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POWER ELECTRICAL SYSTEM FAULT DIAGNOSIS BASED ON EXPERT SYSTEM, SIMULATOR AND ARTIFICIAL NEURAL NETS

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Рассматривается гибридная система (ГС), используемая для анализа аварийных состояний электрических систем (ЭС), которая включает экспертную и моделирующую подсистемы, искусственные нейронные сети. Используя аварийную информацию о работе устройств релейной защиты и выключателей, ГС идентифицирует поврежденные элементы ЭС, отказы и/или ложную работу устройств защиты, отказы выключателей. При этом допускаются неполнота аварийной информации и возможность существования различных конфигураций ЭС в ее доаварийном состоянии.

I. INTRODUCTION

The rise of fault states (FS) of PES usually is quickly eliminated by actions of protection and automation systems. However, for some cases (including one or more failure and/or wrong actions of protective devices, failure of circuit breakers) those FS lead to de-energizing and large outages for electrical energy consumers. In 6-9 cases from 10 a reason of the damage development is the unexpected behavior of protective devices (malfunction and wrong actions) [1].

The problem of PES FS diagnosis consists of two tasks. The first task consists in estimation of the fault section of PES. Second task consists in analysis and identification of malfunctions and/or wrong actions of protective devices as well as malfunction of circuit breakers. There are different approaches for solving the first task. They are based on expert systems, ANN, logical simulation, statistical analysis etc. In the papers [2,3] approach for both tasks solving was proposed. In this paper we propose else one approach for second task solving.

There is one requirement to solving methods: to consider the Supervisory Control And Data Acquisition (SCADA) system's malfunctions. For second task solving researches integrate the expert systems and simulators [4-6]: the expert system realizes the logic analysis and heuristic search, simulator realizes the simulation of FS and reaction of protective and automation systems. Besides known advantages those systems have also bottlenecks. In order to delete those bottlenecks we additionally use the ANN technique. For ANN training it is possible to use complex models of FS, because ANN training occurs under off-line condition.

The task of diagnosis can be presented as a pattern of the recognition problem. It is possible to define function f_j describing protective system's reaction such as $A_{ij} = f_j(B_i)$, where B_i – set of the failure relays and circuit breakers for FS **i**, $A_{i,j}$ – j-pattern for FS i (function of FS simulation). However, it is impossible to receive inverse function f^{1}_{j}, that would be ensured by the B_i definition on the basis of the response -- protective system's reaction $B_i = f^{1}_{j}(A_{i,j})$ (function of FS recognition). The set of training samples for ANN is $< A_{i,j}, B_i >$, where $A_{i,j}$ – ANN inputs and B_i – ANN outputs. For ANN training it is necessary to simulate the faults and all probable FS for each element of PES. Every FS corresponds to various combinations of failures of protective devices and/or circuit breakers. Every FS has one or several patterns. A pattern of FS is represented by a set of alarm signals. Perfect pattern of FS ($A_{i,0}$) is the complete set of the alarm signals (without malfunctions of SCADA system) for one normal (all lines are energized) pre-fault configuration of PES. Every FS has several various patterns, appropriated to various failures of SCADA system and various pre-fault configurations of PES. These patterns we call "noisy patterns". Moreover, even the perfect pattern can't always unequivocally and precisely describes FS. Malfunction of protective devices and/or circuit breakers can distort the perfect pattern of FS. The main complexities of the similar approaches are connected with a combinatorial explosion's problem for FS identification in large PES [7]. The number of different FS depends on number pre-fault configurations of PES. The number of pre-fault configurations exponentially increases with raising of PES size.

II. THE PROPOSED APPROACH

We used ANN in structure of HS for complex FS diagnosis. The structure of training ANN under off-line conditions and structure of using ANN under on-line condition are shown in Fig.1, 2. Before the identification task's solving we assume that the fault element of PES is already known (this is the first task's solution). We admit the incompleteness of the alarm signals set caused by malfunctions of SCADA system. We admit also distortion owing to false operations of protective devices. The approach proposed in this work is an innovation compared with the paper [8] in the part of FS identification not only for substation but also for complex PES.

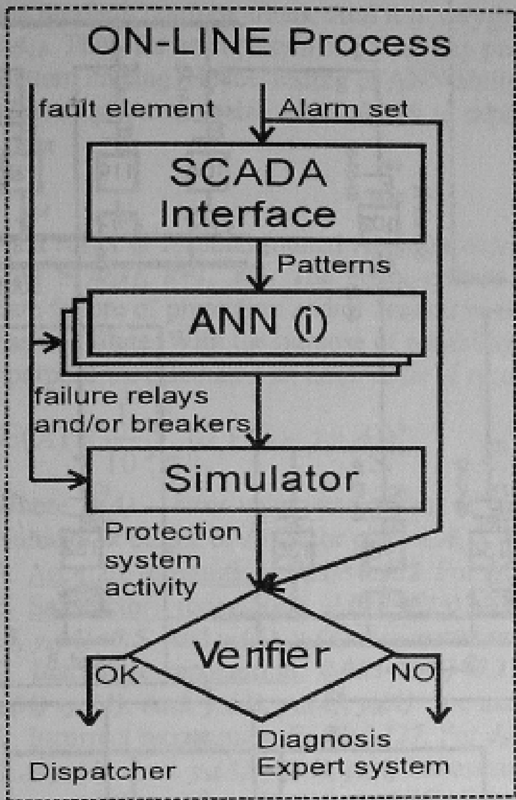

Fig.1: The structure of ANN training under off-line condition.

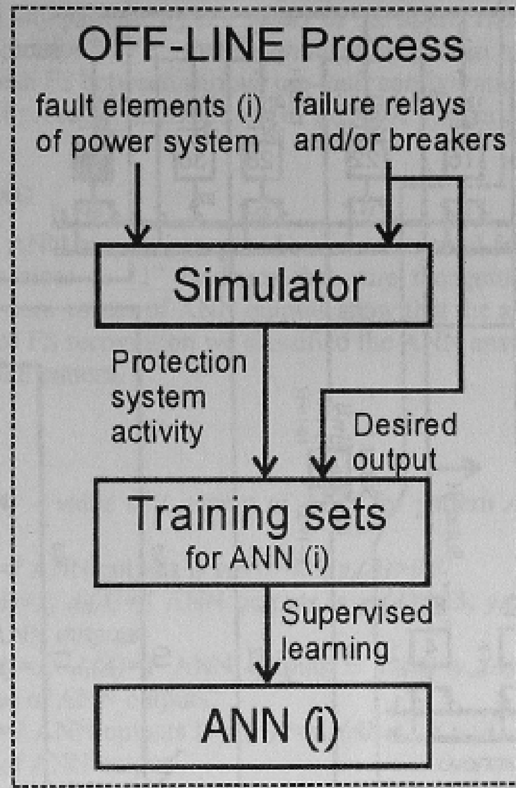

Fig.2: The structure of using ANN under on-line condition.

For any FS in PES all alarm signals belong to the certain sub-net of PES. The centre (approximately) of this sub-net is the fault element of PES. The borders of FS define the size of sub-net and depend on amount of simultaneous failures of protection and/or circuit breakers. Thus it is enough to limit a consideration of pre-fault configurations only for sub-net. If the PES has $\mathbf{2^n}$ different configurations, where **n** – number of branches, then a sub-net has $\mathbf{2^m}$ different configurations, where **m** – number of branches of sub-net and **m** is much less than **n**.

Nevertheless, for real PES the size of sub-nets is large enough especially for sub-nets in cases which deal with two and more simultaneous malfunctions of protective devices and/or circuit breakers. The number ($\mathbf{2^m}$) of sub-net configurations is large as well. However, in practice a state of PES corresponds not each configuration. There are many restrictions for states of PES. As a rule, the normal state of PES corresponds to a configuration with all energized lines. The several de-energized lines make the parameters (indexes) of PES condition (reliability, profitability etc.) worse. And as the practice shows the number of the simultaneously de-energized lines for every sub-net is limited according to the criterions mentioned above. Theoretically if sub-net consists of ***m*** branches (***q*** from them are opened) then number of possible configurations can be determined by polynomial coefficient

$$C_q^m = \frac{m(m-1)\dots(m-q+1)}{q(q-1)\dots 1}$$

For example, for PES sub-net (Fig. 3) formed by fault on L0 the number of configurations is equal 512 (2^9). And number of configurations with any two simultaneously de-energized lines is equal 36 (C_2^9). Let's limit C_q^m with a number of allowable states of PES then we considerably reduce amount of possible FS. The transfer from the analysis of FS in PES to the analysis of FS in sub-net of PES and consideration to limit the amount pre-fault configurations allows to remove a problem of combinatorial explosion.

A normal state of Donbass-110 kV PES fragment corresponds all energized lines (Fig.3). Let's analysis of FS caused by various failures of protection and/or circuit breakers at fault on a line L0. On the basis of simulation of FS for various combinations of failures we shall receive space of FS.

Thus, we can construct ANN which has 32 inputs and 20 outputs. The inputs of ANN receive the 32-digit binary vectors. These vectors are pattern of FS ($A_{i,0}$). One alarm signal corresponds each separate input of ANN. If this alarm signal is received then appropriate input values is "1", if such alarm signal is not received then input values is "0". Each output of ANN corresponds to one failure device. If for some pattern of FS value of one or several ANN outputs is "1", than it means the failure of the appropriate protection or circuit breaker. The training set consists of training samples $<A_{i,0}, B_i>$. The size of the training set is equals to number of FS.

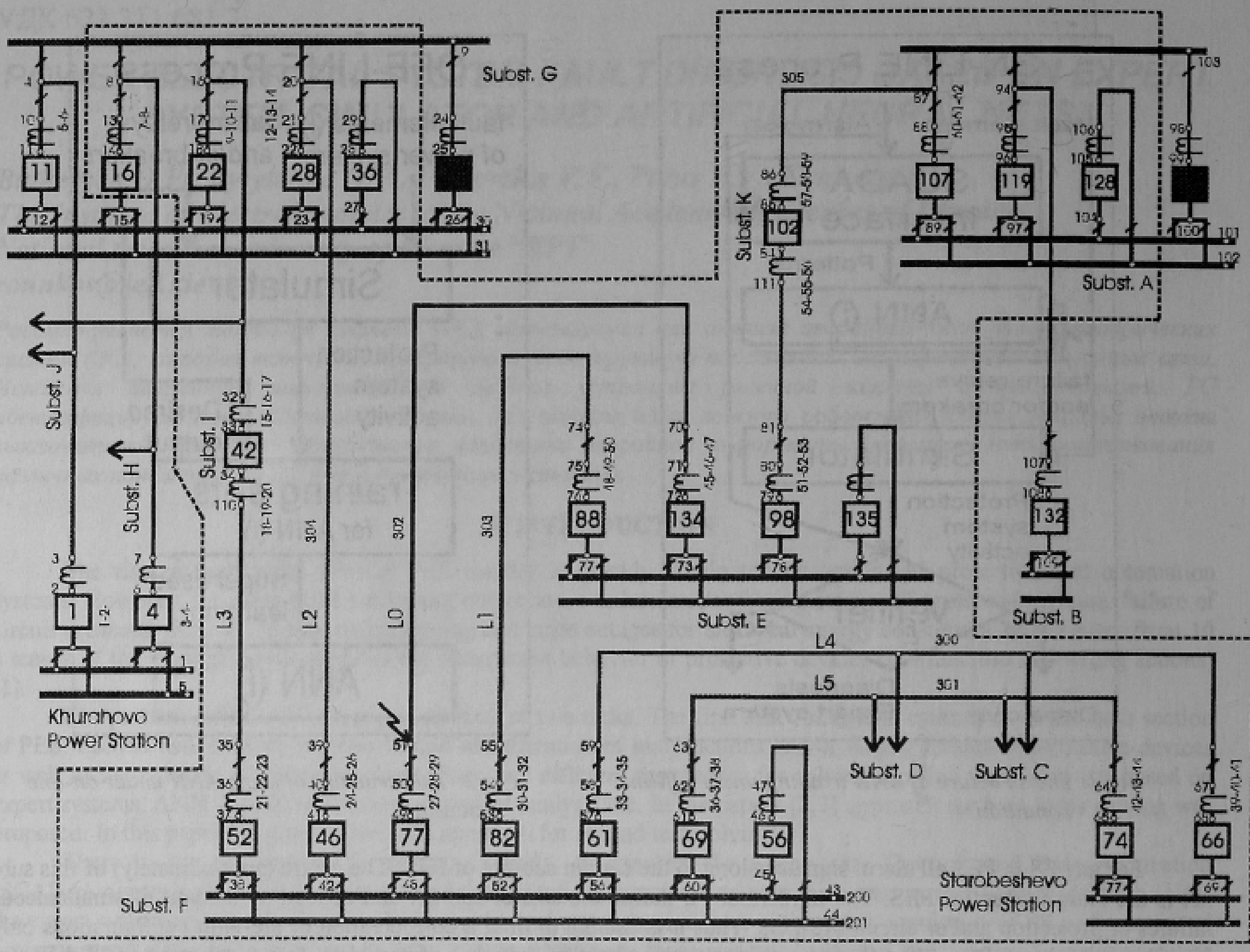

Fig.3. Donbass-110 kV power electrical system's fragment.

In this work we used Multi-Layer Perseptron (MLP) type of ANN with two hidden layers (Fig. 4). The main attention was given for analysis of the different factor's influence (different pre-fault configurations of PES, failures in SCADA systems, malfunctions of protective devices and/or circuit breakers) on quality of the FS identification. The testing of the trained ANN shows that ANN able to distinguish various distorted or noised patterns of FS. As it was mentioned above the training set consists of the perfect patterns of various FS appropriated for one normal pre-fault configuration of PES. This configuration corresponds to a normal state of PES. Firstly, we are interested in ANN ability to distinguish FS for different pre-fault configurations of PES (those patterns are absent in the training set). Secondly, to distinguish FS between wrong actions of protective devices and/or malfunction of circuit breakers (distorted patterns) and malfunction of SCADA systems (incomplete patterns).

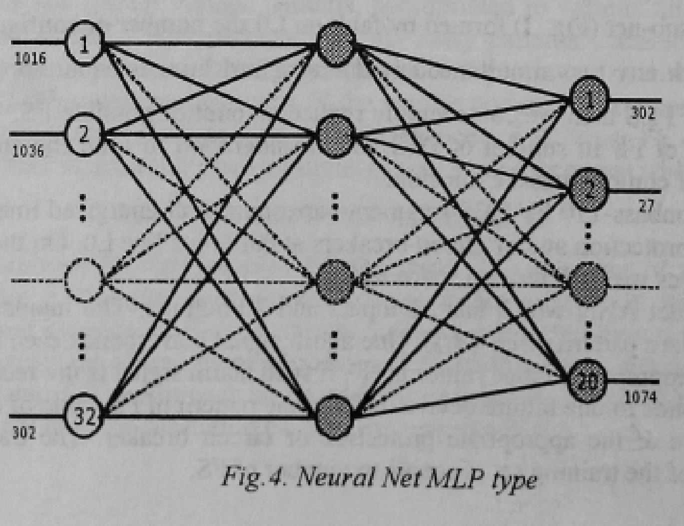

Fig.4. Neural Net MLP type

The simulation of FS for various pre-fault configurations of PES will form patterns $A_{i,j}$, $j=1, p$, where p - number of various pre-fault configurations. And it is very important that any pattern $A_{i,j}$ is a subset of the appropriated perfect patterns $A_{i,0}$. Thus, for each pattern of FS for any pre-fault configuration of PES there is an identical pattern received by perfect pattern noising. Hence, testing of ANN ability to distinguish FS between various pre-fault configurations of PES we simultaneously testing also ANN ability to take into account probable malfunctions of SCADA system and on the contrary.

III. TESTING

As a result of respond trained ANN on new patterns the ANN outputs accept values in an interval from "0" to "1". ($y_k(A) = [0,1]$, $k=1, 20$). The ANN outputs with values close to "1" evidence that sure recognition of the appropriate failure of protection and/or breaker is obtained. The zero values of ANN outputs show that the appropriate device has no failure. With the purpose of reliability estimation of FS recognition we classified the ANN answers on 4. For this purpose we calculated an error value of recognition of each pattern.

$$E(A) = \frac{1}{10}\sum_{i=1}^{20}(d_i(A) - y_i(A))^2$$

Where $E(A)$ – error value recognition of pattern A; $y_k(A)$ – value of k output of ANN for pattern A; $d_k(A)$ – desired value of k output of ANN for pattern A.

A. Accurate recognition. $E(A)<0.032$. For $d_k(A)=1$, $d_l(A)=1$ ANN outputs is $y_k(A)>0.5$, $y_l(A)>0.5$.

B. Satisfactory recognition. $0{,}032<E(A)<0.067$. For $d_k(A)=1$, $d_l(A)=1$ ANN outputs is $y_k(A)>0.5$, $y_l(A)<0.5$ or $y_l(A)>0.5$, $y_k(A)<0.5$. And $y_k(A)$, $y_l(A)$ are maximum values of ANN outputs.

C. Inaccurate recognition. $0{,}053<E(A)<0.177$. For $d_k(A)=1$, $d_l(A)=1$ ANN outputs is $y_k(A)<y_m(A)<y_l(A)$ or $y_l(A)<y_m(A)<y_k(A)$. And, $y_k(A)$, $y_m(A)$, $y_l(A)$ are maximum values of ANN outputs.

D. Incorrect recognition. $E(A)>0.127$. For $d_k(A)=1$, $d_l(A)=1$ ANN outputs is $y_k(A) < y_m(A) <\ldots< y_l(A)$ or $y_l(A)< y_m(A)< \ldots < y_k(A)$. And $y_k(A)$, $y_m(A)$, $y_l(A)$ are maximum values of ANN outputs.

1.Testing recognition with malfunction of SCADA systems (incomplete patterns of FS) (Fig.5). For each of 25 perfect patterns there were generated many noised patterns.

2. Testing recognition FS for different pre-fault configurations of PES (Fig.6). For production of testing set were simulated FS for five pre-fault configurations of PES. As a result the testing set contains 113 patterns. The results of recognition are shown in Fig 8.

3. Testing recognition FS, that includes false operations of protection and/or breakers (distorted patterns) (Fig.7). Each of 25 perfect patterns was distorted by various 10 alarms. The testing set consists of 250 patterns.

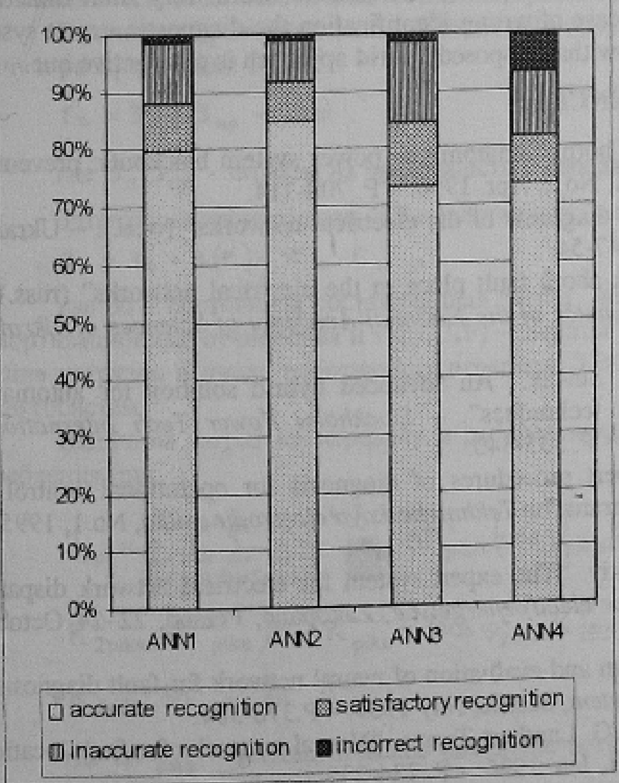

Fig.5. Results of testing for case of SCADA failures.

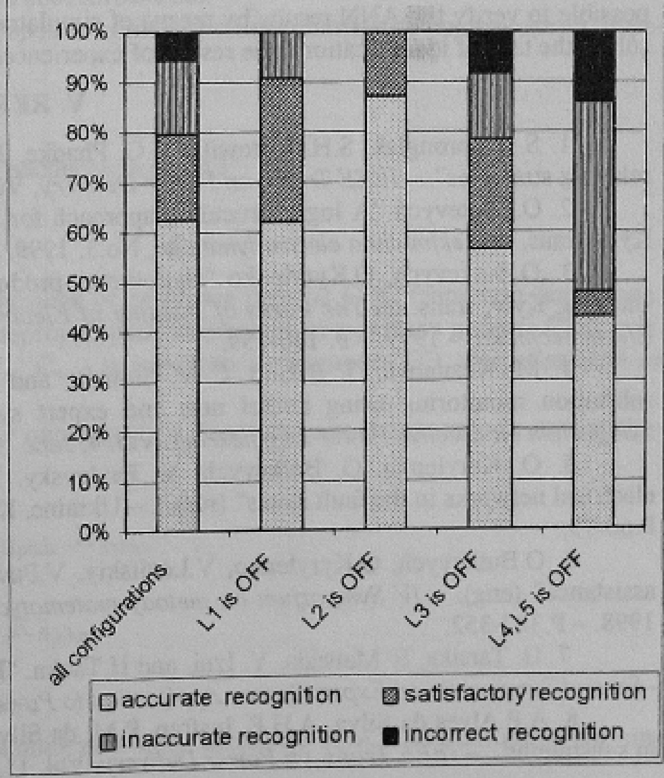

Fig.6. Results of testing for different pre-fault configurations.

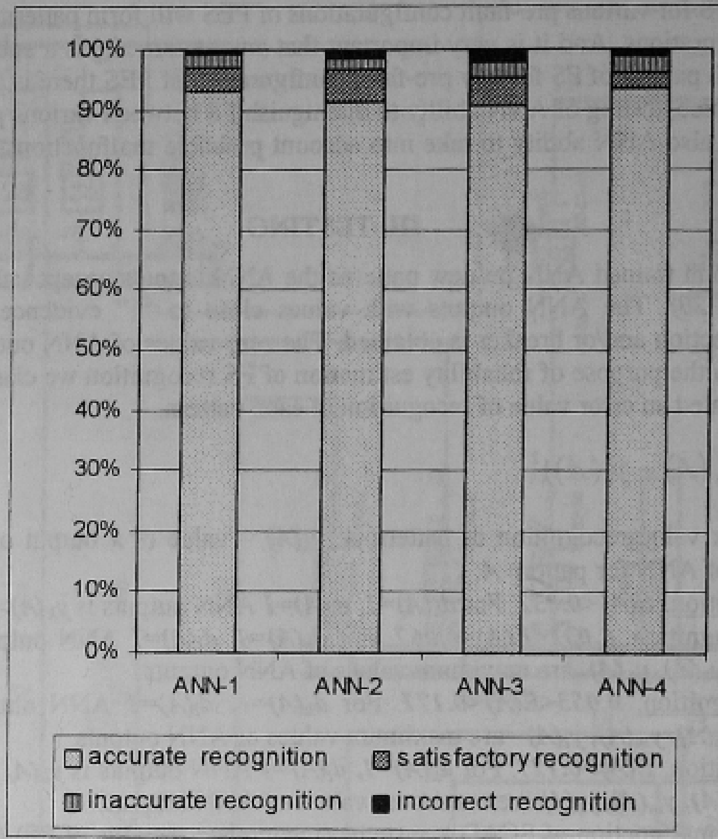

Fig. 7: Results of testing for case of wrong protective device's action.

IV. CONCLUSION

The new approach based on expert system, simulator and artificial neural nets for creation of identification system for protection relays and circuit breakers failures recognition is proposed. The structure of identification system is proposed. The ANN construction for each element of PES and the FS analysis only in appropriate sub-net allow solve the problem mentioned above. This HS recognizes the protection and/or breakers failures within very short time. It is possible to verify the ANN results by means of simulator. In case of wrong identification the diagnostic expert system solves the task of identification. The results of experiences show that proposed hybrid approach is perspective one.

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