufficient [6, 8, 13, 16]. Faults are often and continuously present in externally operable high-voltage distribution networks, and information about the occurrence of such a situation cannot be distinguished during visual observation by the means currently available at substations [11, 13, 15]. Identification of the causes of situations is difficult and is associated with the lack of reliable information about the actual state of the network sections among consumers, configuration, state of high-voltage equipment, deviations in the technological processes of network load operation, etc. [15–18].

Replenishment of the lack of information is drawn from the capabilities of intelligent search algorithms for pattern recognition, which are able to extract semantic states from transient signals occurring in networks [5, 8–16].

Further, when developing the SI method, the patterns of structural diagrams, which are stages in solving the problems of synthesis of automatic control and protection algorithms, are summarised in a general sequence [5, 8–16], namely, from information structures describing transients in a network, through a formal presentation of information in high-voltage network equipment, then dynamically changing network operating modes, to the synthesis of the necessary algorithms for structural processing of information in automatic devices.

The tasks of numerical assessment of the sufficiency of the signal information volume for automatic decision-making on shutting down a damaged part

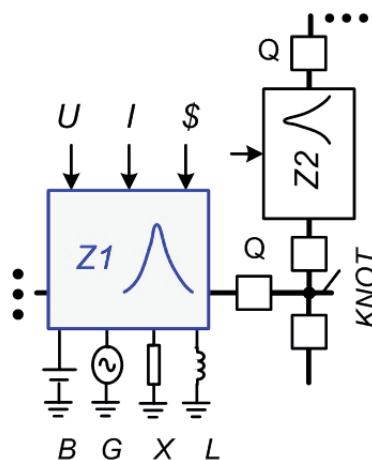


Figure 1.
Unified circuit of smart grid Driver-EU-OCP.

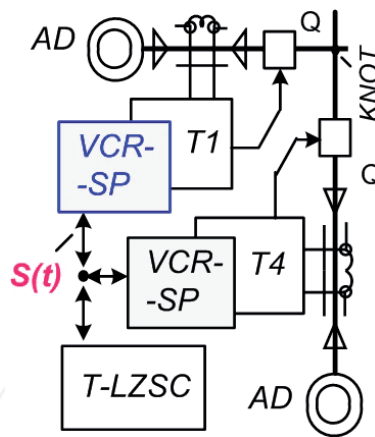


Figure 2.
 Diagram of a smart grid that is unique to a local measure and a signal $S(t)$. T —RPA terminal.

of an object are analysed (**Figure 2**). Algorithms for controlling the amount of information are implemented in the VCR, with built-in general purpose software information sensors and an arbitration function of RPA algorithms. The device is located in each OCP cell [7–9, 15–16]. A method is proposed for obtaining the necessary additional information based on the sequence of steps of the SI method, namely, structured separation of information, control of the passage of elementary information components according to the structural diagrams of the control and OCP protection object, then through relay protection and automation devices RPA, and to the output of the SCADA control system [5, 11].

2. Separation of dynamic objects with variable structure into a separate class

Dynamic OCP management and control objects are those in which their internal information state develops sequentially in time, a new state replacing the previous one. We will call the elementary state the semantic situation SN , for example, $S1$ ‘normal operation’ or ‘NM’. One SN gives rise to another or many possible known developments. Such transitions to a fixed SN are similar to the operation of automaton models. A sequential change in time of the parameters, structure, dynamic properties and individual elements of the OCP is possible. The removal of sections from the OCP structure for various reasons or combining them into a common structure during the operation of automatic control devices is typical.

The OCP is characterised primarily by a change in time of the internal structure. Parametric changes are the result of such a change. For example, the task of adjusting the coordinate parameter L to changing the coordinate parameter C is successfully solved (**Figure 3**). Changes in parameter C result in changes of different types—(A) a change in the structure of the OCP by disconnecting the QN switches of the separated sections of the OCP; (B) there is a test change of the parameter L during operational work in the ‘NM’ mode, while the structure of the OCP does not change; and (C) the damaged section is disconnected by the QN switch by selective relay protection. In some modes of structural change, when damage occurs, blocking changes in the parametric coordinate L .

An analysis is made of the methods for describing well-known typical schemes of RPA systems to justify the possibility of operating with such a concept. So, on well-known typical schemes, a single-line OCP scheme, EU executive bodies,

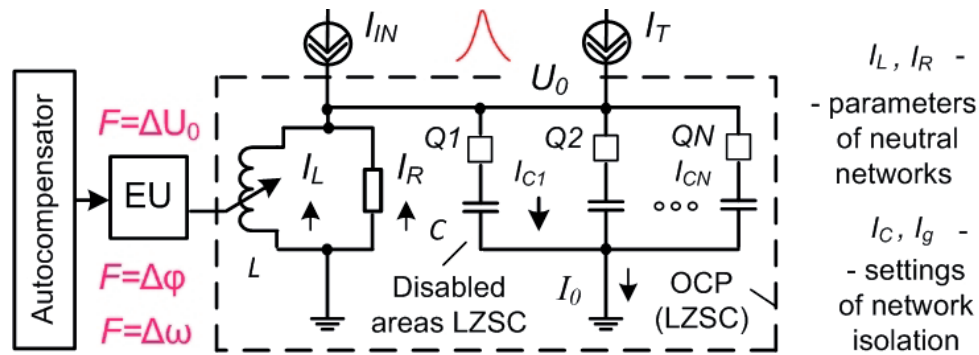


Figure 3. Structural scheme OCP (LZSC) with a Petersen's coil L.

measuring transformers and the measuring part of the relay are indicated (**Figure 3**). The relay output was initially replaced with a multiple control result—from immediate shutdown to alarm.

In RPA tasks, the perturbation control principle is common. It is known that this principle is characterised by the presence of fatal errors and is relevant in the event of catastrophic failures in the OCP equipment. But most of the insulation damage to the network (75–98%), according to well-known statistics, can self-destruct. To do this, RPA algorithms must steadily determine such a transition process. Case studies have found that, in such SN situations, robustness of the RPA systems was not achieved.

3. Description of the SI method for working with dynamic OCP

The SI method is universal enough to describe various tasks and implement modern concepts of technology development [6–13]. It consists of a description of the sequence of patterns as steps to solve the problem. The steps are due to the dynamic development of processes, control algorithms and moments of issuing control commands. Patterns are generalised equivalent structure (GES) schemes. They allow us to uniformly describe known and new devices within the framework of network development concepts (**Figure 4**). The GES scheme consists of automata A—morphological MorphA, syntactic (SyntA) and semantic (SemA). The SyntA machine controls the correct sequence of primary terminal symbols (TS) in the TS chains in the input information. SyntA states are nonterminal symbols (NTS) that appear when TS chains are known to SyntA recognition engines. The basis of GES circuits is the sensing S-detector introduced. It detects the semantic signal $S(t)$, which is formed sequentially in the GES schemes of the object, recognition and control algorithms and is used at all hierarchical levels of information processing.

The quality of processing dynamic information flows in RPA systems in energy networks is controlled by the semantic signal $S(t)$ (**Figure 4**). Such a signal is formed at each hierarchical level of processing the total amount of information in the system—morphological, syntactic and semantic. The amount of information about the state of the OCP is allocated and controlled by RPA devices based on demodulation of the information components in transient signals (**Figure 5**).

The relationship of TS and NTS in the GES scheme is described by the rules P . Rules P are divided into groups of selectivity PS and blocking PB . Rules P are assigned weights KSN and KBM , according to the contribution to the overall semantic output

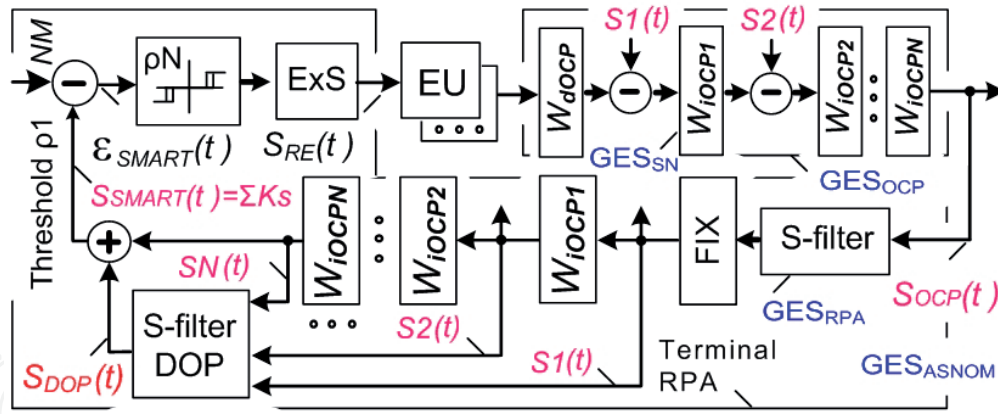


Figure 4. Diagram of the GES_{ASNOM} of system stabilisation ASNOM based on $S_{SMART}(t)$.

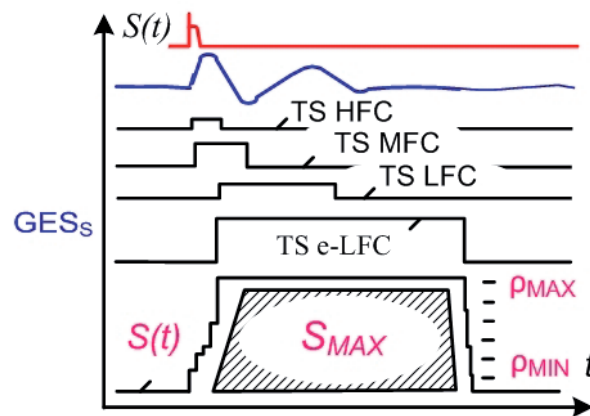


Figure 5. Formation of a signal with an $S(t)$ signal—maximum amount of information.

$S_{SMART}(t)$. So, the information part of the S-filter is highlighted. The SemA output generates a semantic signal $S_{SMART}(t) = For(t) - Against(t)$ (1). The $S_{SMART}(t)$ signal reflects changes in semantic information in the OCP and in the system of automatic stabilisation of the normal operating mode (ASNOM) of the network (Figure 4).

$$S_{SMART}(t) = FIX[\beta \times K_S SB \times (S_S S(t) - S_S B(t))] = FIX[\beta \times K_S SB \times f(\Sigma KSN(t) - \Sigma KBM(t))], \quad (1)$$

where $N = 1, 2, \dots; M = 1, 2, \dots; \Sigma$ is the sum of all weight coefficients KSN or KBM , which establish the significance of the rules PS and PB of the SyntA automaton and the weight coefficient $K_S SB$ of the resulting root rule $P_S SB$ of the SemA automaton; and β is the general scaling factor. The FIX function describes the operation of the fixation unit, in which, during the development of transients, the activated rules PS and PB are stored for a while to accumulate the $S_{SMART}(t)$ value. This signal can vary between '0%' and '100%' (Figure 6). The FIX function is similar to the operation of the emergency recorder and acts when the 'activating' TS appears, which is set in the settings of the RPA device. Such a TS is commonly known for OCP.

The GES scheme is mathematically described by a list—grammar G as shown in Eq. (2).

$$G_O \rightarrow (TSSN, TSBM, NTSSN, NTSBM, PSN, PBM, P_S S, P_S B, P_S SB), \quad (2)$$

where O are objects, for example, OCP, GES, TS, RPA, ASNOM, SCADA, PS and PB —the rules for connecting TS and secondary NTS—and P_{GSB} is the resulting root rule of the GES scheme. The executive bodies EU of the ASNOM system (**Figure 4**) are the outputs of the RPA algorithms, combined by the block of the ExS expert system. The final semantic conclusions are formed in ExS, and decisions are made on the automatic removal of deviations from p1 ‘NM’ of the normal mode (NM) of OCP operation.

The OCP is presented on a single information field of elementary information components of TS. From these TS, an SN formation tree, a TS terminal symbol tree describing the SN structure and signal control $S_{\text{OCP}}(t)$ are built.

The SI method allows you to describe SN semantic situations by passing them through the GES_{OCP} information block diagram. This is controlled by the sense signal $S(t)$. Its area (otherwise, power in the interval of control duration) can be considered the meaning of events in the OCP circuit (**Figure 5**). By the amount of information that is formed in the structural diagram TS, we mean the area $S(t)$. The authors of [6–16] studied the construction of a tree that recognises systems in RPA devices based on the generation and control of the $S_{\text{RPA}}(t)$ signal. The $S_{\text{RPA}}(t)$ signal in recognition algorithms controls the course of processes in the OCP in meaning. General control of all OCP loops is performed similarly within the framework of the ASNOM and SCADA systems with the corresponding G_{ASNOM} , G_{SCADA} grammars and S_{ASNOM} and S_{SCADA} signals (**Figure 4**).

Thus, the structure of the OCP can be described by a set of GES_{RPA} schemes, i.e. the sum of Σ components and their G_O grammars, namely,

$$\begin{aligned} G_{\text{OCP}} &\approx \Sigma G_{\text{GES}} = \Sigma G_{\text{TS}} = \Sigma G_{\text{RPA}} = \Sigma G_{\text{ASNOM}} \\ &= G_{\text{SCADA}}, \Sigma \text{—the sum of the components.} \end{aligned} \quad (3)$$

The OCP objects are managed within the ASNOM system (**Figure 4**). Stabilisation is achieved by the criterion of the minimum deviation of the power of the semantic signal $S(t)$ from the setpoint of the ‘normal mode’ system. The class of objects is controlled by issuing commands to the RPA device. The formation of commands is controlled on the time axis of the emergency file as a reaction of the recognition algorithm to the input signals from the OCP.

Figure 6 shows the $\text{GES}_{\text{COMAND}}$ diagram as a command generation template in the ASNOM system. Teams manage not only the settings but primarily the structure of the OCP. Therefore, the ASNOM system differs from adaptive systems, which are characterised by a change in the parameters or structure of the controller depending on changes in the parameters of the object or external disturbances.

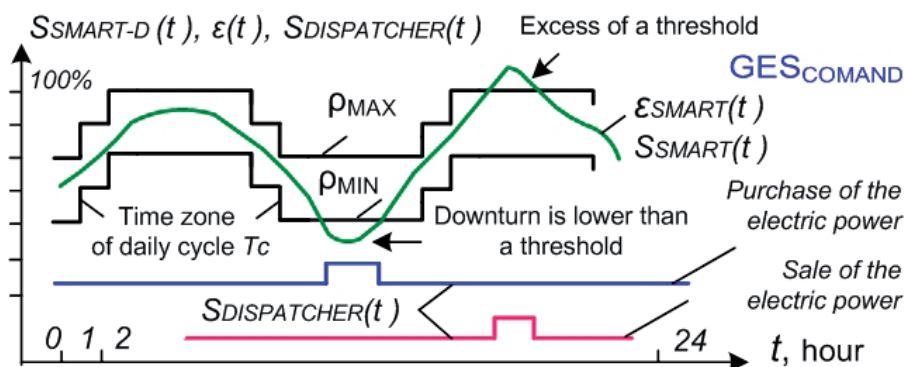


Figure 6. $\text{GES}_{\text{COMAND}}$ scheme. Illustration of change of a signal $S(t)$ and thresholds ρ_N .

The operation of technological and other processes in the network is considered further along the OCP–SCADA chain, where $G_{SCADA} = \Sigma G_{ASNOM}$ (Figure 4).

4. Research problem description

Identifying the site or location of damage in the OCP from the indicated types of damage is a difficult task to put into practice (Figures 2 and 3).

Selective relays from the main phase to ground faults are separately available in large numbers. Relays are widespread but are characterised by instability. By device stability, we mean the quality of recognition of *SN* semantic situations in transient signals in the OCP, which is necessary for the correct operation of devices in the ASNOM system. To ensure the stability of the relay protection and automation devices, it turns out that in some cases the traditional choice of the settings for the operation of these devices is not enough. The same type of device with the same algorithm is installed in different networks. In each network, high-voltage equipment has its own specifics and operating history, exhaustion factors, etc. Therefore, it is possible to have complex interfering extraneous signals at the installation sites of devices that are present for long periods of time and for which the use of devices is not designed.

The flow of information develops sequentially in the object and can be interrupted and resumed for various reasons. This property of the object during operation can lead the ASNOM stabilisation system to instability.

Studies show that recognising RPA algorithms is often built on the analysis of only one or several *SNs* [16–18]. In the remaining *SN*, the algorithms are blocked during the development of damage to the OCP and do not recognise the change of *SN* and *SN* scenarios. In this case, the available information is not used. However, the change of *SN* and *SN* scenarios allows one to highlight this additional information and use the additional rules of the *DOP* in recognition algorithms (Figure 4).

The reasons for the instability of the work are insufficient information to make a decision on the management of OCP, the similarity in structure and content of the main situations of *SN* with interference and unrecognisable *SNs*. It was revealed that volume restrictions may be a consequence of: (1) minimisation and shortcomings of synthesised recognition algorithms; (2) the influence of various conditions of specific sections of the network when introducing devices with the same methods; and (3) the lack of redundancy in the reception and processing of signals. It is known that redundancy of information allows you to work with distortions, extraneous signals, interference and more. This requirement may not be implemented, despite the fact that the amount of information should correspond to the complexity of the task. We will consider ways to address these causes of violations of the recognition of dynamically changing information.

If, when modelling in CAD on a joint model of information sensors *TS* and an object, it turns out that the signal $S(t)$ does not track the gradation of changes in the transient in the OCP and changes roughly, without distinguishing close *SN* situations, this is a sign of insufficient information for recognition. For the success of solving the recognition problem, it is necessary to provide a sufficient amount of information. If it turns out that it is necessary to use the internal coordinate of the object, then it is necessary to ensure the formation of such information. To do this, an additional *TS* sensor is needed for direct or indirect information acquisition.

Studies show that a residual amount of information is present in the situation recognition tree [16–18]. Information is captured by the *FIX* unit and evaluated by other algorithms. In the case of continued development of the processes in the OCP, algorithms for additional recognition of information in the *DOP* block are involved (Figure 4). Additional algorithms are also used to clarify the recognition and

completion of the amount of information as well as for self-monitoring and partial diagnostics of the object, evaluating its performance, equipment and algorithms that make up the ExS expert system.

The purpose of further study is to obtain an additional amount of information from the OCP for its use in the GES_{RPA} recognition tree to increase the stability of RPA algorithms. To do this, the passage of the elementary component of interest is tracked along the template structures, which are the GES_{OCP} , GES_{SN} , GES_{ASNOM} schemes, a separate SN situation, a scenario of SN changing in time and a tree of possible SN developments. It can also be considered from the place of origin to the exit to the OCP through the coordinates of the OCP to the input of the recognition system and then according to the patterns of the GES schemes to the control system output of interest (Figure 4).

5. The development of well-known methods of working with dynamic OCP

There are several types of description of object models OCP:

- A. Only by electrical parameters. The description of the models is based on the coordinates of currents, voltages, conductivities, etc. It is typical for him to study the parameters of movements in time using mathematical dependencies and identification by RLC elements [7], performed on the basis of functional modelling (integration of differential equations). Each test impact leads to a transient in time. A general solution is sought as attractors and hodographs of unit calculations. But these methods do not eliminate the fragmentation of the obtained results, the loss of compatibility for high-frequency components (HFC) and super-slow information (s-LFC) and informal empirical data preparation. Therefore, most RPA devices have been developed by heuristic, expert methods.
- B. A structural-operator (SO) method. It establishes a connection between electrical and information parameters [7]. It is used to describe network circuits as a control object and control algorithms for the network zero sequence circuit. However, when solving related problems, namely, RPA, it turned out that the means of this method are not enough.
- C. A structural-informational (SI) method that works only with informational semantic components. The establishment of interconnections between elementary information components (terminal symbols, TS) is considered, which can be detected from electrical parameters. The movements in dynamics are considered, similarly to the automaton model, as transitions between states. Modelling leads to visual methods for displaying the results in the form of attractors and hodographs. Equilibrium points of solutions can be found by the game theory method. This allows you to work with electric power OCP on a more abstract level. The use of the SI method of pattern recognition removes such restrictions on the processing of only information without the participation of parametric components.

Studies show that the first two methods for describing OCP models are limited to obtaining a parametric OCP control system.

Fuzzy logic and neural network methods are well known. Common to these methods are the following actions: the decomposition of information into

elementary components; multiplication by weights; summation of the result; and comparison of the result with many threshold values. However, the extent to which these methods are used is limited by the specifics of the tasks they are to solve, for example, the dynamic development of the transition process in an OCP.

According to the SI method, the OCP structure is represented by transient signals [11–13]. The description is based on the fact that the total amount of information is supplied by all of the oscillatory circuits. These circuits constitute the OCP (Figure 7). Such an OCP model allows one to operate only on semantic components while improving RPA device algorithms. The OCP also appears to be a list of SN semantic situations.

An SN situation is understood as a dynamic change in the output of the OCP block diagram as a reaction to the appearance of changes at any point of the OCP (input or internal) [8–9]. That is, the SN modulates the industrial frequency signals in the OCP. Demodulation of the signals makes it possible to recognise the SN situation among the well-known and rather limited number of SN. Recognition is performed by automatic machines (A). Cases of a complex, simple SN situation and dynamic SN change [9–11] are taken into account. The signals at the output of the OCP are characterised by the consistent development in time of information components. These components are distinguished by information sensors [8]. The sensor outputs are terminal symbols and are grouped in TS chains. The totality of a TS is a morphological automaton (MorphA).

6. Description of the OCP by frequency components

According to the SI-method, all available information about the OCP is monitored. First of all, the OCP is replaced by oscillatory circuits with the corresponding frequency components (FC), that is, from the HFC to the super-LFC (Figure 7). Low-quality contours, in which only one half-wave of oscillation develops, are also vibrational. It is known that in RPA and SCADA devices, input information is sampled by time in the ADC block. The sampling frequency of the ADC is selected based on the presence of the highest-frequency component in the OCP. So, the ADC block will fix in the input signal all the components with a lower natural frequency (i.e. all the LFCs). So with the well-known operator description of the OCP, $y(t) = W(D) \cdot x(t)$. Constants in W with indices n and m describe the highest frequencies with which movements in the OCP are possible. We assume further that for the ADC, these constants a_N, b_M will be the initial a_0, b_0 . Then all other frequencies in the new W will be slower; therefore a_N, b_M will be the slowest s-LFCs. This

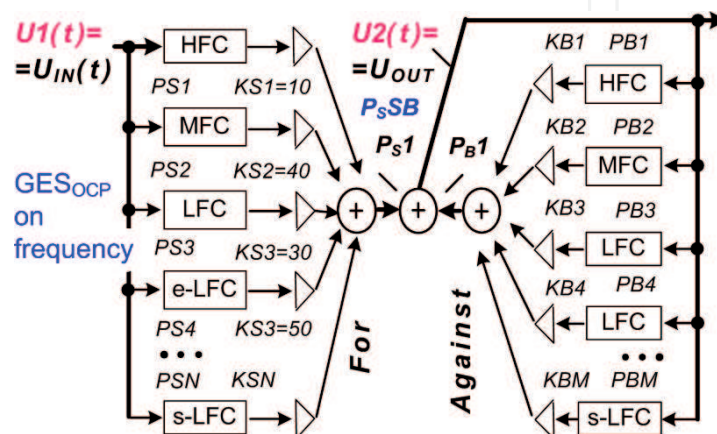


Figure 7.
 Equivalent structural scheme of GES_{OCP} with division of movements by frequencies.

allows us to provide a description of the OCP transfer function W for the highest-frequency component, which can be recorded by the ADC. You can control all the slow oscillatory circuits of the OCP. Very low-frequency motions may be present in the OCP. The lowest-frequency components and movements in the OCP can be considered informational (**Figure 7**).

This record allows you to highlight the presence of super-LFC in the OCP using the signals of emergency files of RPA devices. Such frequency components are generated in the OCP (**Figure 7**) by input shock effects of overvoltage, short circuit, OPG, operational switching, etc. Motions in super-LFC circuits of the OCP can be in different time ranges—second, monthly, annual and so on, for example, envelope industrial frequency response (e-LFC). e-LFC mathematically summarises signal circuits in OCP. s-LFC is only an information loop.

The OCP structure is represented by the GES_{OCP} scheme in the common field of TS information sensors that recognise SN situations. Each SN is divided into elementary components—nonterminal components of NTS. Information components are controlled by a logical change in TS outputs. For example, the amplitude parameters of the signals of the OCP loops are monitored and represented by the corresponding TS. Each OCP oscillation circuit is controlled by RPA devices. Devices at a morphological hierarchical level will be further represented by a GES_{TS} scheme with a G_{TS} grammar (**Figure 9**).

Extending the discussion about the presence of information loops to the features of higher-frequency loops, we can separate the signal description of processes in the OCP from the information description of the essence of the processes. This implies the task of searching for vibrational components in the ranges of the LFCs of super-LFCs by means of analysis in CAD of the frequency components of the alarm file signals. Solving the problem of separating parametric and information loops will help fill the lack of information when recognising SN situations in OCP.

7. Description of OCP equipment by information components

It is proposed to implement the stable working of recognition devices based on an algorithm for the selective search (SP) for a sufficient amount of information to perform RPA functions. The amount of information is accumulated based on the control of a number of information components, for example, the type of damage, the steadiness of the development of damage, the location of the damage, the presence of selective and blocking signs for damaged and undamaged areas, the absence of extraneous semantic situations, etc.

Further, attention is paid to the formation of OCP grammar for the tasks of improving the algorithms of RPA devices. It is necessary to develop consistent structural trees of OCP and RPA with respect to the semantic signal $S(t)$ as well as a method for the end-to-end mathematical description of transients in the ‘network equipment-RPA devices’ hierarchical chain in the automatic control system (**Figure 4**). This is part of the developed SI method.

The SI method is based on the application of sequential graphic transformations from a circuit diagram based on electrical parameters and the transition to a circuit based on information components. The structural-operator method is involved for the formal description of the OCP by parametric components [7]. Then the transition to the description of the SI method is carried out only by information components. The transition is performed by introducing terminal symbol sensors at the control points of the OCP scheme (**Figure 9**). In the internal OCP scheme, these can be imaginary points, since most of the structure of the OCP is not divided into control parts.

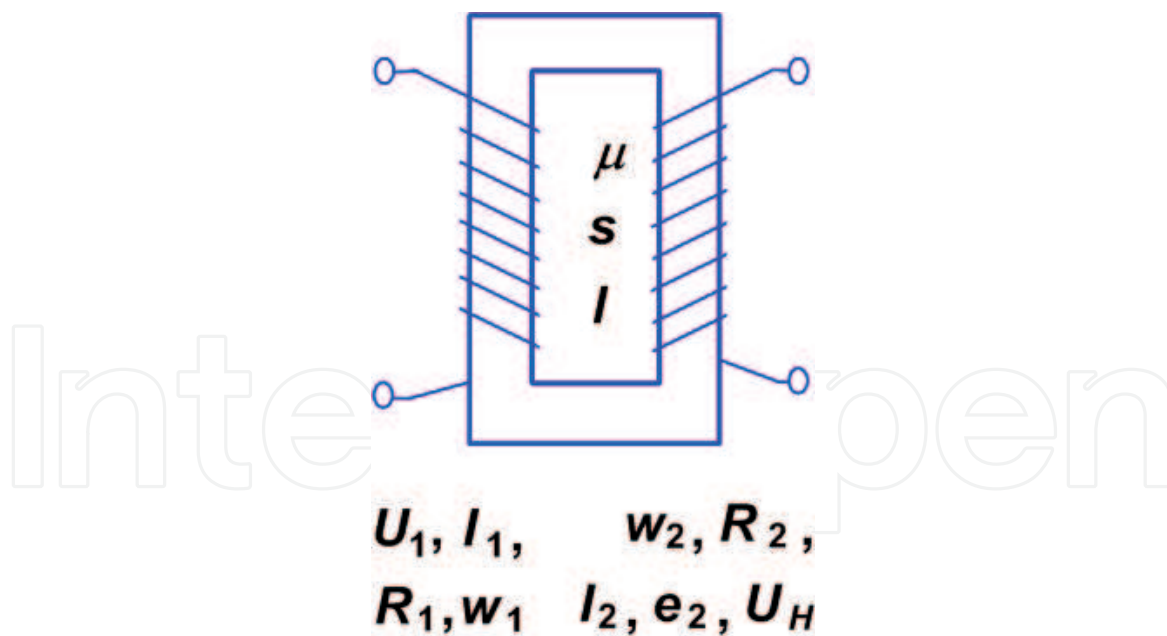


Figure 8.
 Hardware example diagram.

For example, **Figure 8** shows the SO description in the form of electrical parameters of one of the elements of the OCP—transformer. Information flows are generated by inertial fields and are described by the operators $D = d/dt$, $1/D = S$. The input to the circuit is the coordinate of the perturbation signal $SN(t)$ for OCP. According to the SI method, at each control point of the circuit, the output of the elementary transfer function must be monitored by the TS sensor with the corresponding weight coefficient. TS consists of a GES_{TS} scheme. It includes a filter and a threshold element ρN . The TS acts as an observer for the operation of the structural-operator diagram of the OCP. Naturally, this is an imaginary and often unrealisable scheme in connection practice. But the implementation of such a solution is performed in CAD. This makes it possible to implement a theoretical description of the OCP scheme. In OCP, all TSs are combined into a more general S-filter, which generates the signal $S_{OCP}(t)$ and is controlled by the threshold ρN . Thus, a rigorous mathematical description of the OCP is feasible.

This allows you to build a mathematical model of OCP in CAD for the selective search algorithm SP to reach the maximum amount of information. Functional modelling in CAD will provide an additional amount. The passage of the informational components of the SN semantic situation through the structural-informational models of electrically connected equipment (**Figure 8**) of the OCP using the signals of real emergency files supplied by modern devices is simulated. If theoretically and practically received amount of information from real OCP is sufficient for recognition, then the problem is solved by practically recognisable algorithms. OCP is observed and controlled by recognition algorithms. If the theoretical amount of information is not sufficient for distinguishing SN and making decisions in particular cases or in the general case, then indirect methods of detecting errors in management are necessary.

8. Representation of OCP by semantic components

GES_{OCP} scheme description. The structural tree of $SN \rightarrow TS$ formation for the OCP uses the internal coordinates and OCP contours not observed by the GES_{RPA} device circuits (**Figure 9**). The construction of the GES_{OCP} scheme proceeds from three foundations:

- a. *Structural-operator description.* We will compile descriptions of the OCP and high-voltage equipment based on **Figure 9**. We will divide the description elements into alternative streams ‘For’ and ‘Against’ in relation to the formation of the OCP output.
- b. *Separation of movements by frequencies.* We transform the structural-operator description of the OCP to the canonical form of a digital filter with an infinite impulse response (IIR) according to the rules of structural transformations (**Figure 10**). This possibility follows from the theory of filtration, according to which any inertial model can be described by an IIR or FIR filter. We will focus on the ‘central’ elements of the GES scheme. The ‘Cons’ group includes flows initiated by the U_{OUT} output and arriving with a minus sign at the central internal adder. The elements of the ‘Cons’ group belong to the *Filter* block on the basis that the *Filter* passes only a selective signal.
- c. *Mutual grammar mapping of $G_{OCP} \approx \Sigma G_{RPA}$.* In the OCP structural models obtained, when the situation is $S1$ ‘NM’, the output information stream ‘balances’ the input stream. If the ‘balance’ is violated, a transient occurs in the OCP. The transition to a new state of the SyntA automaton occurs as the transition process develops and is determined by the SN situation. Since the physically non-separable design of the OCP and equipment has its own movements, the IIR filter scheme is more consistent with the OCP scheme.

The OCP model is built on the basis of a bundle relative to the internal adder. In the IIR filter scheme, each rule P is assigned a weight coefficient KN or KM (**Figure 10**). In the structure of digital filters, the inertia is set discretely by the SyntA structural automaton, and the dynamic behaviour of the filters (their own transient process)

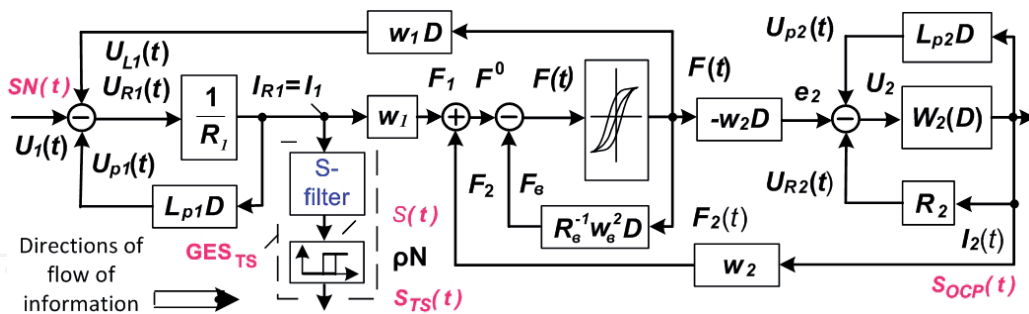


Figure 9. Structural schemes of ownership, prompted by the operator method.

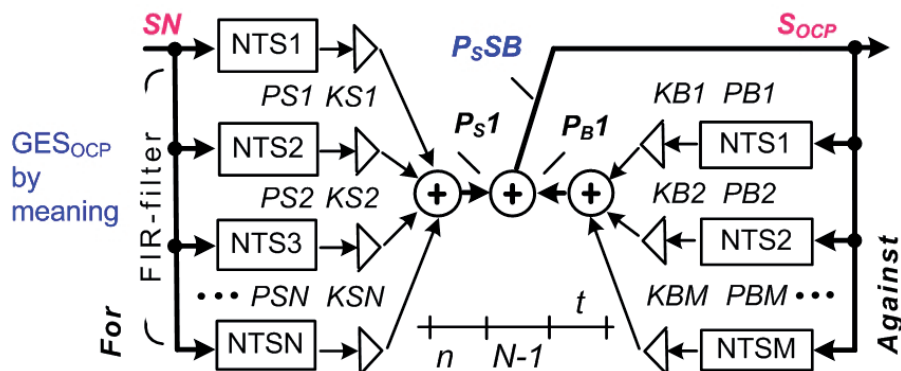


Figure 10. GES_{OCP} scheme for dividing SN situations into elementary components of NTS .

depends on the information received from the input and from the output of the OCP circuit. The G_{OCP} grammar differs from G_{RPA} in (2, 3) in that its elements have an oscillatory, harmonic output, while G_{RPA} elements have a threshold output.

Separation of movements by frequencies: The OCP representation is introduced as a description of the G_{OCP} grammar, including a list of SN situations (root S characters). SNs are interconnected by the semantic rules of PN (Figure 11) and characterise the work of OCP. In turn, the SNs themselves are represented by semantic information components (terminal and nonterminal symbols) and the PN rules of their relationship. Thus, the lists of the grammar G and the GES schemes form the semantic model of OCP, composed of semantic components. The start and end vertex is the SN 'NM' situation.

By dividing the movements according to frequencies, we mean to clarify the number and parameters of the oscillatory circuits in the OCP (Figure 7). Based on the descriptions obtained by the structural-operator method [7], it is possible to represent the structure of the OCP definition tree in the form of the relationship of a number of oscillatory or inertial circuits (Figures 7 and 9). The method of dividing movements by frequencies from the point of view of the SI method is as follows.

According to the SI method, when frequency motions are divided, all the frequency circuits of the OCP are controlled [9–11]. If the selective GES_{RPA} part (synchronous detector) controls one circuit (Figure 7), then the blocking part of the GES_{RPA} monitors the other circuits. For information to appear in the slowest OCP loop, a series of events in the transition process must occur, and a sufficiently large amount of information should have accumulated. But the goal of the RPA is to minimise the development of events in the OCP. As a result of this, movement in super-slow circuits rarely occurs; the appearance of transient information in the OCP can be interrupted. This leads to the indicated conflicts 'a' to 'c'.

For the OCP scheme: (A) The number and parameters of the oscillatory circuits in the OCP are determined from the mathematical descriptions and signals of the emergency files (Figures 7 and 8). (B) An OCP is drawn up in the form of an IIR filter (Figure 9). (C) The GES_{OCP} scheme is compiled in the form of an FIR filter as the inverse of the GES_{RPA} scheme according to $G_{OCP} \approx \Sigma G_{RPA}$ relative to ΔSN (Figure 10). (D) The elements MorphA, SyntA and SemA stand

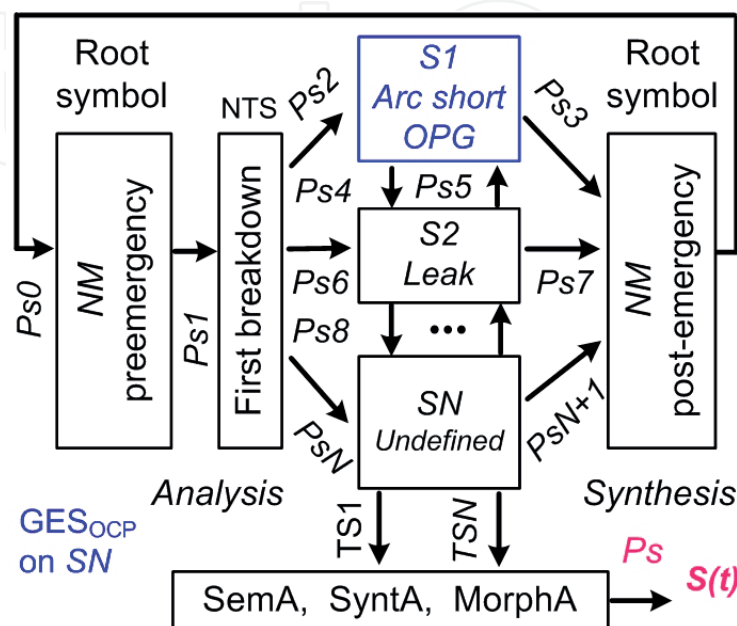


Figure 11. Scheme of the 'GES_{OCP} by the SN situation'. Shaping SN and signal situations $S(t)$.

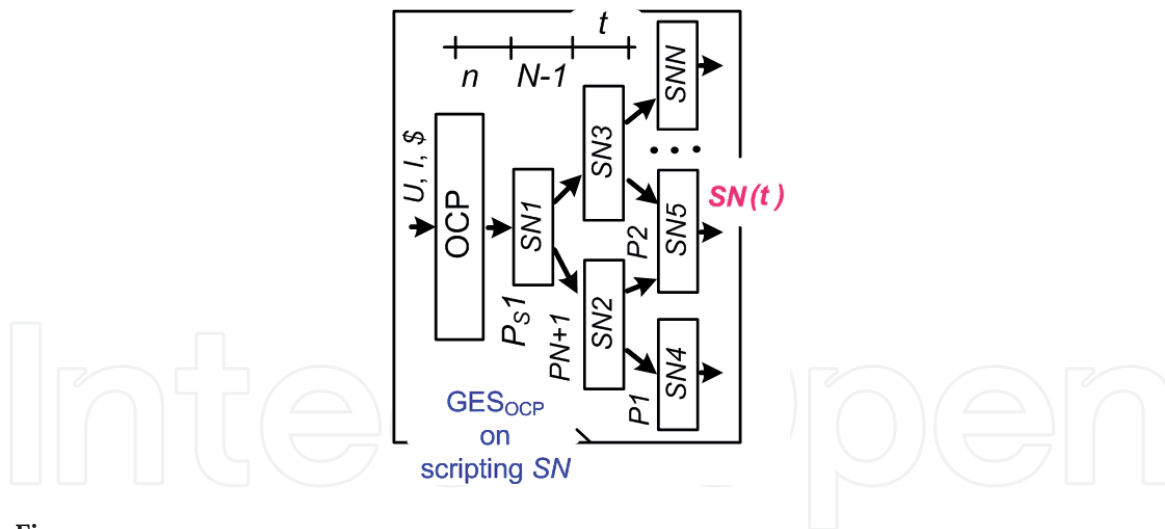


Figure 12.
Tree scripting SN in dynamics by signal $S(t)$.

out in G_{OCP} and are implemented in separate computing parts. (E) W_{TABL} is filled out to represent the OCP. Training and supervising samples of SN situations are formed.

Such a volume of simultaneously solved problems leads to a limited capability to divide movements by frequencies for modelling in the OCP and solving smart grid problems.

Separation of movements by meaning: Further solution of the problems leads to using the method of separation of movements by meaning [9–11]. We will understand the separation of the dynamic flow of information into hierarchically subordinate structural elementary parts and the operation of these parts (**Figures 10–12**). Additionally, the division into alternative information flows ‘For-Against’ is performed.

The relationship of the methods of separation of movements: The separation of motions in frequencies determines the structure of oscillatory motions in the OCP (**Figure 7**), but the meaning of these motions is determined by the division in meaning (**Figure 10**). To clarify the relationship of the methods, an analogy can be introduced. The method for separating movements by frequencies describes the relationship of all the available circuit elements. This description is located within a single plane. At the same time, the LFC processes take up the resources of the computing system while the HFC processes are being calculated. The method of separation of movements by meaning represents the relationship of the elements in the circuit, not in the plane but in space [11–13].

Within the framework of the SI method, we can talk about the method of separating movements by frequencies as an additional preliminary hierarchical level of the method of separating movements by meaning. The application of the above methods can be as follows—structural-operator, identification, separation of movements by frequencies to describe the OCP and then the SI method with structural-morphological, structural-syntactic and structural-semantic steps.

9. Structuring OCP semantic SN situations

The parameters of the electrical signals are only the SN carriers. The characteristic features of the input coordinates of the RPA are the natural spatio-temporal sequence of consideration of the information components. The SI method is applied to the description of the OCP. All SN components are located in a certain way relative to each other and relative to the general synchronising time axis [10, 11]. The

semantic information about the state of the OCP can be represented in the form of separate elementary SN situations. Each SN characterises the corresponding known (classical) state of the OCP. The problem arises of separation of the information set of states and recognition of the SN. In the limit, $S_{OCP}(t)$ can be specified by a single SN. This becomes the minimum information for building an OCP model, which reduces the time required for a single calculation in CAD.

The OCP scheme can be in dynamic consideration in one of the semantic situations of SN. Suppose that $S1$ 'NM' corresponds to the steady-state values of the OCP internal parameters (operator outputs, NTS symbols, P rules). Thus, the concept of semantic situation SN means the appearance of the reaction ΔU_{OUT} of the OCP structural scheme in response to a change in Δ in any OCP coordinate. We also understand the structural, logical relationship of the individual TS control points in the structural-operator model of the OCP or equipment that form the transient signals (**Figure 9**). And also SN means a part of the OCP formation tree with activated root symbols PS , PB , then NTS and TS. The steady state of the OCP parameters can be distinguished and named SN. By the SN situation template is meant the sequence of characters PS , PB , TS, NTS of the OCP tree established for this SN, which is formally described by the G_{OCP} grammar. Thus, it is necessary to systematise all SN situations. These SN definitions are based on the OCP. The definition of SN relative to RPA devices is introduced as an analogy—each SN corresponds to a stencil with the corresponding sequence of 'selectivity windows'. Compilation of the OCP generation tree can be planned using the table transfer function $W_{TABL} = TSN/SN$ [9, 11]. W_{TABL} is populated based on emergency files as well as by calculating OCP models and GES_{RPA} schemes in CAD.

The SN tree consists of a series of SN, replacing one another in time logically sequentially as the transition process develops (**Figure 12**). A scenario of SN development is formed.

A special role in the operation of the OCP is the situation of SN 'NM'. Although this SN does not apply to single-phase insulation faults to ground (OPG), it is from this that it begins, and it ends with its analysis of the transient into semantic and structural-informational components (**Figure 13**). The normal SN mode includes: (a) SN 'NM' itself; (b) SN 'processes not related to OPG'; and (c) SN 'neutral displacement', caused by the exceeding the normalised levels of emergency situations and resulting from the operation of the technological equipment of the distribution network.

Characteristic SN situations can be highlighted (**Figure 12**). The initial OPG breakdown (the first damage to the network insulation until a pronounced neutral reaction of the network), then the network reaction to the initial breakdown, subsequent OPG breakdowns and the restoration of SN 'NM' after OPG elimination are different stages of the transition process, of which OPG is a particular case. Of these named elementary SNs, the ' GES_{OCP} by SN situation' formation tree is composed. Recognition algorithm in RPA devices restores exactly such SNs, SN scripts and SN

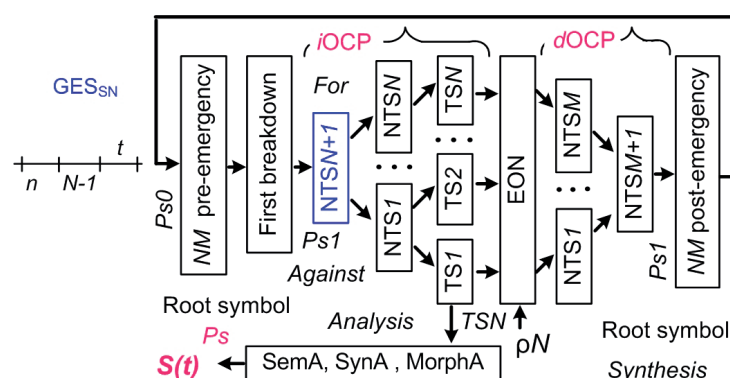


Figure 13. Structural schemes of GES_{SN} semantic situation SN in OCP by signal $S(t)$.

script tree. Therefore, the description of the OCP obtained by the SI method should return all possible relationships in SN in the SN tree.

In the dynamics, a sequential change of the elementary SN occurs. As a result, a scenario for the development of the SN appears. The OCP can be in one SN state for a long time (e.g. SN 'NM', SN 'metallic OPG', SN 'skew'), for a short time (SN 'metallic') or very briefly (SN 'first half-wave OPG'). Scenarios of SN development can also be sequentially described by the logical change of certain elementary SN s. Such scenarios are typical for OCP and should have their own names (e.g. SN 'intermittent arc', SN 'self-eliminating multiple breakdowns'). In RPA algorithms, such SN scenarios are restored at a semantic level of recognition. It is possible to create an SN transition tree (**Figure 12**). Both mutually inverse formation and recognition trees make up the 'GES_{OCP} scheme for the SN situation'. We can distinguish 'GES_{OCP} along oscillatory circuits' schemes for considering the separation of movement and a 'GES_{OCP} scheme for SN semantic situations', which shows movement in the meaning of SN situations.

Thus, the recognition algorithm determines not only the SN situation but also the essence of the transition process in the OCP. At this recognition level, a significant part of the non-selective operation of RPA devices occurs due to the limited or lack of appropriate PN rules in RPA algorithms.

The task associated with RPA and OCP management has the peculiarity of intersecting SN semantic situations. Generally speaking, in order to increase the stability of the operation of RPA algorithms for each area of overlapping situations SN , it is desirable to define its own information sensor TS. The more it is necessary to determine the current SN , the greater the number of TS that should be laid in the structure of the algorithms. Reducing this intersection is the ultimate goal of a theoretical description of the OCP. For this, according to the theory of information, it is necessary to supply an excessive amount of information for rechecking, determining errors and recovering information from errors for a recognition system. In practice, the implementation of this important property does not occur. This leads to recognition errors.

In a real OCP, there are third-party processes unrelated to typical SN situations and SN scenarios. These may be present for a long time and be registered by some TS in the RPA. They need to be discovered and their named list compiled. Formation can be in CAD based on mathematical functional modelling, with real emergency files. In the presence of a generated mathematical model of the OCP or individual equipment, it is possible to introduce situational changes from the signal source at a certain moment during the transition process, which interfere with SN 'NM', for example, by short-circuiting or shunting a single element, or a series of elements in the structural-operator model of OCP, or equipment (**Figure 8**). This leads to observable transients. Similarly, it is possible to repair the cause of damage through transient signals in real emergency files.

10. Drawing up a combined GES scheme

The combined scheme in **Figure 14** allows one to obtain a high-quality SN recognition model in view of the mutual reflection of $G_{OCP} \approx \Sigma G_{RPA}$ and the possibility of comparing $S_{OCP}(t)$ and $S_{RPA}(t)$. From a comparison of the parts of **Figure 14**, it follows that the synchronous detector is a 'central' element in the GES_{OCP} scheme. It is known that a synchronous detector consists of a comparing element based on the multiplication or summation, a zero component filter and a threshold device. The filter turns out to be feedbacks from the U_{OUT} output to the common adder. When replacing the elements covered by feedbacks in **Figures 7** and **10** with the transfer function, a more general OCP scheme is obtained in the form of a unidirectional $SN \rightarrow TS$ formation tree (**Figure 14**). The scheme makes it possible to solve modelling problems and smart grid information tasks [7–16].

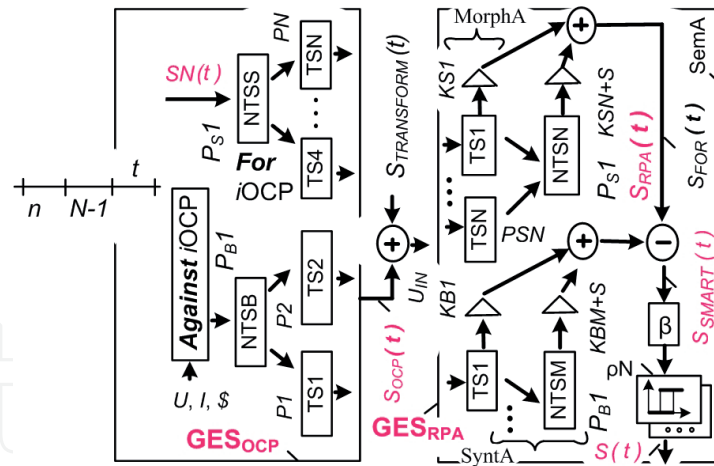


Figure 14. Structural schemes of GES_{OCP} and GES_{RPA} by signal $S(t)$ and $G_{OCP} \approx \Sigma G_{RPA}$.

The minimum information for constructing an OCP model are two elements of the $iOCP$ information part—a selective TS and a blocking TS. Also, the bundle—the signal source $S_{OCP}(t)$ and the controlled frequency generator—will be the minimum OCP model [11–13]. The generator can have amplitude, frequency and phase modulation of the output signal from the super-LFC to HFC range, depending on the problem being solved. Such OCP models minimise the time required for a single calculation. Thus, models of the OCP, RPA devices and S-detector were built. The $S_{OCP}(t)$ recovery algorithm from the OCP model can be used to decrypt the accumulated emergency files (**Figures 11–13**). For this, models of the ExS expert system and the diagnostic message generator are used (**Figure 4**).

11. Balancing structures and algorithms using game theory

A ‘balancing’ task arises when considering GES schemes (**Figure 14**). According to $G_{OCP} \approx \Sigma G_{RPA}$, it is possible to set the ‘balance’ task for the GES_{OCP} scheme as well. The solution of the ‘balancing’ problem is a development of the theory of the SI method [8–11]. A numerical determination of the equilibrium point of GES schemes is proposed when considering the ‘For-Against’ problems for OCP and ‘selectivity-blocking’ using the game theory method [14]. The result is compared with the published solution through the method of dynamic functional modelling [11, 17]. This section briefly discusses the algorithm for solving the problem, designed in the form of a computing module. The problem when using computational modules is the possibility of a multivariate interpretation in the formulation of the problem and in the analysis of the results. The following aspects of the problem have emerged—(a) the need to be an expert in the specific problem being solved; (b) being sure of the possibility of using the module to solve the particular problem; and (c) it requires the presence of training and supervising samples of real semantic situations for testing and verification of results. Experience of using the module can be gained on the basis of modelling in CAD.

In the ‘balancing’ game, the competitors are the two root weights, $K_S S$ selectivity and $K_S B$ blocking, where the corresponding root characters are $S_S S$ and $S_S B$. The contest is won (victory) V , when there is a clear victory for $K_S S$ or $K_S B$ —the correct operation of the threshold element ρN . It is lost L if there is ‘error excessive response ρN ’. The competitors have the following features, aimed at implementing the requirement to increase the stability of RPA devices in complex SN situations. The $K_S B$ blocking group always fights ‘compete $K_S S$ and $K_S B$ ’ until they win: ‘The $S_S B(t)$ signal is greater than $S_S S(t)$ ’ of the blocking group and retreats with ‘error excessive

←	↓	<i>Selectivity, 1-z, For, (Doves, D), K_SS</i>	<i>Blocking, z, K_SB, Against (Hawk, H)</i>
$S_D(z)$	Selectivity, <i>For (Doves), K_SS</i>	$S(S,S) = (V-L)/2-E$ $S(S,S) = 30$	$S(S,B) = -L$ $S(S,B) = -5$
$S_H(z)$	Blocking, <i>Against (Hawk), K_SB</i>	$S(B,S) = V$ $S(B,S) = 75$	$S(B,B) = (V-W)/2$ $S(B,B) = -37.5$

Table 1.

Payment matrix of the participants in the ‘balancing’ game with example.

operation ρN ’ in the case of serious injuries, with ‘error excessive failure ρN ’. The $K_S S$ selectivity group is limited by the threats of winning: ‘The $S_S S(t)$ signal is greater than the threshold ρN ’; however, if it gets to a ‘complex SN ’ bout, the selectivity group recedes, with ‘error excessive ρN failure’.

Thus, there are four game options. These appear more pronounced in a difficult SN situation, when there is little information for the correct operation of the threshold element ρN . The results of the game are evaluated in the form of arbitrary units (points) received or lost by the participants.

In the ‘grammar G of one of the devices’ population, we denote the share of the blocking group with z , and then the fraction of the selectivity group will be $1-z$. If two competitors $K_S S$ and $K_S B$ are randomly participating in a ‘one of the SN situations’ clash, then with a probability of $z \times 2$, they are two $K_S B$; with a probability of $(1-z) \times 2$, they are two $K_S S$; and with a probability of $2 \times z \times (1-z)$, they are $K_S S$ versus $K_S B$.

Let us designate the parameters of the ‘balancing’ game as damage from injury W , ‘error excessive failure of ρN ’ and energy consumption E for the opposition ‘operation–failure of ρN ’. We will assume that in the ‘balancing’ game, the winning ‘correct work ρN ’ is estimated as follows (Table 1)—victory $V = 75$ points, loss $L = 5$ points, damage from injury $W = 150$ points and energy consumption for opposing $E = 5$ points. Let us find the average number of points that competitors $K_S S$ and $K_S B$ get as a result of the ‘one of the trainings SN ’ fight. The results of the ‘balancing’ game can be visualised in the form of a payment matrix (Table 1). Based on Table 1, on average for the blocking group, we get

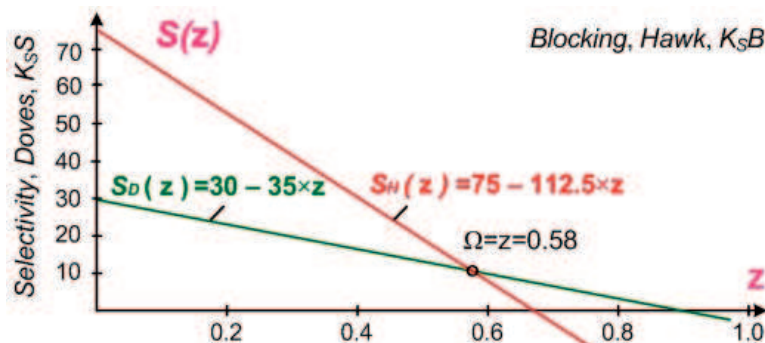
$$S_B(z) = S_H(z) = 0.5 \times (V-W) \times z + V \times (1-z) = V - 0.5 \times (V+W) \times z = 75 - 112.5 \times z.$$

Similarly, for the selectivity group, we get.

$$S_S(z) = S_D(z) = -L \times z + [0.5 \times (V-L) - E] \times (1-z) = 0.5 \times (V-L) - E - [0.5 \times (V+L) - E] \times z = 30 - 35 \times z.$$

The graphs of these equations in the S - z coordinate axes are shown in Figure 15. As can be seen, the winning lines ‘correct work of ρN ’ for the groups selectivity $K_S S$ and blocking $K_S B$ intersect at the equilibrium point Ω defined by the relation:

$$\Omega = 75 - 112.5 \times z = 30 - 35 \times z, z = 45/77.5 = 0.58.$$

**Figure 15.**

Graph of the winning line of the participants in the ‘balancing’ game.

In **Figure 15**, we choose the reliability point $z_{\text{RELIABILITY}} = 0.8 \times z = 0.8 \times 0.58 = 0.464$. At this point, we put $S_S(z)/S_B(z) = K_{SS}/K_{SB}$. The ratio $k_R = K_{SS}/K_{SB} = 13.76/22.8$. Then,

$$K_{SS} = k_R/(k_R + 1) = 0.356, K_{SB} = 1/(k_R + 1) = 0.624.$$

12. The specifics of managing dynamic objects

An object is considered to be managed when it can be transferred from any initial state using an input action to a given state within a finite time. In this case, the ASNOM system stability requirement must not be violated. Stability of operation is understood as the ability of the system to return to the initial SN 'NM' situation when OCP parameters change within specified limits in the absence of malfunctions in the system (**Figure 4**).

A latent malfunction should lead to exceeding, by one or several components of the vector of parameters Ξ , the limits acceptable for the normal operation of the OCP. The fact of exceeding by Ξ the boundaries of the parameters will be considered a sign of a latent or developing SN 'unrecognised' situation. A change in the steady-state value of one parameter Ξ leads to a change in the steady-state value of the parameters Ξ of all the components of the boundary vector.

In dynamics, some SN, given the random, complex, spontaneous development of damage, or the irregular, unstable behaviour of OCP elements, can replace one another very quickly, according to the GES_{SN} or GES_{OCP} tree SN scenarios. Such situations are 'difficult'. A more complete definition and separation of the SN 'violation NM' is possible based on automatic control of the ASNOM system's controllability parameters [13]. These parameters are controlled if a disturbance appears. Natural functional disturbances of the OCP are not a sufficiently complete search signal of self-control from the point of view of determining and separating the SN 'violation NM'. So, for example, in the case of malfunctions of the elements of the formation of the information signal $3u_0$, the error ε mismatch in the ASNOM system will still remain in the zero zone (**Figure 3**). Although natural resonance detuning is not a sufficient search signal, its use can increase the frequency of self-checking. For a more complete definition and separation of the SN 'violation NM', an artificial search action is introduced into a closed ASNOM system (**Figure 4**).

It can be proposed to use 'additional' information components in the selective search algorithm SP of sufficient information in cases where there are no 'main' information components, despite the fact that this proposal tends to solve the problem in the direction of 'complicating' the devices. For this, additional rules for the recognition of P_{DOP} and an excess of information and additional recognition time are required. The device solves the following problems within the framework of the automatic stabilisation system: (1) eliminating the ambiguity of determining the essence of transients; (2) control of the amount of information necessary for the operation of relay protection and automation algorithms; (3) monitoring the current possibility of self-destruction of the damage site; (4) monitoring the effectiveness of measures over long time intervals; and (5) implementation of the requirements of self-monitoring and diagnostics when 'energised'.

13. Simulation in CAD of OCP control algorithms

All the variety and 'complexity' of real-world network signals is controlled by the high-frequency emergency files of RPA device registrars. These registrars supply emergency files for outsourcing analysis. [8, 11, 15]. To solve the control

problems and eliminate the instability of the algorithms, we will continue to use the dynamic synthesis method in CAD. A presentable sample of signals from the OCP emergency files is used. In the synthesis and development of real-time algorithms in CAD systems, real circuit diagrams are used. The physical implementation of tasks is monitored in a continuous improvement mode, from 'simple' to 'essential'.

A model is being developed in *Matlab* to study the properties of a class of dynamic objects for the synthesis of algorithms for managing them over time [11–16]. Monitoring the operation of the system and algorithms is performed at a given time interval in the form of alarm file signals (**Figures 4, 7, 9, 13, and 14**). Device models are also represented by GES_{TS} and GES_{RPA} schemes. The more structured and detailed the description of such schemes is obtained, the more qualitatively it is possible to build stable recognition algorithms. Sources of interference signals and damage are used for 'hacking', connected to control points of the device. Hacking signals are generated by arcing and interference burning models for various types of development of insulation damage, in emergency operation modes and in normal operation of an object. The training and control samples of signals of real emergency files are generated.

The purpose of the simulation is to develop ways to search for additional information. The modelling problems were solved by dividing the project into hierarchically subordinate computational parts with the result reduced in the generalising part [11–13]. Each part is calculated separately. Groups of preparatory, main and resulting elements are allocated. Each subsequent group is less active and does not consume computing resources. The more elements in the circuit, the more computing parts it can be divided into. As a result, the time required for a single calculation is reduced while maintaining the stability of the calculation. For example, the group of preparatory elements (MorphA) may include the signal sources, both generating and controlling, of measuring transformers, etc. In the group of basic elements (SyntA) are the inertial circuits of equipment, etc. (**Figure 4**). The resulting group (SemA) includes elements of the executive bodies, of operational switching, etc. Thus, in addition to modelling, first a certain third-party algorithm for preparing the project for calculation follows. Such an algorithm can be automated. The main general synchronising parameters for the separation of movements are the well-known preliminary settings of the CAD project—the calculation time and control points for displaying information.

14. Examples of dynamic OCP control algorithms

The practical significance of the work comes from solving the problems of protection against earth faults in medium-voltage networks of 6–35 kV [7–9, 16–18]. The results are used to improve the ASNOM system devices (**Figures 1–4**), namely, a selective search for the SP of a damaged part of the 'P-VCR-SP' network with the functions of a high-frequency recorder VCR, an RPA terminal 'T-LZSC-ARC' with the function of auto-compensation of ARC capacitive currents and a widget 'W-LZSC' for a window graphically representing of the terminal information on the computer display of the automatic control system.

An analysis of the waveforms of the real high-frequency transient emergency files in the OCP shows that as the transient develops, the ASNOM system will in most cases enter a state of information sufficiency [11–13]. Therefore, if the ASNOM system is not blocked in the case of insufficient information, as is usually done in known devices, and continues to work according to the appropriate algorithms, then the solution of the problems will be achieved.

Automatic resolution of practical conflicts: The important practical significance of the whole work is automatic conflict resolution in the work of RPA

algorithms, the lack of solutions of which has led to a decrease in the reliability of OCP operation, but could not be resolved by other methods. In resolving conflicts previously, there was a reliance on technical and economic optimisation methods, with which it is difficult to practically eliminate doubts about the correctness of the method chosen for dealing with the development of damage in the network. Conflicts were found during practical research in real networks.

Known management conflicts for OCP are: (A) The requirement to quickly disconnect the damaged section of the OCP and realise the network's ability to isolate itself for self-repair; (B) The possibility of damage to the weakened isolation area of high-voltage equipment caused by a voltage increase in healthy phases in cases of the malfunctioning of protective equipment, and the recorded efficiency of the resonant network's neutral tuning; (C) Automation of the control algorithms of technological processes and the forced opening (transfer to alarm) of the output of an unstable selective relay protection; (D) The tradition of full control over the operation of the network, but a lack of control over the long-term effectiveness and correct functioning of the protective equipment of the network and of the devices that implement the selected type of neutral grounding in the tasks under consideration. Here are some examples of resolving some conflicts:

Conflict resolution A: 'temporary compromise'. This is based on the formulation of the general problem of stabilising the normal operating mode of the OCP (**Figure 16**). It is based on a change in the response time t_{OFF} of the selective search relay SP depending on the value of the semantic signal $S(t)$. Change t_{OFF} is not prohibited for the OCP and may be in the range 0.1 s to 4 h. **Figure 17** shows a diagram illustrating the change in the t_{OFF} value depending on the appearance of various (structural) information (TS, NTS) components of the transition process in the OCP. If, during the transition process, counting from the appearance of 'LFC3u₀', the indicated TS and NTS have appeared, and then the damaged section will be disconnected after the corresponding

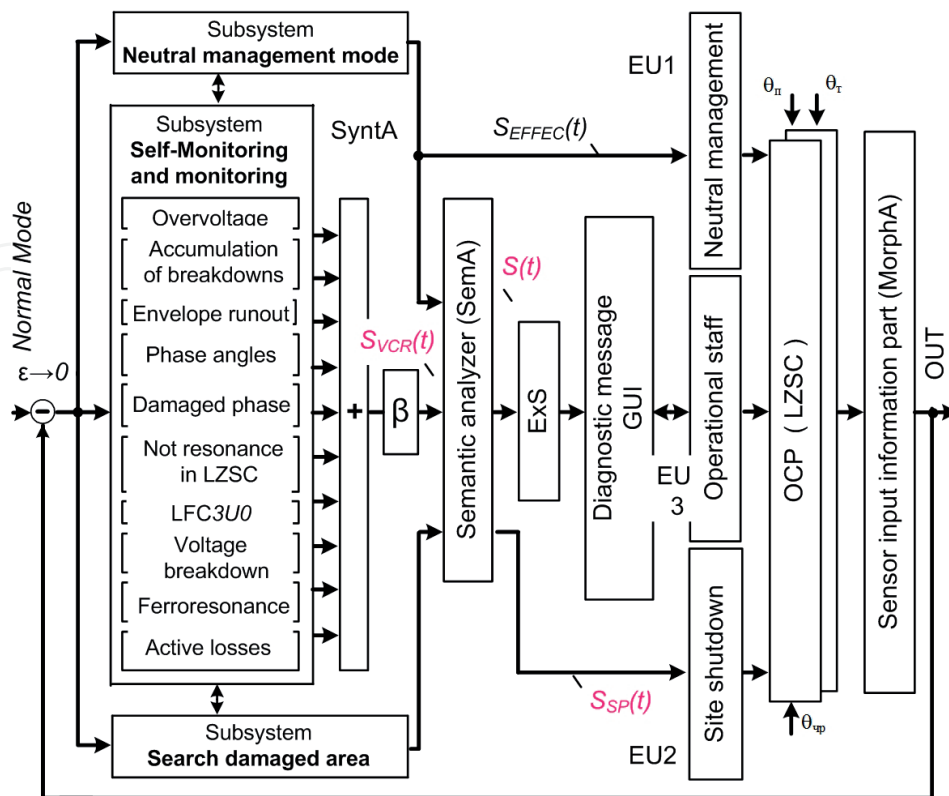


Figure 16. Method for automatically resolving a temporary conflict between SP devices and resonant tuning of a network zero sequence loop (LZSC).

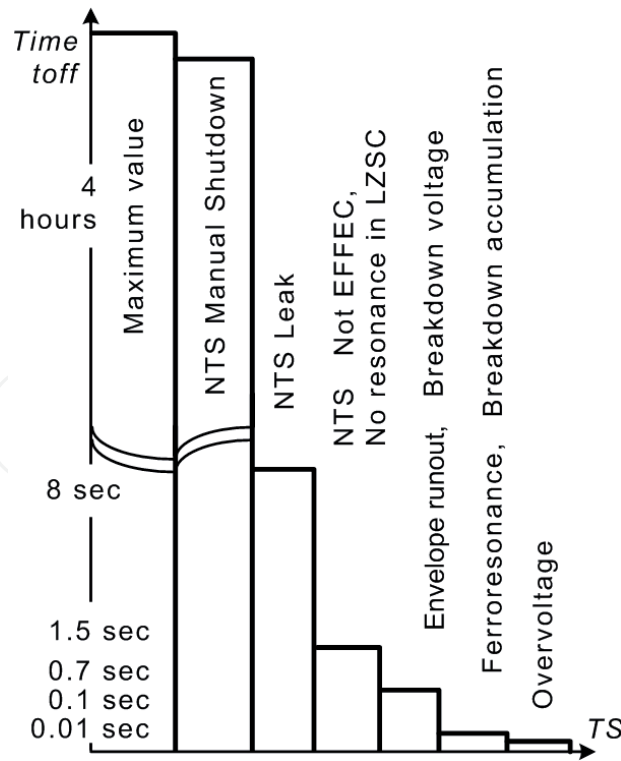


Figure 17.
Changes in time t_{OFF} in the ASNOM system depending on $S(t)$.

time interval t_{OFF} . If a longer t_{OFF} time has elapsed from the start of the transient than indicated, and then TS and NTN appear, then disconnection occurs immediately.

Conflict resolution C: ‘automation of algorithms’. Analysis of the solution of the problem at the modelling stage shows that for correct and effective working of the operational staff in the event of the appearance of SN ‘undetectable’, it is necessary to display the operation of the ASNOM system in the ‘scanner-analyser’ mode (Figures 4 and 16). The screen displays the line of the entire transient process in the network, starting from the background and ending with the current moment. This will help the operating staff in the absence of automatic repair of the damaged network section to eliminate it in manual mode.

Conflict resolution D: ‘on the coincidence of exits’. A method is proposed for the selective search of the required amount of information to detect equipment failures, failures in RPA devices and then through the RPA devices OCP faults (Figures 4 and 15). The algorithm generalises the functions of self-monitoring, monitoring and diagnostics ‘under voltage’. The criteria of active and passive selective SP search are used with the control of natural and artificial transient processes in the OCP [11, 13]. For example, the active methods may include phase-voltage imbalance in a network with a resonantly tuned neutral or phase shunting to ground in a network with an isolated neutral (Figure 3).

An outsourcing method for investigating SN situations using alarm file signals is being implemented. For this, specialised organisations or individual specialists may be involved. Firstly, it is assigned that the output of the TS is formed as efficiently as possible. If the recognition ability is preserved and the amount of information is sufficient, then the second stage of the investigation begins—the establishment and refinement of the parameters of the TS, their weight coefficients of significance and the quality of the TS structural elements. If the problem is not solved, we must investigate further along the information formation chain. The structural tree of the formation of information inside the control object (high-voltage network equipment) should be studied.

15. Expanding the scope of the SI method

The SI method is universal enough for tasks that can be reduced to informational. Information flows can describe the control and protection algorithms of various control objects not only in the energy sector but also in other areas of control. The problems of automatic control in the classical setting are being solved. For example, coordinate control, search, extreme, adaptive, optimal, automatic, automated, expert, dispatch control systems, etc. The problems of pattern recognition in linguistics are solved: decision-making tasks based on morphological features, for example, biological, mechanical, etc., and recognition of information carried by sound vibrations, for example, cochlear and sound pattern recognisers in medicine.

The SI method allows to improve control systems with a lack of initial information in situations that are difficult in meaning when operating the control object. When the input information is changed, impulse rarely appears, consisting of separate diverse components.

Consistent application of SI method templates allows you to not ignore the necessary stages of obtaining results when solving management problems. The statement of management is carried out in the dynamics of the development of processes with the issuance of management commands, for example, up-down, buy-sell, etc. So, first, when solving problems, a workplace is built that allows you to realise the final desired result in CAD, for example, a device issuing commands and receiving input signals. The final result is immediately controlled. In case of its inconsistency, part of the control algorithm changes. Further, as the problem is solved, control algorithms are improved. The development of algorithms proceeds along the path of improvement: 'from the simple to the necessary'.

16. Conclusions

1. A class of dynamic control and protection objects has been allocated for solving problems of improving control algorithms. The development of the SI method for dynamic objects with minimal reference to the specifics of objects is shown. A generalisation of the results is carried out for application to a wider range of tasks in relation to the initial electrical tasks.
2. Problem-solving is obtained using the instrument of formation and control of a semantic signal. It allows you to operate with a minimum of information but to control the necessary amount of information and solve problems at a more abstract level as well as simulate the operation of specific recognition algorithms, taking into account the specific operation of objects.
3. A sequence of patterns is presented that allows one to obtain solutions of problems by the SI method. Templates are the reference points for the solution. By templates, you can explore the passage of information components as on navigation charts through interconnected structures. Examples are considered for OCP, individual equipment, transient recognition algorithms and automatic control systems, which can be reduced to dynamic ones.
4. A method of restructuring the general task of describing the OCP into elementary information components is shown. The principles of the separation of movements by frequencies and meaning for the analysis of the flow of information through the elements of the OCP and recognition algorithms by dis-

crete steps are shown. Operating the structure of information flows will help to improve recognition algorithms and ensure the stability of their work.

5. Solving the problems of analysing the operation of algorithms and recognising situations is performed at the workplace in CAD in two ways—by functional modelling and by using game theory. The functional modelling takes into account the inertia of movements in the contours of the object as well as the movement of information in the recognition algorithms. Real-time algorithms are presented on a temporary scan of alarm file signals received by device registrars from real objects. Situations make up a library of test signals. An album of the results of modelling emergency files with the results of ‘hacking’ algorithms and countering ‘hacking’ is accumulating. Game theory makes it possible to get a static solution on the points of equilibrium and recognition, which may be the recognition algorithm. This also applies to the object of control and protection. A computing module for use in relay protection and automation tasks is described. The methodology for generating information for the module should prevent misuse of the module and facilitate the interpretation of the results.
6. According to the SI method, control algorithms are synthesised based on the equality of the GES forming and recognising grammars. The chapter focuses on the formative grammar of the OCP, high-voltage equipment, the structure of the *SN* semantic situation, the passage of the *SN* script through the GES_{OCP} and GES equipment circuits as the input of control and monitoring algorithms. Methods for the analysis and synthesis of the recognising grammar are described in detail in the articles from the list of published sources. The recognition algorithms are written off to the finished devices. They are improved for each network, taking into account the reaction of the algorithms to the signals from real emergency files, and the network model in CAD.
7. The general algorithm for the automatic control of dynamic objects is developed in the form of the selective search for sufficient information for recognition. The SP algorithm makes it possible to synthesise new and analyse well-known algorithms for relay protection and automatic control of ‘complex’ objects with a tunable structure, distributed parameters and the spontaneous development of damage.
8. It is possible to compensate for the lack of information in difficult semantic situations through new ways of obtaining information, additional information sensors and increasing their intellectual capabilities. Separate sensors are required for all the parameters of the input signals—frequency, phase, transit time and the ratio of special moments in the transient signals in the network.
9. Several practical examples of the application of the theoretical part of the description are given. This is, first of all, the solution of known conflict situations of automatic control, manifested in the dynamics of the development of semantic situations, namely: (A) The operating time of the automatic system for compensating capacitive currents and the operation of selective relays can and should be variable according to the volume of the semantic signal. (B) Distinguishing between a working and a faulty system in the absence of output commands can be based on analysis of the semantic situations under natural and test influences. (C) Recognition systems need to be built as a dynamic sequence of the opening ‘windows of selectivity’ as one of the moves through the semantic situation tree and the situation scenario tree.

10. The approach considered is proposed for the joint analysis and synthesis not only of algorithms and software products of semantic processing of information at different levels of the hierarchy of control systems but also for constructive technical solutions. In this analysis, the method is applied in the 'bottom-up' direction, that is, starting from the processing of information by a multitude of information sensors; next, the processing of information is concentrated in the 'branches' of the processing of the structural-semantic relationships and then in the 'root' of automatic decision-making on the outcome. It is clear that, for synthesis problems, this method is best applied 'bottom-up'.

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