Circuit Breaker Test Equipment

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***Abstract* – Switching elements are present in low, medium and high voltage transport and distribution networks. Circuit breaker is a switch that automatically interrupts the flow of electric current if the current exceeds a specific limit. Circuit breakers are used most frequently as a safety measure where too much current through a circuit could be unsafe. Their electrical and mechanical qualities are important for proper functioning of the electrical plants. Evaluation of their performances is the main topic described in this paper. Test equipment allows "off-line" test of switching elements in low, medium and high voltage installations to ensure they remain safe and perform in a reliable manner. It makes such a predictive maintained that aims early detection of potential operational problems. Five quantities can be measured in this article: contact voltage and current to measure the circuit breaker's current path resistance, two currents through the contacts closing and opening coils and contact displacement signal.**

Keywords - *circuit breaker; operating parameters; maintenance; virtual instrument; off-line test*

I. INTRODUCTION

Because of the importance to the optimum functioning of national energy systems, it is important to have an evaluation of the performance of existing devices and equipment. The most important are the breakers and separators. The circuit breaker is an indispensable device in the power line, and one of the most important safety mechanisms [1]. The circuit breakers job is to cut off the circuit whenever the current is above a safe level [1]. They provide protection respectively separation of subnets from the main network. Their quality is even better with the circuit as their influence is minimal, so the losses are minimal. The objective of this article is the realization of a test system that allows a rapid assessment of medium and high voltage breakers in power stations, Fig. 1.

Fig. 1. Power distribution facility

The rating of automation is high and can be harvest many other parameters. The command can trigger contact opening / closing from a computing system. Medium-voltage and high voltage circuit breakers operate by current sensing protective relays, through current transformers. Medium-voltage circuit breakers can use separate current sensors and protective relays, instead of incorporated thermal or magnetic relying. Electrical power transmission networks have protected and controlled by high-voltage breakers. High-voltage breakers are usually solenoid-operated. In substations, the protective relay schemes protect equipment and grid from various types of overload or ground/earth fault. This article reviews common DC tests perform on circuit breakers to ensure they remain safe and complete in a reliable manner. If circuit breaker resistance increases, the result is an important decrease in the contact's ability to carry current. An example of contact resistance degradation is cause by excessive corrosion of contacts [2], [3]. One way to check contacts is to apply DC current and measure the voltage drop across the closed contacts. The breaker contact resistance results according by Ohm's law. It is recommended that for circuit breaker contacts, the resistance test be made with at least 100 Amperes direct current [2], [3]. Using of a higher current value gives more reliable results than using lower current values. The resistance value typically measured is in micro-ohms [2], [3], [4].

II. DESIGN PRINCIPLE

A. Theory of Operation

Signals waveforms are present in Fig. 2, representing simulation of them. In the top of diagrams are present signals in trigger coils ("on" and "off"). In the middle diagrams is a represented mobile contact movement. In bottom of diagrams are represented voltage and current through circuit breaker contacts. Signals (U1, U2, U3, U4, and U5) measured are processing by software with a high grade of automation. If primary signals are not voltages (e.g. currents) these must be converted into voltages, according with data acquisition device. If breaker has more than one pole (e.g. three phase device), each pole is test separately. Circuit breaker contact resistance, R_C, can be estimate by (1), k represent a coefficient, results from current to voltage conversion and entire calibration of test equipment. U_1 and U_2 represent voltage depending of current and, respectively, the voltage across the circuit breaker.

$$R_C = k \cdot R_S \cdot U_2 / U_1 \qquad (1)$$

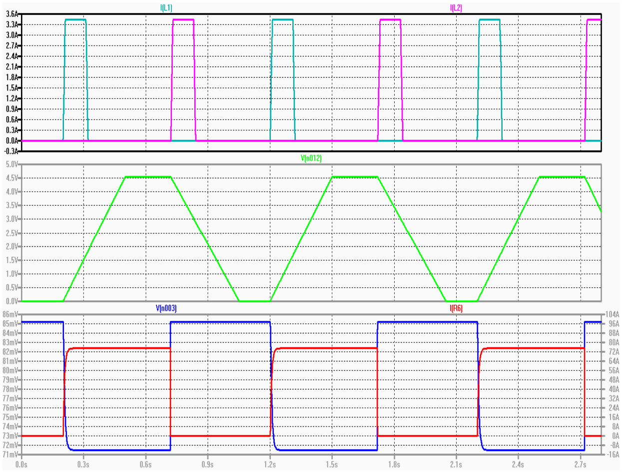

Fig. 2. Signals waveform (simulation)

Speed of contact closing is determined using linear variation of position sensor (potentiometer) and knowing initial and final time of contact displacement, (2). Voltage across potentiometer “U”, voltage variation “ΔU”, and time interval “Δt” are main components of how to find out speed of closing contacts.

$$\Delta U = U \cdot \Delta X / l\,, \quad \Delta X = \Delta U \cdot l / U, \quad v = \Delta X / \Delta t \tag{2}$$

B. Schematics

Proposed off-line test adapting designs are present in Fig. 3. The following components are represented: “K” is the circuit breaker tested, “U” is a DC power source (usual a 12 V auto battery), “Rp” is total resistance of high current circuit without circuit breaker resistance and without shunt resistance, shunt resistance “Rs” is used to convert high current into voltage, “A” is a differential or instrumentation amplifier, “Rs_1” and “Rs_2” are used to measure current through coils and “P” is to measure movement of mobile contact of circuit-breaker [5].

Because is intend to reduce overall costs of test equipment (by using low-cost DAQ board), some timing circuits was additionally developed. Because of sequentially evolution of signals, in Fig. 4 are present an example of bloc diagrams of activate coils command signals. First component is a delay block and is useful to give some time to DAQ board to record data including moments before “on” trigger signal. After delay block “τ_1”, initial position X1 and initial moment t1 are found. A monostable block “M1” give signal to activate “on” trigger coil. Delay block “τ_2” is useful to avoid overlap “on” and “off” signals. During “M1” and “τ_1” stages, are located moment t2 and coordinate X2. An example of algorithm to localize X2 is to locate in data recording location when signal does not change its value from that moment forward. Monostable “M2” give signal to “off” trigger coil [5], [6].

Another possibility is to use higher performance DAQ board to generate command signals or use a microcontroller to generate command signals. These simplify hardware but can increase complexity of software. These two solutions give more flexibility to test equipment. Depending on local conditions, one solution or another can be implementing.

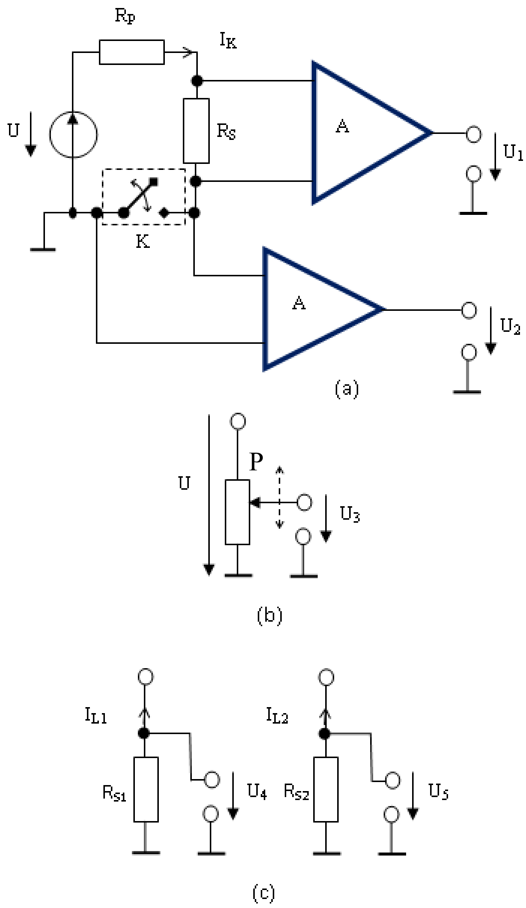

Fig. 3. Conditioning circuit of voltage and current (a), position (b) and coils currents (c) [7]

Delay and monostable blocks can be implemented using analog components (e.g. 555 timer) or digital components (TTL or CMOS technology) or command signals can be synthesize by a microcontroller.

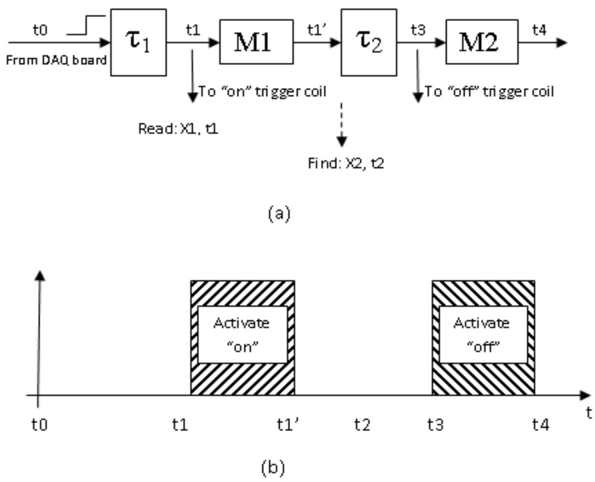

Fig. 4. Block diagram (a) and timming sequance (b)

III. Timing Schematics and DAQ Part

An example of design of timing circuit, according with Fig. 4.a, represented in Fig. 5. Can be used TTL circuits or CMOS, and components values can be different because of some difference between low and high threshold.

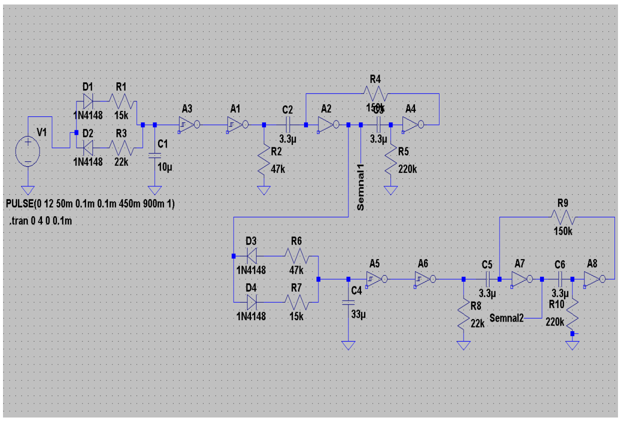

Fig. 5. Example of timing circuit (design with logic circuit)

Other more comfortable schematics are based on microcontroller. In this case, have more flexibility and can be adapt quickly. In addition, it can be implemented schematics with analog integrated circuits, Fig. 6.

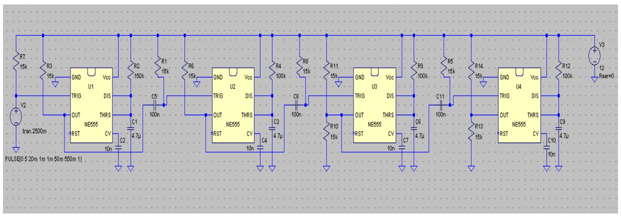

Fig. 6. Example of timming circuit (design with analog circuits)

Using any implementation chart signals should look like Fig. 7. The outputs signals are the third and fifth diagram. Depending of circuit breaker manufacturer (there are many types of circuit breaker design), it is possible to make some adjustments of timing.

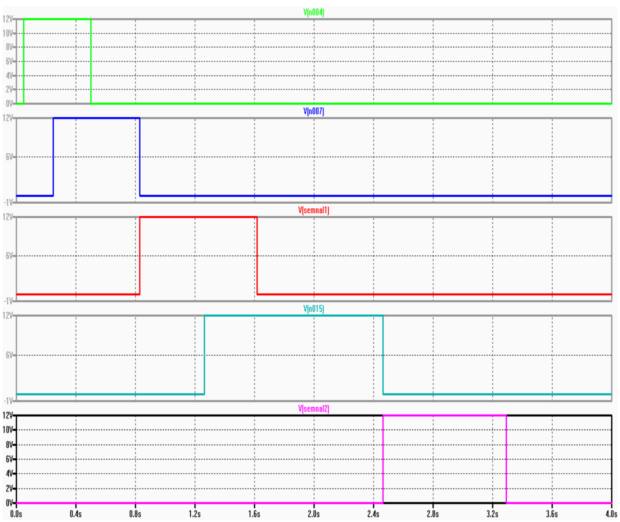

Fig. 7. Signals of timing circuit

USB-6008, Fig. 8, is an acquisition device manufactured by National Instruments (also producer LabVIEW IDE) and is a low-cost part of the range components DAQ (Data Acquisition) used in measurement and data acquisition. By facilitating communication on the type of USB plug-and-play devices are simple enough for rapid measurements and also versatile enough being recommended even for complex applications for data acquisition. USB-6008 acquisition card is ideal for a range of applications where low cost, small size and simplicity are key components. There are applications where there is require to use the analog inputs in differential mode. In the present case the differential mode is not used for practical purposes (low-level signal require amplification anyway; external circuitry providing a separation between power circuits and acquisition board) [8], [9].

Fig. 8. NI USB-6008 DAQ Board

Parameters of this device are low-cost, bus-powered multifunction DAQ, 12-Bit, up to 10 kS/s, 8 analog inputs. Useful to this DAQ board is possibility to power supply additional components (200mA load, 5V) [10], [11].

IV. Software

Software application was made using virtual instrumentation integrated development environment from National Instruments, LabVIEW. The program is the most important component of a virtual instrument. An intuitive front panel of application is present in Fig. 9. Diagram corresponding to trigger digital output of DAQ board and processing the signal is present in Fig. 10. Was chosen as a mode of operation, run once the entire measurement process to avoid faulty maneuvers on breaker [10], [11].

Main element here and other sequence is DAQ Assistant. It creates, edits, and runs tasks using NI-DAQmx. NI-DAQmx is new product from National Instruments, a next-generation data acquisition driver. NI-DAQmx incorporates new driver design and API, complete with new VIs/functions and development tools for controlling National Instruments DAQ devices. NI-DAQmx is different from the Traditional NI-DAQ driver. When place this Express VI on the block diagram, the DAQ Assistant create a new task. After create a task, it is easy to edit that task (double-click the DAQ Assistant Express VI). For continuous measurement or generation, a solution is to place loop around the DAQ Assistant Express VI [10], [11].

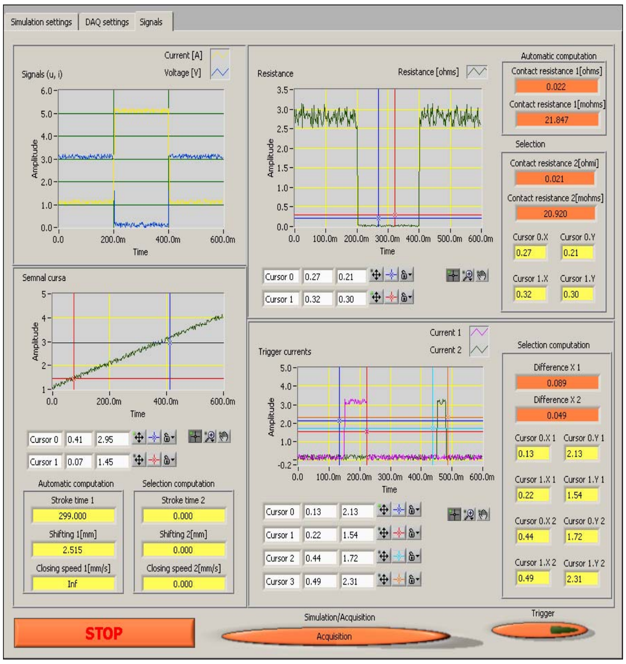

Fig. 9. Front panel of application

For continuous single-point input or output, the DAQ Assistant Express VI might not give reasonable performance [11], [12]. A good example is to use the Stop parameter to prevent the Express VI from stopping the task until the last iteration [11], [12]. The program has two modes: simulation (useful for tracking its operation) and acquisition (in which the actual measurement is performing). Measurement first step is to make program initialization and awaiting a command. Measurement process is complete by sending a trigger signal card acquisition output (can be analog or digital output). Reading the data for a sufficient time to include opening and closing the breaker contacts is the next step. The data are ready for processing (separation and scaling). Simulation operating mode synthesizes these signals. Both modes offer similar signals to be processed thereafter. Processing stages provides both automatically extracting the information, as the interest of the five signals, and the ability to query areas of interest from waveforms graph. Automatic determination of contact resistance for example, uses statistical processing of signals [11], [12].

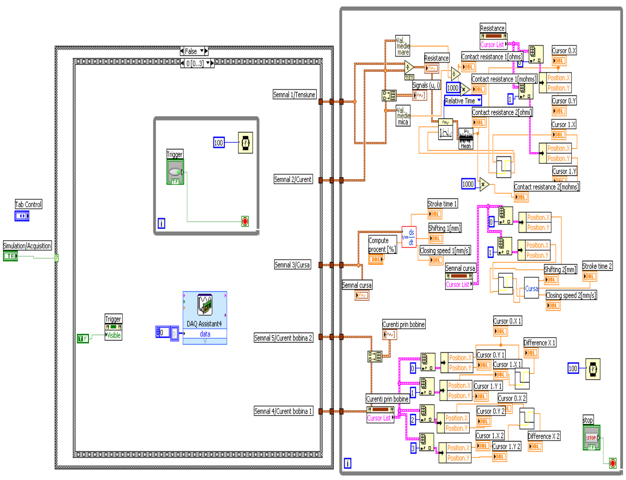

Fig. 10. Main part of software diagram

The application has possibility to make a manual selection of interest points to make a specific evaluation of parameters. For example, speed of closing/opening contacts it is not constant on entire course. By interest is speed of contacts in proximity of opening/closing contacts. This can be done by placing cursors on interest times moments. This is an advantage of manual and automatic circuit breaker parameters determination.

Another facility is possibility to generate a report with images and texts of interest. In Fig. 11 is present an example of diagram of generating report virtual instrument. It has both JavaScript and specific virtual instrument setting components.

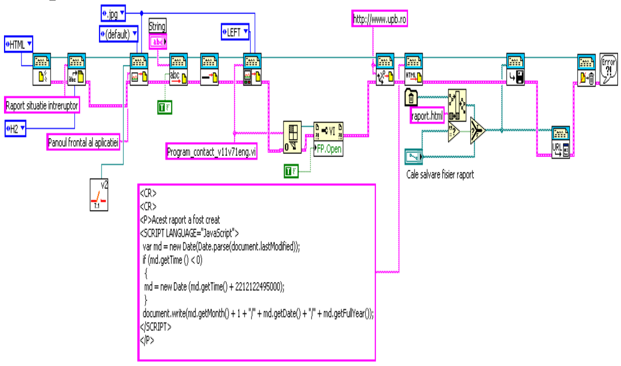

Fig. 11. Diagram of generating report virtual instrument

In table I are present some example of resistance of circuit breaker contacts. Was tested two type of circuit breaker (low-voltage and medium voltage).

TABLE I. EXAMPLES OF CONTACT RESISTANCE

Circuit breaker	**Resistance [mΩ]**		
	Phase 1	***Phase 2***	***Phase 3***
Low voltage (690V)	0.025	0.057	0.021
Medium Voltage (20kV)	0.028	0.024	0.022

Low voltage tested circuit breaker (Moeller IZMH3-V4000) is out of operation because of contact resistance unbalance (phase 2).

V. CONCLUSIONS

For all types of electrical installations, it is recommended to do periodical maintenance of electrical equipments. Because of high diversity of circuit breaker, this example of test equipment must be adapted (from mechanical point of view) to every situation. In this paper, DC measurement of resistance it is used as "off-line" circuit breaker test. Complexity of using this test equipment is to do some maneuvers to pass the circuit breaker in "off-line" mode and connect into measurement path.

The above example can be low cost equipment with high grade of versatility. Fig. 12 presents some experimental modules (control and power modules). The challenge of this type of test equipment is to be able to test circuit breaker in "on-line" mode (without take out circuit breaker from power line). This is not easy to set into practice because of AC presence in current path. There are some possibilities to develop such type of AC test equipment.

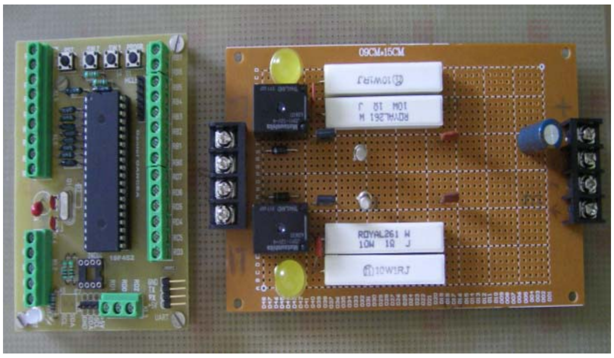

Fig. 12. Experimental 1: microcontroller control module (left) and power module (right)

One principle is to measure circuit breaker contact temperature (where is possible) and using Wiedemann-Franz-Lorenz equation to find voltage across circuit breaker contact (here is possible to have some weaknesses, depending by contact structure).

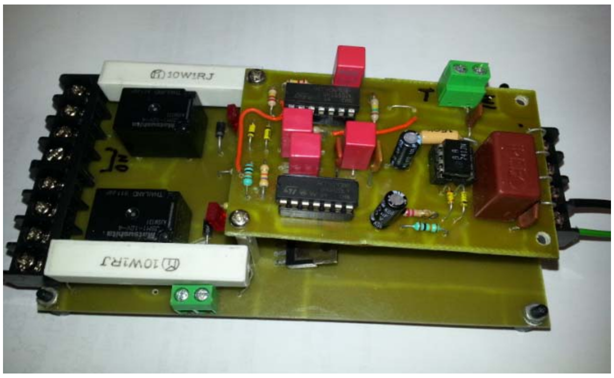

Fig. 13. Experimental 2: Integrated circuit module (top) and power module (bottom)

Another challenge is to develop the mobile side displacement measurement without mechanical contact, regardless of the mechanical part, which allows the motion measurement. This can give somewhat equipment independence by circuit breaker design and increase speed of measurement.

This equipment is developed to have high flexibility, low cost and independent resources (a laptop with data acquisition card, an adaptation electronic block and car battery are hardware components).

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