Measurements of Gas Pressure into the MV Arc Plasma Environment

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Current interrupters equipped with arc quenching system based on combination of forced air flow and gassing material were the object of the research described in this paper. Arc quenching gas pressure inside the extinguishing chamber in direct vicinity of plasma arc was recorded by means of developed measurement system resistant for heavy duty conditions existent inside the chamber during breaking. Gas pressure was estimated for several values of load current at 12/24 kV source voltage.

Keywords: arc quenching, measurement, gas pressure, arc energy, arc plasma

1 RESEARCH TOPICS

Air insulated load-break switches are one of the most frequently used current interrupters for Medium Voltage (MV) power networks operation. Located into the Ring Main Units (RMU) and equipped with effective arc extinguishing systems, are suitable for interrupting a load currents ranged from a few to hundreds of amperes. For arc quenching efficiency enhancement switches are usually equipped with extinguishing systems linking various technologies. Typically combination of air forced flow together with gassing material combination is utilized [1]. Arc quenching effectiveness is strictly connected with arc cooling medium volume and pressure value existing inside the quenching chamber and responsible for both: arc temperature decrease and chamber atmosphere deionization [1, 2]. Depending on the utilized quenching method, interrupted current determines also volume of gasses generated from the chamber gassing material and in consequence has a significant impact on arc quenching effectiveness. In turn a voltage level at the contacts has an influence on restrikes occurrence probability.

Precise valuation of such interrupters type extinguishing system effectiveness is problematical due to extremely heavy duty conditions occurring in plasma arc environment. Because of high temperature occurrence in the chamber caused by plasma presence, phenomenon short duration and risk of high energy electric breakdown between the contact system and measurement equipment, problem of gas pressure into the extinguishing system valuation is usually realized by means of dedicated Computational Fluid Dynamics (CFD) simulations [1, 3] and dedicated calculations [4, 5]. The recent development of measurement systems allows for utilization of a new equipment providing measurements at ultra-hostile environments [6, 7].

Material included in this paper reports results of gas pressure inside the extinguishing chamber evaluation. Tests were performed by means of developed measurement system equipped with high-frequency dynamic piezoelectric pressure sensor. Attempts to apply similar sensor in described case has already been performed but for low voltage systems characterized by disproportionately lower energy dissipated by arc plasma [7]. The system described in this paper has been experimentally verified during large number of tests for capacitive current interruption at supplying voltage between 12 kV and 24 kV. By using a fiber optic connection between the sensor and measurement fixture based on AC/CA converters, no additional electrostatic shielding was required and risk of breakdown to the measurement equipment was minimized. Gas pressure measurements were performed for typical switch equipped with combined air flow-gassing material arc quenching system. For full-scale analysis of gas pressure and distribution inside the extinguishing system, measurements inside the chamber made of polioxymethylene (POM) and inside the cylinder responsible for air flow were realized. Such a procedure gave an idea for arc quenching behavior realized by mixture of forced air flow and POM gassing.

2 EXPERIMENTAL SET-UP DESCRIPTION

Objects of the research were a typical 12 kV and 24 kV air insulated load-break switches equipped with extinguishing system based on forced air flow through the nozzle made of gassing material. Tested switches are dedicated for interrupting maximum load currents ranged from 400 A to 1250 A at 12/24 kV. Depending on the current value and occurred arcing time different factor, is decisive for arc quenching efficiency (forced air blow, gassing material). To perform analysis of utilized in these type of switches extinguishing method, tests including gas pressure measurements inside the extinguishing chamber in direct vicinity of arc plasma was developed (Fig. 1).

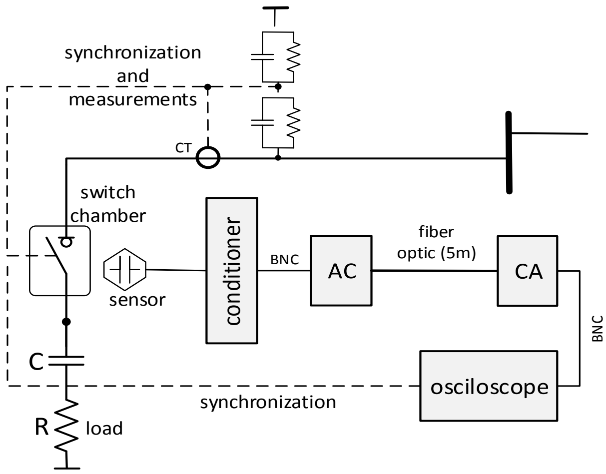


Fig. 1: Measurement stand diagram

Presented in Fig. 1 tests stand comprises the following measurement fixture:

- high frequency pressure sensor responsible for transformation of the pressure change signal into electric signal,
- conditioner providing sensor signal normalization for further analysis,
- A/C and C/A converters responsible for galvanic separation of high potential set-up part and low potential set-up fixture,
- recording device (oscilloscope),
- triggering system with synchronization of the switch opening moment and trigger–recorder synchronization.

Tests have been performed in the capacitive character load circuit for analysis of current breaking capability under increased transient voltage level. Due to a risk of restrikes, observation of the arcing time increase was expected. As a consequence of increasing arcing time, gassing of the nozzle material was expected, and it was proved during tests e.g. for tests at higher value of load current (Tab. 1).

Two sensor locations were utilized during the tests (Fig. 2) – at the gassing nozzle and at the cylinder right below the fixed contacts.

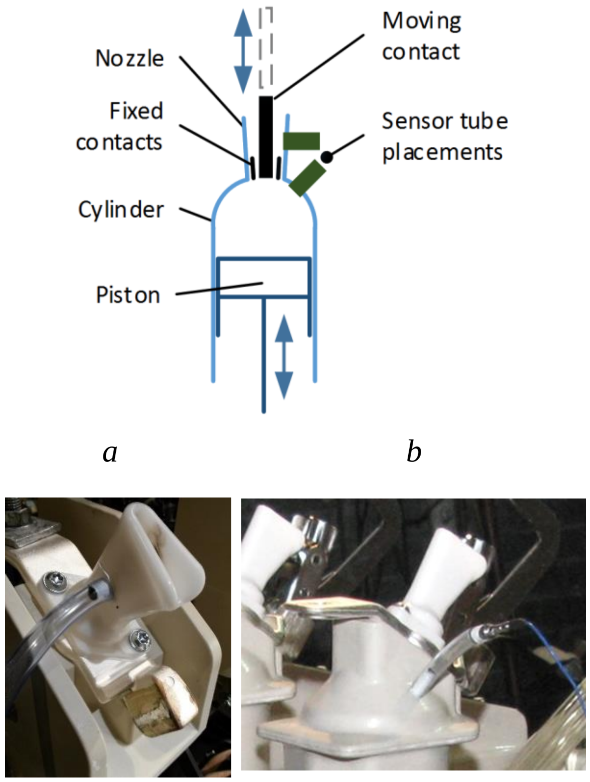


Fig. 2: Pressure sensor tube placements: (a) at the extinguishing nozzle and (b) at the cylinder

Generated gas backflow, expected during arc ignition, into the cylinder analysis was secured by installation of the sensor at the cylinder.

Taking into account pressure sensor principle of operation and to minimize the risk of breakdown between the switch arcing contacts and sensor metal casing, device has been connected to the nozzle through the short polyethylene tube (Fig. 3).

During the preliminary tests (Fig. 4), tube characterized by maximum length of several

(≈10 cm) centimeters was examined. Experiments indicated that tube length has negligible influence on pressure measurements accuracy.

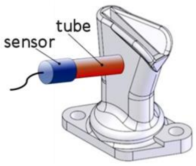


Fig. 3: Pressure sensor fixed at the gassing nozzle

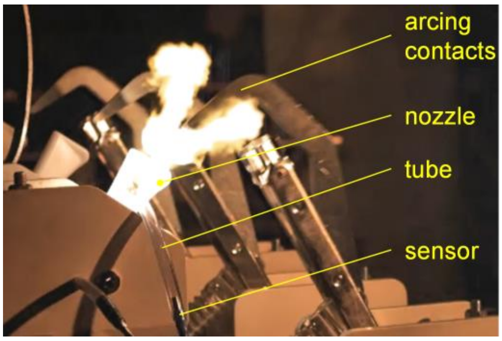
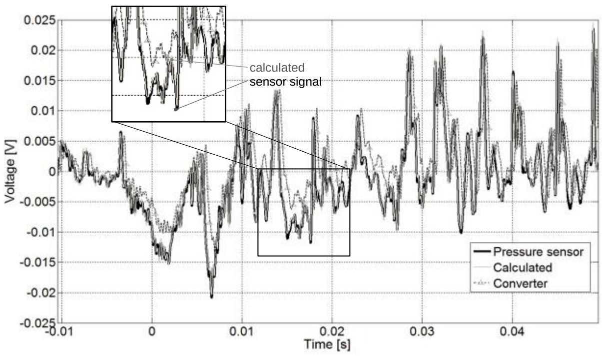


Fig. 4: Pressure measurements during 24 kV tests

To eliminate potential distortion introduced by AC/CA converters (Fig. 1), on recorded pressure signal (v_1), signal frequency response and Fourier transformation (FFT) coupled with output signal (v_2) low frequency noise filtering and inverse FFT has been applied (1).

$$G(\omega) = \frac{FFT(v_2)}{FFT(v_1)} \qquad (1)$$

Resulting signals is characterized by very low discrepancy in comparison to the original sensor signals (Fig. 5).



where: converter – signal at the AC/CA converter output, calculated – converter signal after inverse transformation pressure sensor – pure signal at the sensor output

Fig. 5: Sensor signal, output AC/CA converter signal and recalculated output signals waveforms

3 EXPERIMENTS RESULTS

Tests in cable charging test duty and earth fault test duty were performed according to IEC 62271-103 standard [10].

Basic assumption was to perform the tests with rated supplying voltage of the switches: 12 kV and 24 kV (RMS) and rated currents: 120 A (RMS) (Fig. 6) and 20 A (Fig.7). To check system resistance on possible breakdown occurrence, additional tests for increased voltage were performed. No dielectric breakdown to the sensor and its equipment was observed during more than one hundred of tests shots performed for nominal (U_N) and increased (1.2 U_N) supplying voltage.

For each test duty various moments of contact separation have been selected. It permitted to obtain results for various arcing time duration and in consequence to examine its influence on nozzle material gassing level.

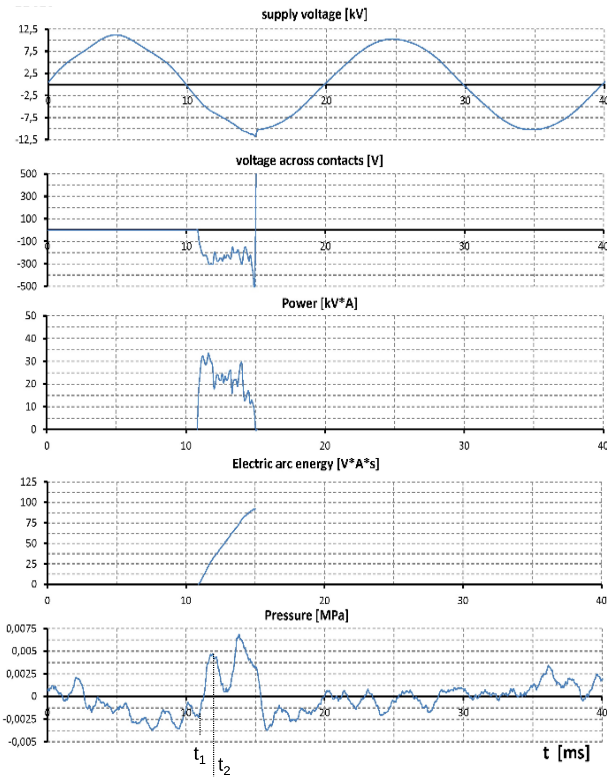


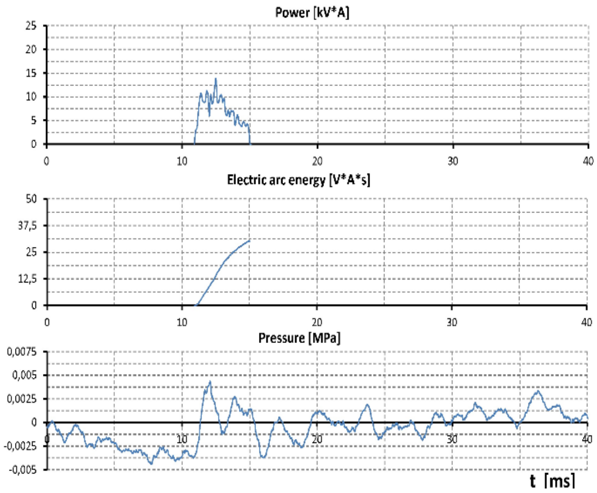
Fig. 6: Signals waveforms recorded for 120A phase load current at 12kV

To compare current level influence on gas pressure inside the nozzle and in consequence material gassing level, tests for 20 A of load current were carried out (Fig. 7). Taking into account specific contacts-quenching nozzle system construction (Fig. 2), characteristic diagram (Fig. 6) elements can be marked out.

Piston movement (Fig. 2.) and simultaneously mechanically forced air flow starts before contacts opening is initiated. Because piston starts moving before arcing contact are opened, at the first stage insignificant gas flow through the nozzle is realized. Before t_1 contact separation moment is reached, temporary and minor underpressure at the sensor is observed. Due to increasing piston movement velocity, recorded negative pressure value smoothly decreases. Contacts opening and at the same time contacts-nozzle system unsealing at the t_1 moment causes increased gas inflow inside the nozzle and in consequence recorded pressure increases. When the movable contacts leaves the nozzle at the t_2 moment gas pressure decreases. Observed strong drop of pressure in the middle of the pressure wave is caused by gas flow through the enlarged top hole at the nozzle combined with temporary decreased piston movement velocity value, what is caused by switch mechanical construction.

Maximum pressure value observed for the 120 A of load current (Fig. 8) results from summary of pressure generated by mechanical extortion (moving piston) and gas generation from the nozzle material (polioxymethylene).

For the lower interrupted currents values, gas generation from the nozzle material is significantly lower in comparison to mechanically forced air flow (Fig. 7).



where: power-electric arc power,

Fig. 7: Exemplary signals waveforms recorded for 20A load currents at 12kV and forced air flow

For comparison, tests without activated forced air flow system were performed. It affected the arcing time elongation (Fig. 8).

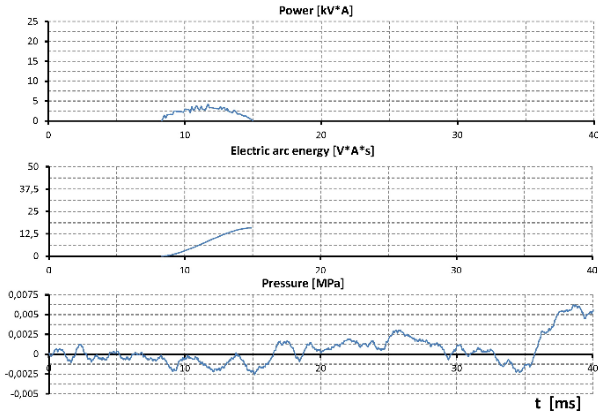


Fig. 8: Exemplary signals waveforms recorded for 20A load currents at 12kV (no forced air flow)

Selected results of pressure values recorded for 20 A and 120 A of load currents are presented in Tab. 1 (Engaged forced air flow system).

Tab. 1: Average results achieved for 12 kV tests

Forced air flow				
Current [A]	max. P_{arc} [kV·A]	t_{arc} [ms]	E_{arc} [V·A·s]	p [kPa]
120	30	≈3.5	75	6.25
	33		87	7.5
	34		87	7
20	15	≈4	≈32	5
	14			3.75
	15			3.75

4 CONCLUSIONS

Developed measurement system indicates applicability for gas pressure estimation, present inside the extinguishing chamber of MV air insulated switches. System is able to operate in heavy duty conditions in the presence of switching arc. System is resistant for dielectric breakdown at the MV of supplying voltage. No breakdown was observed during more than a hundred of performed tests shots.

High variability of recorded pressure values may be caused by pressure resolution level and acoustic wave reflections. Potential distortions introduced by utilized AC/CA converters can be eliminated by means of dedicated mathematical transformation [9] taking into account converters frequency and amplitude response.

For interrupted currents ranged from 20 A to

120 A recorded pressure increase caused by forced air flow is significantly higher than pressure increase resulting from the nozzle material gassing. Required, for reliable current interruption pressure level, coupled with data collected during tests, permits for piston size optimization concerning fabrication costs minimization by means of nozzle outflow geometry and system efficiency optimization.

For higher values of interrupted currents it is expected significant increase of gas volume generated by nozzle gassing material. Therefore it is recommended to perform tests for higher values of currents similar to switch rated values. Tests at higher interrupted current values will permit to estimate relation between the volumes of gas generation from the POM in comparison to mechanically forced air flow generated by movable piston.

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