AROPO - Complex diagnostic system based on transients analysis

M.Švancar, L.Kočiš, P.Spurný

***Abstract*--AROPO is a powerful tool developed for effective diagnostics of components of transmission systems. The diagnostics is based on automatic fault condition recognition through transient record analysis. The main phenomena are circuit breaker (C.B.) breakdowns during no load line switching-off, C.B. restrikes during shunt reactor switching-off, C.B. preignitions switching-on, CVTs capacitance changes, ferroresonance occurrence and saturation of CTs. Results of the transient analysis must be available for TSO operation staff in a very brief and clear form. So interconnection of AROPO system with contemporary database tools and data networks is necessary. The way of AROPO collaboration with SQL database will be presented.**

Limitations through fault recorders capabilities will be discussed. The main limits are caused due to sampling possibilities of fault recorders.

***Keywords*: switching transients, automatic diagnostic tool, fault recorders, device fault prediction**

I. Relationship between device failures and transients

THE very often recorded case of switching transient with clearly known failure of a circuit breaker is the breakdown of C.B. during no loaded overhead line (OHL) switching off (Fig.1).

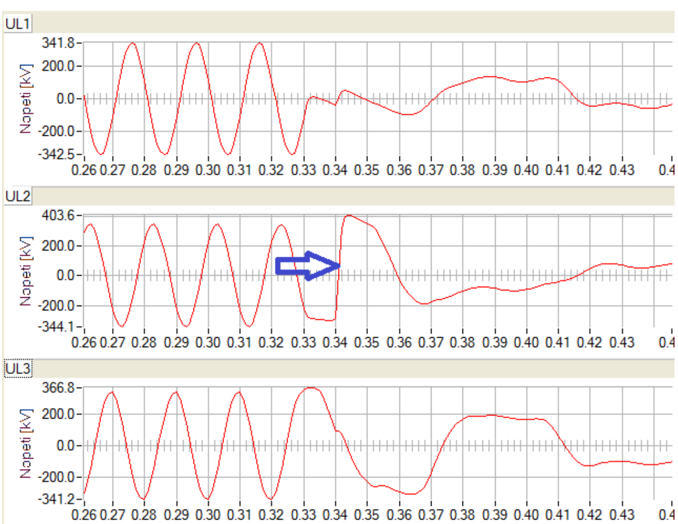

Fig. 1 Breakdown of the line circuit breaker during no-load switching off at 420 kV transmission system (measured with line fault recorder) [1]

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Evident symptoms of insulation degradation were always noticed in the case when the C.B. was dismantled (Fig. 2). This type of fault is the cause of surrounding devices insulation stress and in the worst case can lead to C.B. operation failure with fatal results.

Fig. 2 Circuit breaker (parts of the contact systems after breakdown)

Another significant transient is recorded in case of C.B. preignition during no loaded OHL switching on. This type of transient is an indicator of possible C.B. damage.

There is a wide scale for time duration of the preignition transient phenomena from very short duration times about 0,1-0,5 ms (Fig. 4) to long duration times about 20 ms. This factor causes troubles to practical diagnostics because the fast digital sampling is necessary (out of sampling range of fault recorders).

The occurrence of preignitions (Fig. 3) is often linked with the restrike phenomena that can be observed during equipment switching off. In case of de-energization of shunt reactors that phenomena was measured (in the Czech Republic) (Fig. 5).

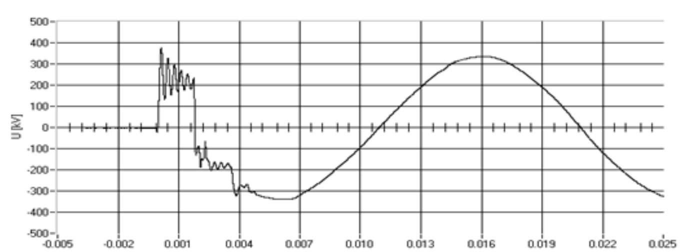

Fig. 3 Preignition of the circuit breaker during energization of the 400 kV transformer (measured with HV capacitor dividers) – duration of preignitions transient about 4 ms.

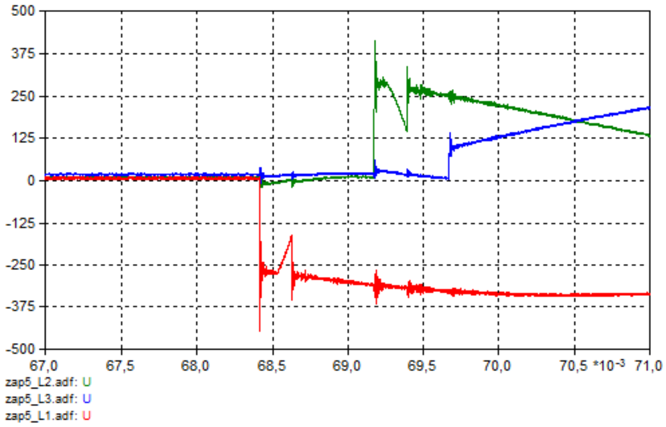

Fig. 4 Preignition of the circuit breaker during energization of the 400 kV shunt reactor (measured with e-field sensors) – duration of preignitions transient about 0.2 ms

Restrikes are significant for degradation state of insulation between the C.B. contact system or contact erosion. Another avalanche development of failure is possible with high probability with risk of C.B. malfunction. Similarly like C.B. restrikes, breakdowns are sources of overvoltage stress of other devices (insulation systems of reactors, transformers, bushings etc.). This problem is the most significant when switching operation is made frequently (compensation reactors switching is typical).

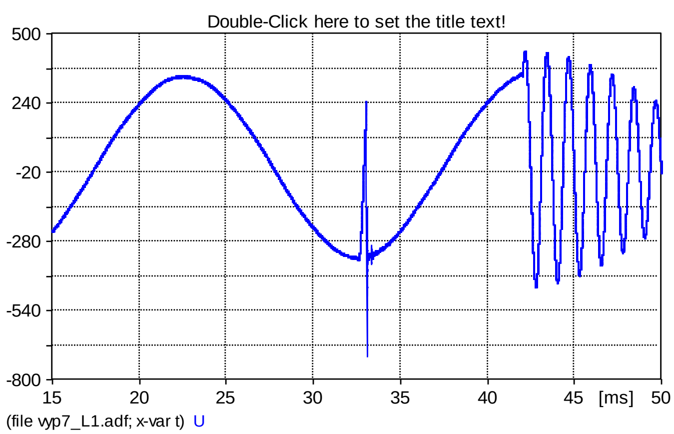

Fig. 5 Restrike of the circuit breaker during de-energization of the 400 kV shunt reactor (measured with e-field sensors)

II. Transients and Ageing of Substation Equipment

The device lifetime and device maintenance plan is influenced by ageing characteristics. Especially the following is important:

- Cumulative transformer loading by inrush currents
- Cumulative transformer loading by short circuit
- Cumulative circuit breaker short circuit current Ii (the value of the short circuit current before its interruption)
- Switching-off current (for calculation of contact ageing) factor K of circuit breakers (K = $\sum n_i I_j^m$ < $K_{critical}$)
- Cumulative temporary overvoltage exposition (number, value and duration) of surge arrester
- Delay between phases sequence during switching

All of these ageing characteristics can be obtain by analysis of recorded transients with fault recorders. There is a necessary condition for setting of fault recorders triggering – there must be triggered by all switching operation, not only failures (short circuits etc.). Evaluation of aging data is the main task of the ACM system (Automatic central monitoring).

III. AROPO – Architecture of the Diagnostic System

AROPO is the software developed in cooperation EGU – HV Laboratory (power system consulting), EGexpert (software developer) and CEPS (TSO in the Czech Republic) and has been in operation since year 2007. AROPO software is permanently analyzing records of transients data from 350 fault recorders from the whole transmission system in the Czech Republic. The main purposes of the software are:

- finding out the equipment with high risk of a failure on the basis of typical transients patterns
- recognizing ageing characteristics from records of transients
- all results are effectively transmitted to ACM (Automatic Central Monitoring) and information systems (eSADA, SAP)

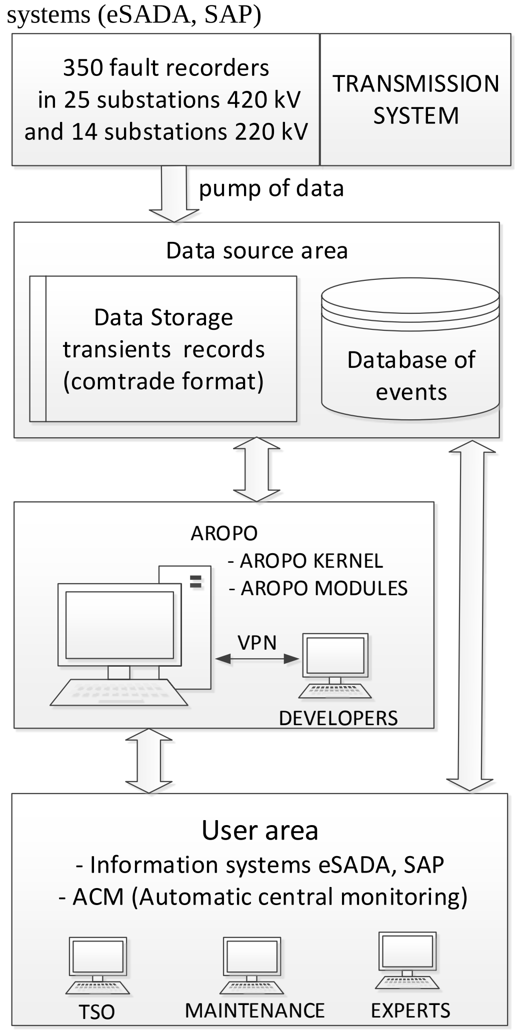

Fig. 6 , Diagram of the basic AROPO architecture

The basic diagram of AROPO architecture is shown in Fig.6. The data from fault recorders in substation are pumped to storage area and head information (timestamp, location, ID) of all transient events is inserted into the database structure (Microsoft SQL Server is used). Settings of the trigger condition of all fault recorders in such a way that recording of all (not only failure) transients (switching manipulations) is enabled represents a very important feature.

AROPO requests for new records to the database in regular time interval (typically 24 h). Then the analysis of the new records starts. The selected record is scanned with all expert modules. The results of the analysis are simply saved in a text file and the necessary information is inserted in database tables. Expert modules are realized in form of Windows dynamic linking library (dll) and can be added or removed by the system administrator.

The superior software (ACM platform-eSADA, SAP) is ready to provide AROPO results to users in a comprehensible format with possibility to use the power of modern database and visualization tools.

IV. AROPO EXPERT MODULES

In 2014 there were 14 expert AROPO modules in operation and 1 module supporting data input (see Table 1).

TABLE I
SUMARY OF AROPO MODULES

Module's name	Brief characteristic of the module
COMTRADE	Supporting module for data input
Circuit Breaker (C.B.) failures	
PRUR	C.B. failure detection, C.B. breakdown during no load OHL switch-off
PREST	C.B. failure detection, preignition of C.B. in switching-on
KOMO	C.B. failure detection, C.B. restrikes during reactors and transf. switch-off
QMCS	Detection of intolerable delay between control signals and C.B. poles opening (closing)
QMCR	Detection of intolerable time delay of sequence C.B. poles opening (closing)
Network abnormal operation circumstances	
ASYN	Synchronization failure detection during switching (phase, voltage)
FERO	Ferorresonance detection
PREP	Overvoltage detection
Voltage (VT), current (CT) device transformers failures	
SATU	Detection of saturation of CT cores which may result in wrong response and function of protections
PETAN	Detection of broken-down armatures of capacitive VT
FREK	Fault detection of anti-resonant circuit of capacitive VT
Ageing characteristics	
ZKRT	Monitoring of short-circuit currents
VYPI	Monitoring of currents switched off by a circuit breaker
NARAZ	Monitoring of transformer loading by inrush currents

The modules in Table 1 are classified into several groups according to their aim. AROPO provides not only failure detection of the transmission system components but it is also useful to find out the ageing characteristics and calculates the equipment health index, useful for device life time evaluation and AROPO get warnings in case of special events like ferroresonance or other kind of overvoltage occurrence.

Every module gives the result in the form of specified output variables. Example of output variables for module PREP (overvoltage detection) and PRUR (circuit breaker breakdowns) is presented in Table 2. The values of the variables are presented for transient in Fig.1. Every of the variables must be clearly connected with a timestamp, physical location (clearly labelling of technical substations equipment in correct phase), data location identification, database record ID.

TABLE 2
OUTPUT VARIABLES OF AROPO MODULES PREP AND PRUR

Module PREP variables and values for case in Fig.1	
OVERVOLT_A = 1,25	overvoltage coefficient based on amplitude measurement
OVERVOLT_E = 1,38	overvoltage coefficient based on RMS measurement
OVERVOLT_E_T1 = 6ms	time duration of the overvoltage when overvoltage is higher than threshold1
OVERVOLT_E_T2 = 4 ms	time duration of the overvoltage when overvoltage is higher than threshold2
OVERVOLT_E_T3 = 3ms	time duration of the overvoltage when overvoltage is higher than threshold3
Module PRUR variables	
BREAKDOWN = 1	Detection of C.B. breakdown and the probability
BREAKDOWN2 = 1	Multiple C.B. breakdowns number
EXTRA = ….	Supplemental information

V. DATABASE APPROACH OF THE DIAGNOSTIC ALGORITHM

AROPO software collaborates with database tables very closely because of huge amount of records saved in fault recorders, which have to be analyzed. All results and program diagnostic info are saved in databases, too. Access to data is enabled through SQL and database engine. The common database format is very useful for flexible service to superior information systems.

AROPO data outputs can be used by expert staff directly for operative maintenance decisions or are available for system ACM (Automatic central monitoring). ACM system operates with data from the following sources:

- database of dispatching control system
- transformer monitoring systems
- EUCLID (lightning detection system)

- AROPO
- SAP system (technological information system)

ACM system was developed for optimization plan of transmission system equipment maintenance. There is a very strong demand for automatic data processing of data from various monitoring and diagnostic information systems.

The ACM support is very useful for responsible decisions making. ACM serves to uncover to non-standard condition or loading of individual facilities, to make maintenance strategy and planning, to monitor of technical condition and history of equipment operation and to calculate of equipment health index.

VI. LIMITS FOR USAGE OF AROPO

The main factor which limits of AROPO results is sampling frequency of fault recorders (1 kSample/s). Some kinds of transients take very short time and the phenomena can't be recorded with fault recorders. As an example there is following comparison of the measurement of the phenomena C.B. restrike using conventional fault recorder and e-field sensor based device with frequency bandwidth from 1 Hz up 1 MHz (5 Msample/s). The measurement was made in October 2014 with the aim of the detection restrikes during 420 kV shunt reactor switching.

On Figures 7, 8 are shown records of the same phenomenon - shunt reactor switching-off. On the Figure 7, where the record was made by e-field sensor system, there is clearly identified 4-multiple restrike of the circuit breaker. On the Figure 8, where the record was made by standard fault recorder, the area of restrikes are marked in circle. Due to sampling frequency and 500 Hz filter there is impossible to recognize exactly number of restrikes. On the other hand the AROPO's module KOMO really did the detection of the C.B. failure. The process of the KOMO detection is presented on the Figure 9. It is based in finding out significant voltage drop after current zero crossing (the same phase). On the Figure 9 the voltage drop is between points A1 and A2. This case demonstrates that though the fault recorder wasn't be able clearly record the phenomenon, there were enough significant information for failure detection. At the case of such detections there is strongly recommended to perform a diagnostic overvoltage measurement with sufficient measurement bandwidth (e-field sensor devices or similar).

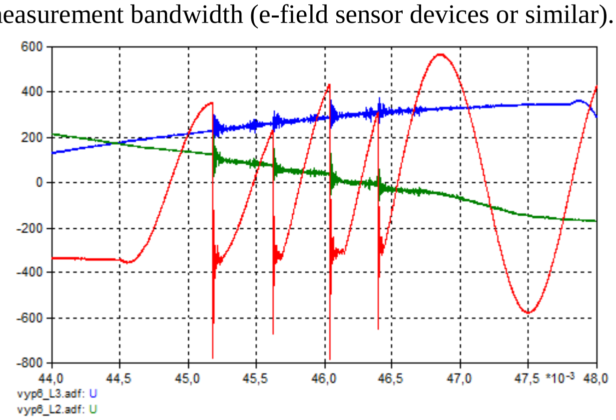

Fig. 7 Multiply restrike of the circuit breaker during de-energization of the 400 kV shunt reactor (measured with e-field sensors)

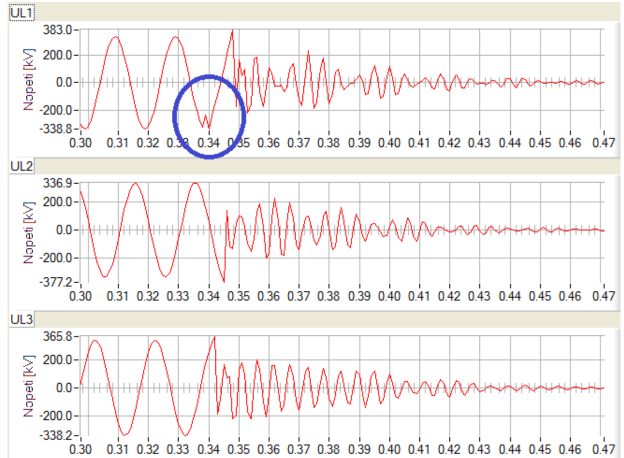

Fig. 8, Multiply restrike of the circuit breaker during deenergization of the 400 kV shunt reactor (measured with fault recorder - AROPO)

TABLE 3
OUTPUT VARIABLES OF AROPO MODULE KOMO

Module KOMO variables and values for case in Fig.8	
KOMORA = 0,72	Coefficient of the voltage drop in the time interval A1-A2 after last current zero crossing
KOMORA_T = 2,00 ms	Time interval between A1 AND A2 (see Fig.9)

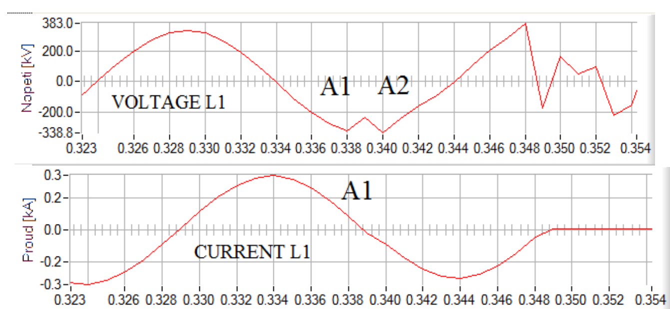

Fig. 9, Illustration of the module KOMO processing

There is a task for sensitivity settings of AROPO modules because the false detection and false alarm is unwanted. In presented example it is a question for which voltage drop is failure detection relevant. For sensitivity purposes each of the modules has possibility of the settings of the key sensitivity parameters in special text file so called *module *.ini file*. The values of this parameters are evaluated by experts from TSO (CEPS a.s.) or EGU - High Voltage Laboratory.

VII. CONCLUSION

For whole time AROPO operation since 2007 was detected some failures and the replacement of that damaged equipment was done subsequently.

The most often is the detection of circuit breakers breakdowns (more than 10 C.B. detected – some replaced).
Other cases of positive diagnostic results are finding out failures of C.B. preignitions (this type of failure can be possibly detected only for the most significant cases due to very fast transients), broken-down of armatures instrument VT

(6 cases), intolerable C.B. poles delay.

AROPO practically eliminated the ferroresonance risky configurations of network in the whole CEPS transmission network.

Figure 10 presents a sample of AROPO ferroresonance record and the Table 4 variables and their values for that record.

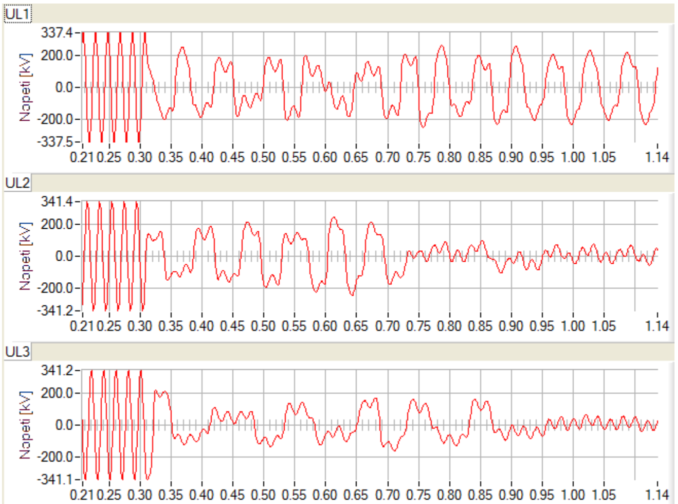

Fig. 10, Ferroresonace in the bay of combined busbar C.B. detected by AROPO (6.10.2014)

TABLE 4
OUTPUT VARIABLES OF AROPO MODULE FERO

Module FERO variables and values for case in Fig.10	
FERO = 2	The level of significance of the ferroresonace
FERO_U = 0,64	Average RMS value of the ferroresonance voltage (p.u.)
FERO_T = 2,40	Time of the ferroresonance phenomena in the record

The contribution of the AROPO for planning of maintenance and evaluation of Index of Health is a subject of the investigation, some notes are in the article [4].

Because the software AROPO has modular architecture the adding of the next modules are possible. Next development of the new modules will be specified by transmission system operator requirements.

VIII. Acknowledgment

The authors gratefully acknowledge to TSO in Czech Republic CEPS a.s. for support and collaboration during whole time of the AROPO development. Without these persons – D.Kopejtková, J.Velek, P. Spurný, M. Kaňok, S.Vnouček – AROPO could not be developed.

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