

ALARM ANALYSIS IN ELECTRIC POWER SYSTEM BASED ON EXPERT SYSTEM

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The occurrence of fault is an unwanted situation in electric power systems where certain network parts detach themselves from the remaining unaffected part of the network. The relay protection system has a task to isolate the faulty units or zone. When a certain protection level is being triggered alarms are sent to the transformer station and the dispatcher centre. These alarms reach the dispatcher centre in a short period of time which can lead the dispatcher to confusion and possible mistakes. To ease the dispatcher's position, an alarm processor is introduced. The alarm processor uses an expert system as its computer programme in the whole spectrum of variations. The analysed alarms are the ones being triggered while the TS 35/10 kV Istok is detaching from the rest of the electric power system. The objective of this project is to analyse alarms which have appeared in the dispatcher centre during the detachment of the TS 35/10 kV Istok, by using the expert system method. Final results have confirmed the section and cause of the TS 35/10 kV Istok detachment from the rest of the electric power system.

Keywords: alarm analysis, artificial intelligence, expert system, fault diagnosis

Analiza alarma u elektroenergetskom sustavu bazirana na ekspertnom sustavu

Izvorni znanstveni članak

Pojava kvara je neželjena situacija u elektroenergetskom sustavu prilikom koje se određeni dijelovi mreže odvajaju od ostatka mreže koja nije zahvaćena kvarom. Sustav relejne zaštite ima zadatak da izdvoji dionice koje se nalaze u kvaru. Pobuda određene zaštite šalje alarm u transformatorsku stanicu i dispečerski centar. Alarmi u dispečerski centar dolaze u kratkom vremenu što može dispečera zbuniti i navesti na pogrešku. Kako bi se olakšao posao dispečerima uvodi se procesor alarma. Procesor alarma kao računalni program koristi ekspertni sustav u cijelom nizu varijanti. Analizirani su alarmi koji se pojavljuju prilikom odvajanja TS 35/10 kV Istok od ostatka elektroenergetskog sustava. Cilj ovog rada je analiza alarma koji su se pojavili u dispečerskom centru prilikom ispada TS 35/10 kV Istok metodom ekspertnog sustava. Dobiveni rezultati su utvrdili dionicu i uzrok ispada TS 35/10 kV Istok od ostatka elektroenergetskog sustava.

Ključne riječi: analiza alarma, dijagnoza kvara, ekspertni sustavi, umjetna inteligencija

1

Introduction

A fault in the electric power system (EPS) activates the relay protection system which isolates the faulted zone. The triggering of certain protection sends a signal to a local transformer substation (TS) and a long-range signal to the dispatch centre. In the dispatch centre, alarms are visible through the SCADA system which alongside a remote control, measurement and monitoring contains the chronological event list (CEL). The dispatch centre receives incoming alarms on CEL and stores them. Alarms consist of a wide group of signals which comprise: signalling the position of the circuit breaker (CB) and the disconnecter, their assembling condition is described with, the activation and the tripping of certain protection. In addition to that they include failure of certain automatic switches inside the secondary development, failure of some devices in the same system, up to some minor alarms such as the signal which shows when TS doors are being opened. At the moment of the fault, alarms appear on the CEL screen and they are positioned above each other, so the alarm on the top points out the last situation in the network. It is easy to supervise all signals and network state as long as the number of alarms and situations is manageable. If some complex situation occurs, it causes an avalanche of a few hundreds alarms within a short period of time, further complicating the situation, and thus disabling the operator's reaction in due time or leading him towards doing a wrong action and consequently towards immense damage [13]. The network fault which cannot be eliminated by the protection due to additional equipment

damage, will thus trigger the secondary protection to do the job, leaving black out areas under suspicion. During the fault, the operator has to process a huge amount of unprocessed data and carry out a complex decision making process within a short period of time. Alarm processors are used for these types of situations. The alarm processor uses the expert system (ES) as its computer programme. It is a computer programme which substitutes an experts thinking process within a narrow action field, to solve complex situations. The expert system consists of the knowledge base, algorithms and communication interface. The expert system treats EPS as a cluster made from network components: conductor wires, busbars, transformers, CBs and relays. During the TS 35/10 kV Istok detachment incoming alarms have been analysed in the dispatch centre using the expert system. The point of this analysis is the right application of this expert system method in the example of TS 35/10 kV Istok detachment from the rest of the distribution network.

2

Expert system method

Artificial intelligence is a scientific field dealing with implementing human thinking and natural phenomena. Expert systems (ES) are just one part of the whole artificial intelligence field. Expert systems are computer programmes which use expert knowledge to solve a complex problem within a narrow problem area [3]. There are many types of ES, and they are different from one another in a way they organize knowledge in their knowledge base. There are three types: Rule Base, Case

Base and Model Base [8]. ES can be off-line and on-line [11]. Here in the paper, ES that forms its knowledge on rule base [4] is analysed. The ES method uses hypothesis method – the same method as humans applied when analysing alarms, just in a modified, automatic version. The hypothesis method begins from the final Point

(hypothesis) trying to include as many facts as possible, so that the hypothesis would stay active. The ES method is based on rules and principles which make hypotheses withholding predesigned fact clusters. The ES method is based on an algorithm which compares the rules. Fig. 1 presents the ES method.

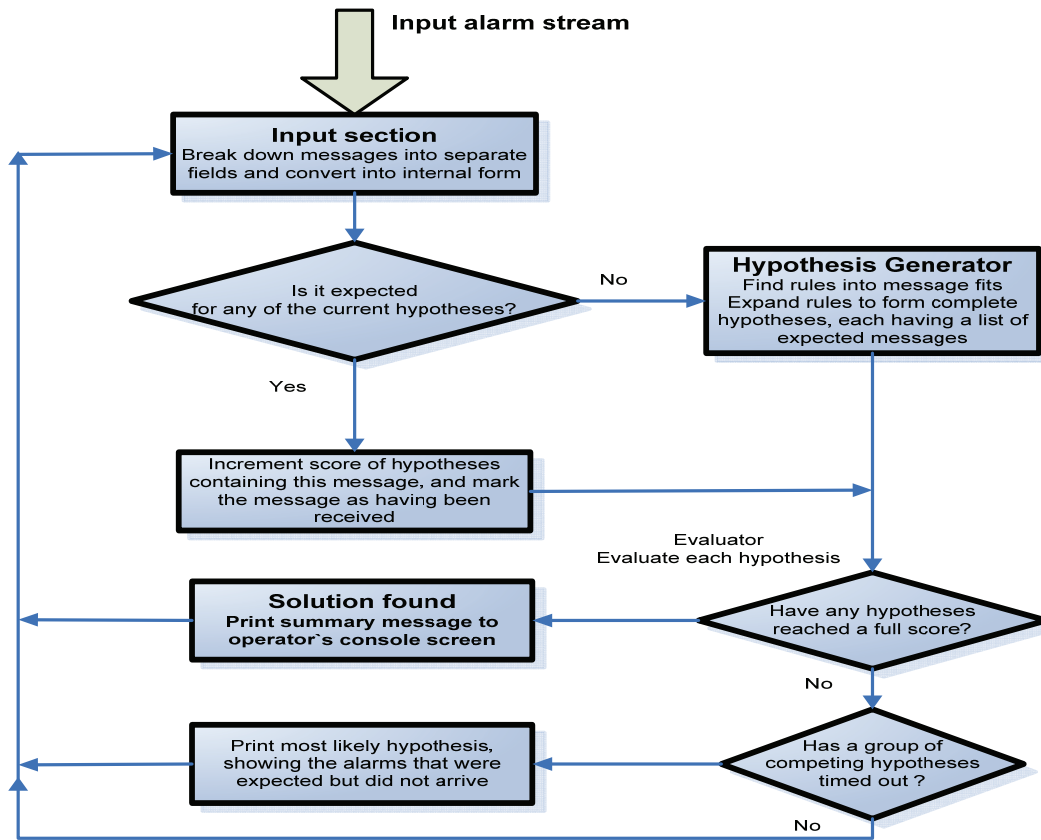


Figure 1 The algorithm for the ES method

Implementing the ES in EPS for the first time is encountered in the 1990s [6]. There are several fields where ES has been implemented: alarm analysis, fault diagnosis, load forecast, planning within the EPS, economic dispatch and production. The most widespread usage of ES is in analysing the alarm and diagnosing the failure, taking up 40 % of its usage, while the planning is used in 15 % of the cases [9]. ES method is shown in Figure 1: an incoming alarm, coming from rule-and-fact knowledge base, forms the hypothesis and checks if the alarm matches particular lists for certain hypothesis. If it does, then it increases the hypothesis for one, and if it does not, then new hypotheses are formed including their related alarm lists. After being increased by one, the hypotheses go to the assessment phase where each hypothesis is checked containing all the alarm signals. If the hypothesis has all the alarms, it gets printed out, if not, then it waits for the following alarm to do further assessment [1]. It should be noted that this is a genetic algorithm (GA) which has all the genetic features: random data entry, a certain type of selection and iteration leading to the possible solution. Diagnostic methods usually use backward reasoning. Relay function can also be viewed as forward reasoning, one thing causing the other. Forward reasoning starts from the known facts towards the goal. Alarm's processor uses ES as the program to analyse

appearing alarms during the fault in EPS. The alarm processor helps the operator to make decisions about the currently unknown black out areas after a breakdown of a certain part of EPS. The ES [2] method used in this paper, tries to organize huge amounts of disorganized data in the logical manner, extracting some diagnosis conclusions. It is important to emphasize that these are not standard numeric variables, but linguistic variables. Making logical relationships for these linguistic variables in a standard procedural language such as C++ requires enormous programming knowledge. Declarative programming is used for these kinds of problems. Here is a list of programs based on artificial intelligence: Lisp, PROLOG or OPS 83. The relationships between the regulations in the data base have six different types: cause-effect, mutual exclusivity, conflict, implication, redundancy and subsumption [12]. The cause-effect relationship and mutual exclusivity are the most commonly used. The only relationship, used in the paper for the rules model of ES, is cause-effect. Rules are formed in the IF-cause format; THEN-effect. The rules can be extended by using operators such as AND, OR, ELSE, ELSE if.

The rules are formed in the lines such as:

Rule A: IF cause
THEN effect.

Rule B: IF Event
THEN Expect.

Rule n: IF x
THEN y.

There are no limits or strict regulations which could determine the number and methods of implementing the rules, but an expert himself/herself has to form a knowledge base in accordance with the field he is dealing with. A knowledge base can have both rules and facts. The ES method uses a hypothesis which people use when analysing alarms in their modified, automatic version. The hypothesis method starts from the end (hypothesis) trying to include as many facts as possible in order to remain active.

Knowledge base consists of network topology and rules for fault diagnosis [5]. Network topology is presented by the facts and it is easily formed as network graph, whose nodes are easily interconnected. Rules for the fault location and fault diagnosis are obtained through interviews with people involved in relay protection. The rules are called cause-effect and can be defined for the components of the EPS to the parts of EPS. In these rules, the true knowledge of specific purpose is defined giving answer to the core of the problem.

Network topology in the form of rules (facts)

Network (bus-1, cb-1, line, on)
Network (line, cb-2, bus-2, on)
Network (bus-2, cb-3, trans-1, on)
Network (bus-2, cb-4, trans-2, on)
Network (trans-1, cb-5, bus-3, on)
Network (trans-2, cb-6, bus-3, on)
Network (bus-3, cb-7, line10, on)

General expression

Network (<nod name>, <cb name>, < nod name>, on/off)
[10].

Now we can present rules of operation.

Rule 1: IF Failure feeder 10 kV <set name>
THEN <protection trip>
AND <circuit breaker 10 kV open>

Rule 2: IF Failure on transformer <set name>
THEN <protection trip>
AND <circuit breaker 10 kV open>
AND <circuit breaker 35 kV open>

Rule 3: IF Failure on feeder 35 kV <set name>
THEN <protection trip>
AND <circuit breaker 35 kV open>

Rule 4: IF simultaneous failure at 35 kV and 10 kV
feeder
THEN <10 kV protection terminated>
AND <35 kV protection trip>

AND <circuit breaker 35 kV open>

Rule 5: IF Non-selective operation of relay
THEN <10 kV protection terminated >
AND <35 kV protection trip>
AND <circuit breaker 35 kV open>

The rules for the fault diagnosis [7] are based on the event tree and backward chaining or on the fault tree which is used to eliminate senseless and illogical conclusions.

Rule A: IF <protection trip>
AND <circuit breaker 10 kV open>
THEN Failure feeder 10 kV <set name>

Rule B: IF <protection trip>
AND <circuit breaker 10 kV open>
AND <circuit breaker 35 kV open>
THEN Failure on transformer <set name>

Rule C: IF <protection trip >
AND <circuit breaker 35 kV open>
THEN Failure on feeder 35 kV <set name>

Rule D: IF <10 kV protection terminated>
AND <35 kV protection trip>
AND <circuit breaker 35 kV open>
THEN simultaneous failure at 35 kV and 10 kV
feeder

Rule E: IF <10 kV protection terminated>
AND <35 kV protection trip>
AND <circuit breaker 35 kV open>
THEN Non-selective operation of relay

Fault tree of rule A shown in Fig. 2.

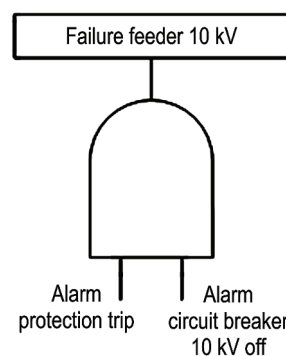


Figure 2 Fault tree of rule A

3

The results of the expert system method analysis

Here, fault event described on February 10, 2010 occurred during fault on 10 kV feeder KTS 108/208, where the entire TS 35/10 kV Istok was detached from the rest of the network. TS 35/10 kV Istok has two possible feeding directions: from TS 110/35 kV Osijek 1 and TS 35/10 kV Šećerana. At the time of the fault TS 35/10 kV Istok was supplied from TS 110/35 kV Osijek 1. We modify method from [9] by putting increment score next to hypothesis.

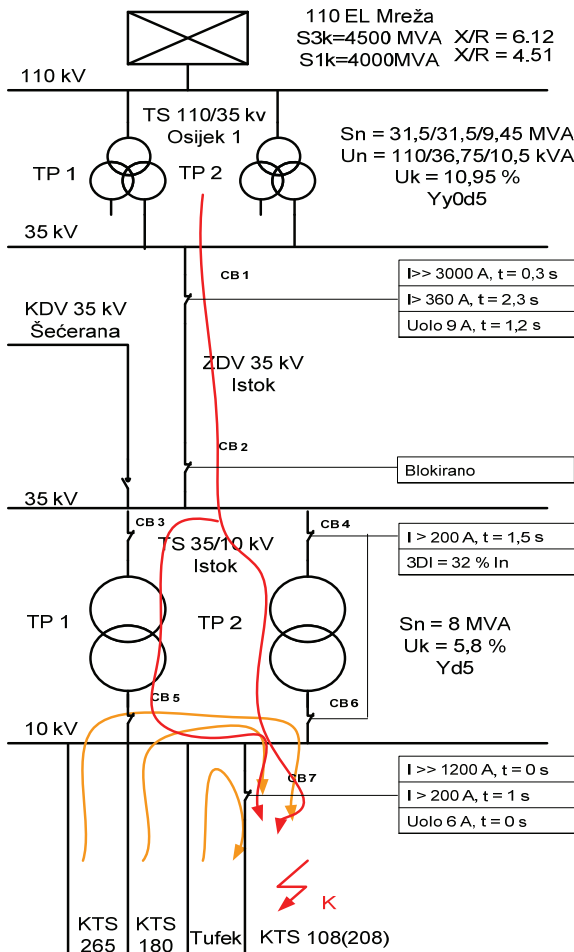


Figure 3 Part of the 35 kV DP Elektroslovanija's network

11.2.2010	08:19:34.807	ISTOK	10	108/208	RAST UZEM	Međupoložaj 00
11.2.2010	08:19:34.344	ISTOK	10	108/208	RAST VOD	ISKLJUCEN
11.2.2010	08:19:34.340	ISTOK	10	108/208	RAST VOD	Stanje kvara 11
11.2.2010	08:17:55.594	ISTOK	10	108/208	RAST S 1	ISKLJUCEN
11.2.2010	08:17:55.564	ISTOK	10	108/208	RAST S 1	Međupoložaj 00
10.2.2010	21:30:25.818	ISTOK	10	TUFEK	PREKIDAC	UKLJUCEN
10.2.2010	21:30:25.815	ISTOK	10	TUFEK	PREKIDAC	Stanje kvara 11
10.2.2010	21:29:57.064	ISTOK	10	KTS 180	PREKIDAC	UKLJUCEN
10.2.2010	21:29:57.055	ISTOK	10	KTS 180	PREKIDAC	Stanje kvara 11
10.2.2010	21:29:25.577	ISTOK	10	KTS 265	PREKIDAC	UKLJUCEN
10.2.2010	21:29:25.570	ISTOK	10	KTS 265	PREKIDAC	Međupoložaj 00
10.2.2010	21:29:11.299	ISTOK		NAPON AC NA SABIRNICAMA	POVRATAK	
10.2.2010	21:28:53.429	ISTOK	35	ZDV OS 1	PREKIDAC	UKLJUCEN
10.2.2010	21:28:53.426	ISTOK	35	ZDV OS 1	PREKIDAC	Međupoložaj 00
10.2.2010	21:28:20.208	OSK 1	35	ISTOK	PREKIDAC	UKLJUCEN
10.2.2010	21:28:20.195	OSK 1	35	ISTOK	PREKIDAC	Stanje kvara 11
10.2.2010	21:27:48.387	ISTOK	10	TUFEK	PREKIDAC	ISKLJUCEN
10.2.2010	21:27:48.378	ISTOK	10	TUFEK	PREKIDAC	Stanje kvara 11
10.2.2010	21:27:33.912	ISTOK	10	KTS 180	PREKIDAC	ISKLJUCEN
10.2.2010	21:27:33.907	ISTOK	10	KTS 180	PREKIDAC	Stanje kvara 11
10.2.2010	21:27:17.159	ISTOK	10	KTS 265	PREKIDAC	ISKLJUCEN
10.2.2010	21:26:41.017	ISTOK	35	ZDV OS 1	PREKIDAC	ISKLJUCEN
10.2.2010	21:26:15.915	OSK 1	35	APU DEF	PRESTANAK	
10.2.2010	21:26:15.906	OSK 1	35	Z. KRATKOSPOJNA	PRESTANAK	
10.2.2010	21:26:15.902	OSK 1		ISPRAVLJAC AC/DC 220V	POVRATAK	
10.2.2010	21:26:15.803	OSK 1	35	ISTOK	PREKIDAC	ISKLJUCEN
10.2.2010	21:26:15.791	OSK 1	35	ISTOK	PREKIDAC	Stanje kvara 11
10.2.2010	21:26:15.754	OSK 1	35	APU DEF	UPOZ	
10.2.2010	21:26:15.743	OSK 1	35	Z. KRATKOSPOJNA	ISK	
10.2.2010	21:26:15.646	OSK 1		ISPRAVLJAC AC/DC 220V	ISPAD	
10.2.2010	21:26:15.527	ISTOK	10	Z. KRATKOSPOJNA	PRESTANAK	

10.2.2010	21:26:15.512	ISTOK		NAPON AC NA SABIRNICAMA	NESTANAK	
10.2.2010	21:26:15.492	ISTOK	10	108/208	PREKIDAC	ISKLJUCEN
10.2.2010	21:26:15.488	ISTOK	10	108/208	PREKIDAC	Međupoložaj 00
10.2.2010	21:26:15.444	ISTOK	10	Z. KRATKOSPOJNA	ISK	
10.2.2010	21:26:15.426	ISTOK	10	108/208	PREKIDAC	UKLJUCEN
10.2.2010	21:26:15.420	ISTOK	10	108/208	PREKIDAC	Međupoložaj 00
10.2.2010	21:25:42.409	ISTOK	35	KDV SEC	PREKIDAC	ISKLJUCEN
10.2.2010	21:25:42.406	ISTOK	35	KDV SEC	PREKIDAC	Stanje kvara 11
10.2.2010	21:25:03.902	ISTOK	35	ZDV OS 1	PREKIDAC	UKLJUCEN
10.2.2010	21:25:03.899	ISTOK	35	ZDV OS 1	PREKIDAC	Međupoložaj 00
10.2.2010	21:24:19.626	ISTOK	35	ZDV OS 1	RAST S 1	UKLJUCEN
10.2.2010	21:24:19.172	ISTOK	35	ZDV OS 1	RAST S 1	Stanje kvara 11
10.2.2010	21:14:42.755	OSK 1	35	ISTOK	PREKIDAC	UKLJUCEN
10.2.2010	21:14:42.743	OSK 1	35	ISTOK	PREKIDAC	Stanje kvara 11
10.2.2010	20:56:06.724	ISTOK	10	TUFEK	PREKIDAC	UKLJUCEN
10.2.2010	20:56:06.721	ISTOK	10	TUFEK	PREKIDAC	Stanje kvara 11
10.2.2010	20:55:38.458	ISTOK	10	KTS 180	PREKIDAC	UKLJUCEN
10.2.2010	20:55:38.456	ISTOK	10	KTS 180	PREKIDAC	Stanje kvara 11
10.2.2010	20:54:45.668	ISTOK	10	KTS 265	PREKIDAC	UKLJUCEN
10.2.2010	20:54:45.661	ISTOK	10	KTS 265	PREKIDAC	Međupoložaj 00
10.2.2010	20:54:23.789	ISTOK	10	TP 2	PREKIDAC	UKLJUCEN
10.2.2010	20:54:23.785	ISTOK	10	TP 2	PREKIDAC	Međupoložaj 00
10.2.2010	20:54:15.927	ISTOK		NAPON AC NA SABIRNICAMA	POVRATAK	
10.2.2010	20:53:56.047	ISTOK	10	TP 1	PREKIDAC	UKLJUCEN
10.2.2010	20:53:56.038	ISTOK	10	TP 1	PREKIDAC	Stanje kvara 11
10.2.2010	20:53:32.875	ISTOK	10	KTS 265	PREKIDAC	ISKLJUCEN
10.2.2010	20:53:32.875	ISTOK	10	KTS 265	PREKIDAC	Stanje kvara 11
10.2.2010	20:53:30.055	ISTOK	35	TP 2	PREKIDAC	UKLJUCEN
10.2.2010	20:53:30.055	ISTOK	35	TP 2	PREKIDAC	Međupoložaj 00
10.2.2010	20:53:15.680	ISTOK	35	TP 1	PREKIDAC	UKLJUCEN
10.2.2010	20:53:15.646	ISTOK	35	TP 1	PREKIDAC	Međupoložaj 00
10.2.2010	20:52:43.043	ISTOK	10	KTS 180	PREKIDAC	ISKLJUCEN
10.2.2010	20:52:43.028	ISTOK	10	KTS 180	PREKIDAC	Stanje kvara 11
10.2.2010	20:52:24.778	ISTOK	35	KDV SEC	PREKIDAC	UKLJUCEN
10.2.2010	20:52:24.775	ISTOK	35	KDV SEC	PREKIDAC	Međupoložaj 00
10.2.2010	20:52:11.265	ISTOK	10	TUFEK	PREKIDAC	ISKLJUCEN
10.2.2010	20:52:11.256	ISTOK	10	TUFEK	PREKIDAC	Stanje kvara 11
10.2.2010	20:51:58.577	ISTOK	35	TP 1	PREKIDAC	ISKLJUCEN
10.2.2010	20:51:58.566	ISTOK	35	TP 1	PREKIDAC	Međupoložaj 00
10.2.2010	20:51:32.616	ISTOK	10	TP 1	PREKIDAC	ISKLJUCEN
10.2.2010	20:51:16.291	ISTOK	35	TP 2	PREKIDAC	ISKLJUCEN
10.2.2010	20:51:16.283	ISTOK	35	TP 2	PREKIDAC	Međupoložaj 00
10.2.2010	20:50:54.248	ISTOK	10	TP 2	PREKIDAC	ISKLJUCEN
10.2.2010	20:50:54.242	ISTOK	10	TP 2	PREKIDAC	Stanje kvara 11
10.2.2010	20:50:41.470	ISTOK	35	ZDV OS 1	RAST S 1	ISKLJUCEN
10.2.2010	20:50:41.092	ISTOK	35	ZDV OS 1	RAST S 1	Stanje kvara 11
10.2.2010	20:50:21.191	ISTOK	35	ZDV OS 1	PREKIDAC	ISKLJUCEN
10.2.2010	20:50:21.189	ISTOK	35	ZDV OS 1	PREKIDAC	Međupoložaj 00
10.2.2010	20:49:15.379	OSK 1	35	APU DEF	PRESTANAK	
10.2.2010	20:49:15.371	OSK 1	35	Z. KRATKOSPOJNA	PRESTANAK	
10.2.2010	20:49:15.357	OSK 1		ISPRAVLJAC AC/DC 220V	POVRATAK	
10.2.2010	20:49:15.266	OSK 1	35	ISTOK	PREKIDAC	ISKLJUCEN
10.2.2010	20:49:15.255	OSK 1	35	ISTOK	PREKIDAC	Stanje kvara 11
10.2.2010	20:49:15.217	OSK 1	35	APU DEF	UPOZ	
10.2.2010	20:49:15.206	OSK 1	35	Z. KRATKOSPOJNA	ISK	
10.2.2010	20:49:15.111	OSK 1		ISPRAVLJAC AC/DC 220V	ISPAD	
10.2.2010	20:49:14.984	ISTOK	10	Z. KRATKOSPOJNA	PRESTANAK	
10.2.2010	20:49:14.948	ISTOK	10	108/208	PREKIDAC	ISKLJUCEN
10.2.2010	20:49:14.939	ISTOK		NAPON AC NA SABIRNICAMA	NESTANAK	
10.2.2010	20:49:14.939	ISTOK	10	108/208	PREKIDAC	Međupoložaj 00
10.2.2010	20:49:14.901	ISTOK	10	Z. KRATKOSPOJNA	ISK	

Figure 4 Alarms from the plant

Relay protection settings of the part of the distribution 35 kV network Elektroslovonija are shown in Fig. 3. Fig. 4 shows the CEL at the TS 35/10 kV Istok in a moment of failure. The bottom of Fig. 3 shows the initial stage of the failure, while the final stage is shown on the top of Fig. 4, viewing from the bottom upwards. Since we are dealing here with electromechanical and static relays with no possibility of recording the current and voltage measurements at the point of failure, the only viable indicator of the situation is the CEL. Method of analysing the CEL relies on the state of the switch (open/close) and the state of the relay (start/trip). Fault diagnosis can be further developed if the relay has the ability to record current and voltage. Therefore, ES can also be programmed to use the state of the switch and relay alongside measuring current and voltage, and thus fulfilling the diagnosis. The presented ES construction will be solely based on the switch and relay states.

Step 1 – Hypotheses are not formed due to no existing alarm

Step 2 – Message (Alarm – 10 kV short-circuit protection trip) finds corresponding hypothesis from the rules and increases it by one.

Hypothesis 1: Failure at 10 kV feeder <setname> +1

Switch 10 kV open
short-circuit protection trip

Step 3 – Estimation phase, not a single hypothesis reaches full score.

Step 4 – Message (Alarm – 10 kV 108/208 circuit breaker open) finds the corresponding hypotheses and increases them by one.

Hypothesis 1: Failure at 10 kV feeder <108/208> +2

circuit breaker 10 kV off
short-circuit protection trip Full score

Step 5 – Estimation phase, hypothesis 1 reaches full score and prints it out.

Step 6 – Message (Alarm – 10 kV short-circuit protection terminated) generates itself by hypothesis 1 and hypothesis 2

Hypothesis 1: Non-selective operation of relay 35 kV +1

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV short-circuit protection terminated

Hypothesis 2: Simultaneous failure at 35 kV and 10 kV VP +1

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Step 7 – Estimation phase, hypotheses 1 and 2 have not reached full score.

Step 8 – Message (Alarm – OS 1 35 kV short-circuit protection trip) increases hypotheses 1 and 2 by one, but hypothesis 3 is also being increased by one.

Hypothesis 1: Non-selective operation of relay 35 kV +2

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 2: Simultaneous failure at both 35 kV and 10 kV feeder +2

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 3: Failure on 35 kV feeder <OS1> +1

circuit breaker 35 kV open
Short-circuit protection trip 35 kV

Step 9 – Estimation phase, not a single hypothesis has reached full score.

Step 10 – Message (Alarm – OS1 35 kV Istok circuit breaker open) increases all three hypotheses by one.

Hypothesis 1: Non-selective operation of relay 35 kV +3

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 2: Simultaneous failure at 35 kV and 10 kV feeder +3

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 3: Failure at 35 kV feeder <OS1> +2

circuit breaker 35 kV open
Short-circuit protection trip 35 kV

Step 11 – Estimation phase, all three hypotheses reach full score and results are printed. There is no longer any active hypothesis.

Description of the manipulation situation within the network will not be included in this analysis for the sake of simplicity. At the moment 20:50:21,191 the operator turns off CB of transmission line towards TS 110/35/10 kV OS1, followed by a disconnecter. Afterwards at 20:50:54,248 operator turns off 10 kV CB of transformer 2, followed by 35 kV CB of transformer 2. The operator at 20:51:32,616 turns off 10 kV CB of transformer 1, followed by 35 kV CB of transformer 1. For unloading 10 kV buses, he switches off feeder 10 kV Tufek at the

moment 20:52:11,265. After that (at the moment 20:52:24,778) he turns on 35 kV CB feeder Šećerana and powers the station from the other side. After these operations he illogically switches off feeder 10 kV KTS 180 at 20:52:43,043 which he was supposed to do after unloading the feeder 10 kV Tufek. At the moment 20:53:15,660 he turns on 35 kV CB of transformer 1, and a bit later 35 kV CB of transformer 2. After that at 20:53:32,875 he illogically turns off feeder 10 kV KTS 265 to unload 10 kV buses which he should have done while disconnecting feeder 10 kV Tufek. At the moment 20:53:56,047 the 10 kV CB of transformer 1 is turned on to feed bus 10 kV by electricity, and at 20:54:23,789 10 kV CB of transformer 2 is turned on thus putting transformers in parallel work. After that 10 kV buses are loaded when at 20:54:45,668 10 kV CB of feeder KTS 265 is turned on, and shortly afterwards feeders 10 kV KTS 180 and feeder 10 kV Tufek. The operator then turns on at 21:14:42.755 35 kV CB of transmission line OS1-Istok, and at 21:42:19.626 he turns on the disconnecter, followed by the CB, leading transmission line into parallel with 35 kV transmission line Šećerana. After that at 21:25:42.409 the operator turns off 35 kV transmission Šećerana, loading buses 10 kV, and at 21:26:15.426 he turns on feeder 10 kV 108/208.

Step 12 – Hypotheses are not formed due to any alarm.

Step 13 – Message (Alarm – 10 kv short-circuit protection off) finds corresponding hypothesis from the rules and increases it by one

Hypothesis 1: Failure at 10 kV feeder <setname> +1

circuit breaker 10 kV open
Short-circuit protection trip

Step 14 – Estimation phase, not a single hypothesis has reached full score.

Step 15 – Message (Alarm – 10 kV 108/208 circuit breaker open) finds corresponding hypotheses and increases them by one.

Hypothesis 1: Failure at 10 kV feeder <108/208> +2

circuit breaker 10 kV open
Short-circuit protection trip Full score

Step 16 – Estimation phase, hypothesis 1 reaches and it is printed out with its corresponding alarms.

Step 17 – Message (Alarm – 10 kV short-circuit protection terminated) generates hypotheses 1 and 2 and increases them by one.

Hypothesis 1: Non-selective operation of relay 35 kV +1

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short circuit protection terminated

Hypothesis 2: Simultaneous failure at 10 kV and 35 kV feeder +1

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Step 18 – Estimation phase of hypotheses 1 and 2 have not reached full score.

Step 19 – Message (Alarm – OS 1 35 kV Short-circuit protection trip) increases hypotheses 1 and 2 by one, but hypothesis 3 is also generated and increased by one.

Hypothesis 1: Non-selective operation of relay 35 kV +2

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV short-circuit protection terminated

Hypothesis 2: Simultaneous failure at 35 kV and 10 kV feeder +2

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 3: Failure at 35 kV feeder <OS1> +1

circuit breaker 35 kV open
Short-circuit protection trip 35 kV

Step 20 – Estimation phase, not a single hypothesis has reached full score.

Step 21 – Message (Alarm – OS1 35 kV Istok circuit breaker open) increased both hypotheses by one.

Hypothesis 1: Non-selective operation of relay 35 kV +3

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 2: Simultaneous failure at 35 kV and 10 kV feeder +3

circuit breaker 35 kV open
Short-circuit protection trip 35 kV
10 kV Short-circuit protection terminated

Hypothesis 3: Failure at 35 kV feeder <OS1> +2

circuit breaker 35 kV open
Short-circuit protection trip 35 kV

Step 22 – Estimation phase of all three hypotheses reaches full score and results are printed out. There are no more active hypotheses.

If results obtained in steps 1 to 11 and steps 12 to 22 are compared it can be seen that they are the same because alarms appear twice based on Fig. 4. First time

alarms are provoked by the fault and second time alarms are provoked by the operator.

4

Conclusion

Alarm analysis is designed by using the expert system method making logically organized structure of failure diagnoses from basics data. The expert system method used in the alarm analysis clearly shows that there was a failure at 10 kV feeder and non-selective operation of relay at 35 kV which protects the transmission line between the two substations. The emergence of the diagnosis (hypothesis) of the failure at 35 kV feeder is an aftermath of the non-selective operation of relay which unnecessarily detached 35 kV feeder. The diagnosis of the simultaneous failure at 35 kV and 10 kV feeder was also rejected, but it will appear on the screen as a fault possibility. This conclusion comes from CEL during the network's transformation to its original state. A dynamic input data are given in the form of linguistic variables, therefore the solution is also a dynamic cluster of linguistic variables (hypotheses). The solution is changed in accordance with the incoming data. Incoming data stochastically arrive according to a generic algorithm which places hypotheses and comparisons in a certain criterion. A number of iterations in the generic algorithm are finite and determined by the number of input alarms.

Further scientific research of the alarm analysis could apply expert systems with uncertainty, expert systems based on unclear logic, fuzzy logic or some other artificial intelligence method. The analysis can be further expanded, if we take measurements of current and voltage into consideration alongside the switch and relay states, at the point of failure and based on common data, thus getting a more complete review of the event. Based on all available data from SCADA, alarm analysis using ES provides a more complete review of the failure events in EPS and directly makes better decision making possible.

5

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