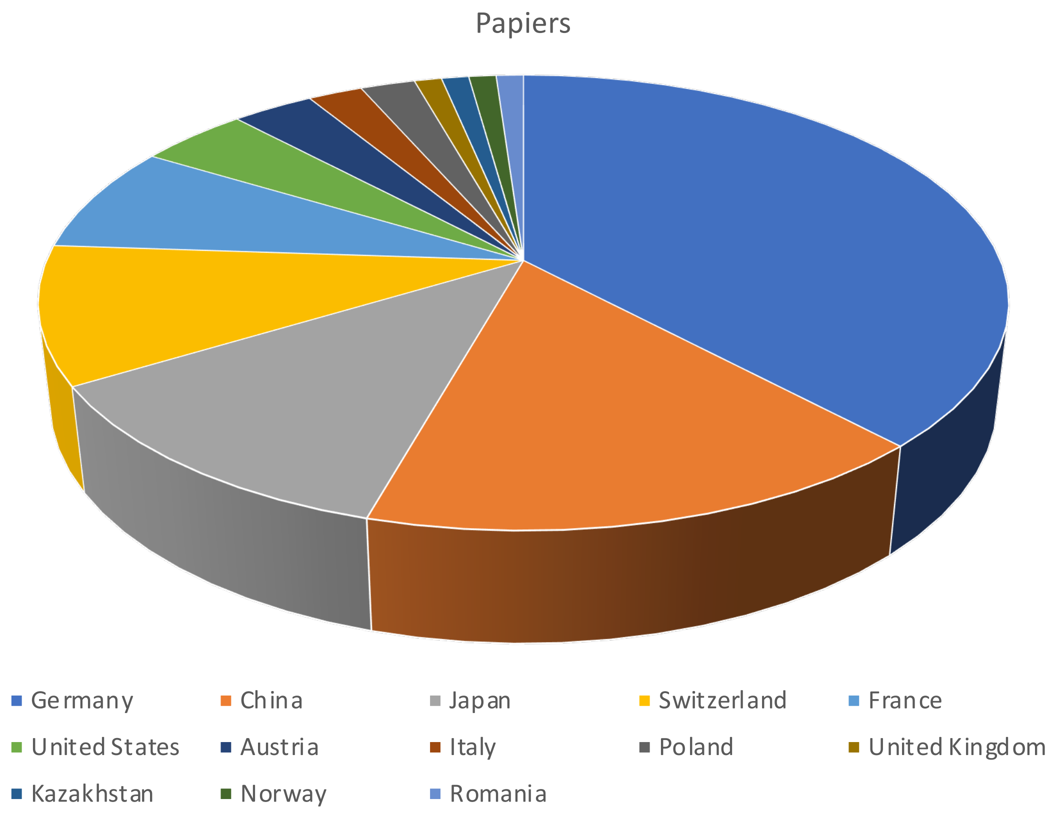
ICEC 2021

7 – 11 Juin 2021

Origines



Papiers
Germany
China
Japan
Switzerland
France
United States
Austria
Italy
Poland
United Kingdom
Kazakhstan
Norway
Romania

Sessions

- **Session 1: Basic Contact Phenomena and Design**
- **Session 2: Switching Behaviour A**
- **Session 3: Switching Behaviour B**
- **Session 4: Arc Interruption and Design**

  Session 5: Connectors and Terminals

  Session 6: Contact Materials and Design I A
- **Session 7: Contact Materials and Design II A**

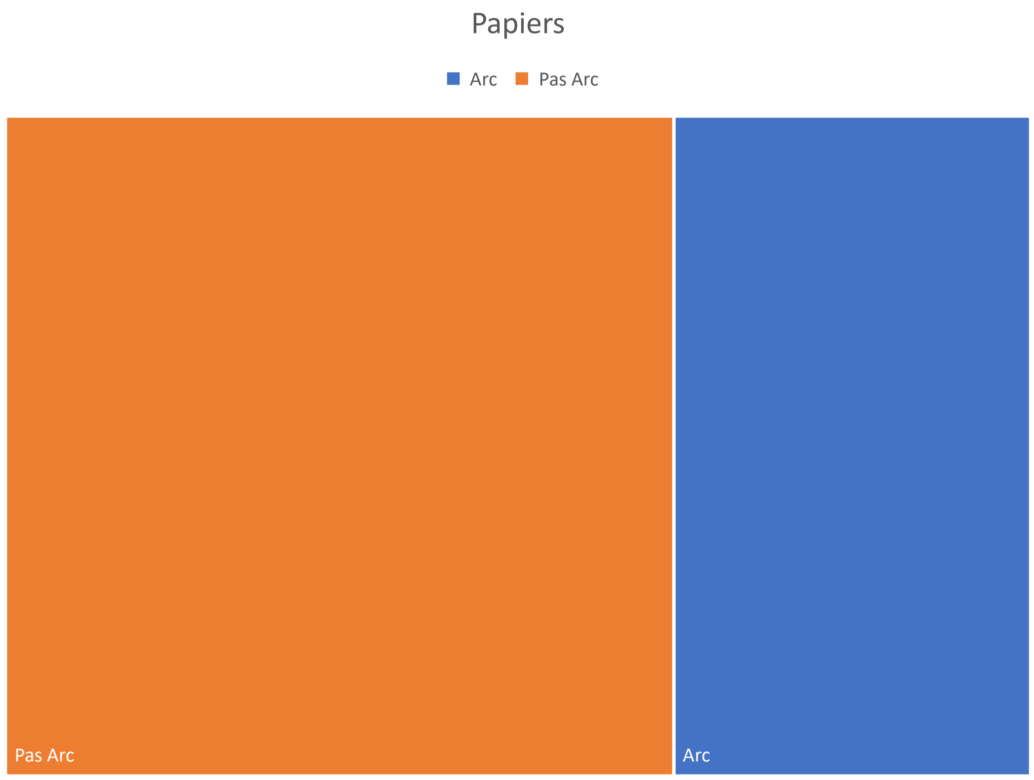
  Session 8: Sliding Contacts
- **Session 9: Automotive Applications**

  Session 10: High and Low Power Contacts

  Session 11: Environmental Effects, Diagnostics and Reliability
- **Session 12: Modeling/Simulation A**
- **Session 13: Modeling/Simulation B**
- **Session 14: New Technologies**

Sessions : 9/14

Papiers



Arc : 30/92 papiers

Session 1: Basic Contact Phenomena and Design

Circuit Control Development since the First International Conference on Electrical Contacts (1961 to 2020)
Paul Slade (Consultant)

Series Electric Plasma Discharges of Failing Contacts up to 10 A at Various Materials
Peter Zeller (University of Applied Sciences Upper Austria)

Measurement and study of arc noise fluctuation by fast camera observations
Jean Baptiste Humbert (Univ Lorraine IJL CNRS), Patrick Schweitzer (Univ lorraine IJL CNRS),
Serge Weber (Univ lorraine IJL CNRS) and Robert Hugon (Univ lorraine IJL CNRS).

Circuit Control Development since the First International Conference on Electrical Contacts (1961 to 2020)

Paul G. Slade, Consultant, Ithaca, U.S.A., paulgslade@verizon.net

Abstract

The paper reviews 60 years (1961 – 2020) development of circuit breakers, contactors, relays and switches. It also reviews the developments in measurement and analytical techniques that have enabled the further understanding of arc interruption and switching contact performance. The introduction of the high-speed oscilloscope in the early 1960s, for the first time, made possible observation of current and voltage down to the nano-second level. This led to a better understanding of arc formation, arc interruption and arc erosion. The scanning electron microscope introduced in 1965 permitted the detailed study of arc erosion effects. The addition of x-ray analysis in the early 1970's allowed a detailed analysis of elemental changes in contact surfaces. The development of advanced vacuum technology in the late 1960s enabled introduction of the sealed-for-life, power-vacuum interrupter for medium voltage distribution circuits. In the 1970s electronic sensors began to replace the electro-mechanical sensors to control circuit breakers, contactors and relays. Integrated circuit technology then was increasingly introduced into these sensors. Today there are many circuit breakers and other switches that can respond to many types of circuit conditions and determine the action to be taken. The personal computer (PC) first introduced in the 1980s began a revolution in the engineer's and scientist's world. Who remembers secretaries, the written letter and the slide presentation etc.? The PC became so powerful that in the 1990s circuit breakers and other types of switch could be designed at the engineer's desk top using 3-D drafting software. The introduction of finite element analysis (e.g. ANSOFT) and arc modeling software (e.g. FLUENT) has aided the advanced development of all switching devices. The MEMS (micro-electro-mechanical systems) switches were introduced in the late 1990s. In the future circuit breakers and other switches will continue to be used to switch and isolate electrical circuits in spite of the inroads of power electronic devices. They will become more compact and will also become more intelligent as more advanced sensor technology is introduced. The vacuum interrupter, now the prevalent technology for 5kV to 40.5kV circuits will start to dominate higher voltage circuits (72kV to 170kV). Perhaps even the MEMS switch will find a commercial application!

Series Electric Plasma Discharges of Failing Contacts up to 10 A at Various Materials

Peter Zeller, University of Applied Sciences Upper Austria, Wels, Austria, peter.zeller@fh-wels.at

Abstract

Latest, efficient and cost competitive power electronics products are providing the technology to realise future DC powered energy supply. Apart from a number of advantages of DC systems (lower power losses compared to AC systems, no capacitive losses, etc.), one challenge of DC systems is to treat arc faults. Especially series arcing can be very stable and has to be detected by appropriate approaches in order to avoid long lasting and very stable plasma discharges. In literature, the analyzation of the spectrum of either the system current or - voltage is introduced. The aim of this work is to investigate whether such an approach will provide a reliable method to detect series contact faults in general with a special focus on the feedback of plasma discharges to the signal noise across a failing contact. Experiments in a current range from 1 A to 10 A at low inductive (0 mH) and high inductive (4 mH) loads were performed. The failing contact was filmed by means of a colour high speed camera. The voltage signal was split into subsequent 1 ms observation intervals, where the spectrum was processed by a standard FFT algorithm. Defining a harmonic content (HC) value (square root of the sum of the quadratic amplitudes of the single harmonics) and an arbitrary HC trigger level, the failing contact could be detected with a good performance for copper (96% to 97% correct detections) and aluminium (97% to 98% correct detections), whereas the detection rate for brass and steel was poor. These results are corresponding to the plasma discharge phenomena (glowing contact and arc): any deflection from the stable plasma discharge equilibrium by plasma root displacement, contact material eruptions, etc. cause detectable noise. The permanent disturbance of the plasma by the effects listed before are strongly correlated with the contact material performance. Future work should cover the transfer of results for this specific detection method for more realistic circuits and sensor locations, as well as the improvement of the detection algorithm by multiple subsequent trigger processing.

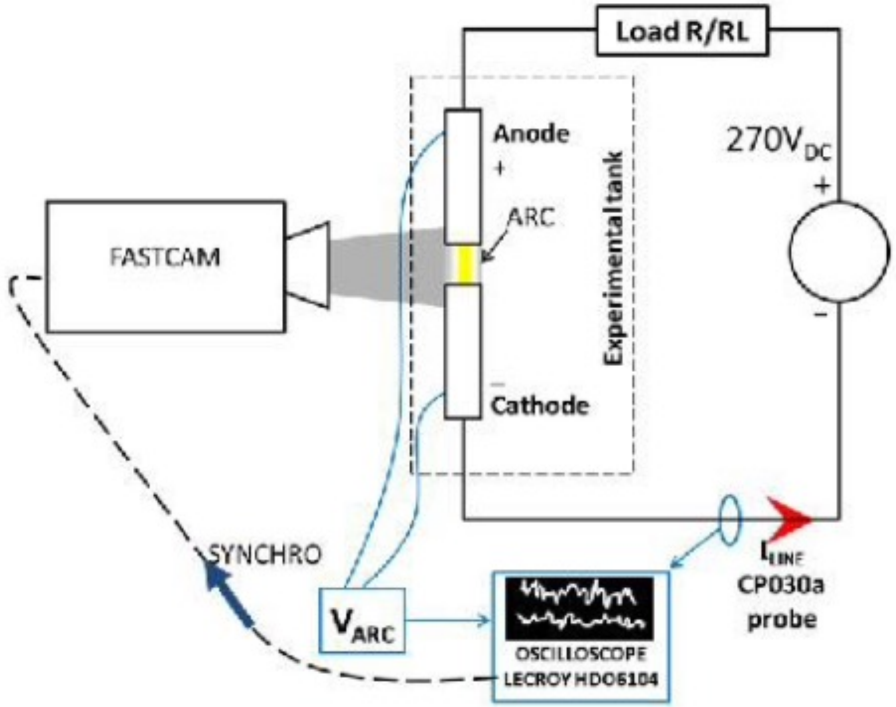


Fig. 1 Experimental test bench

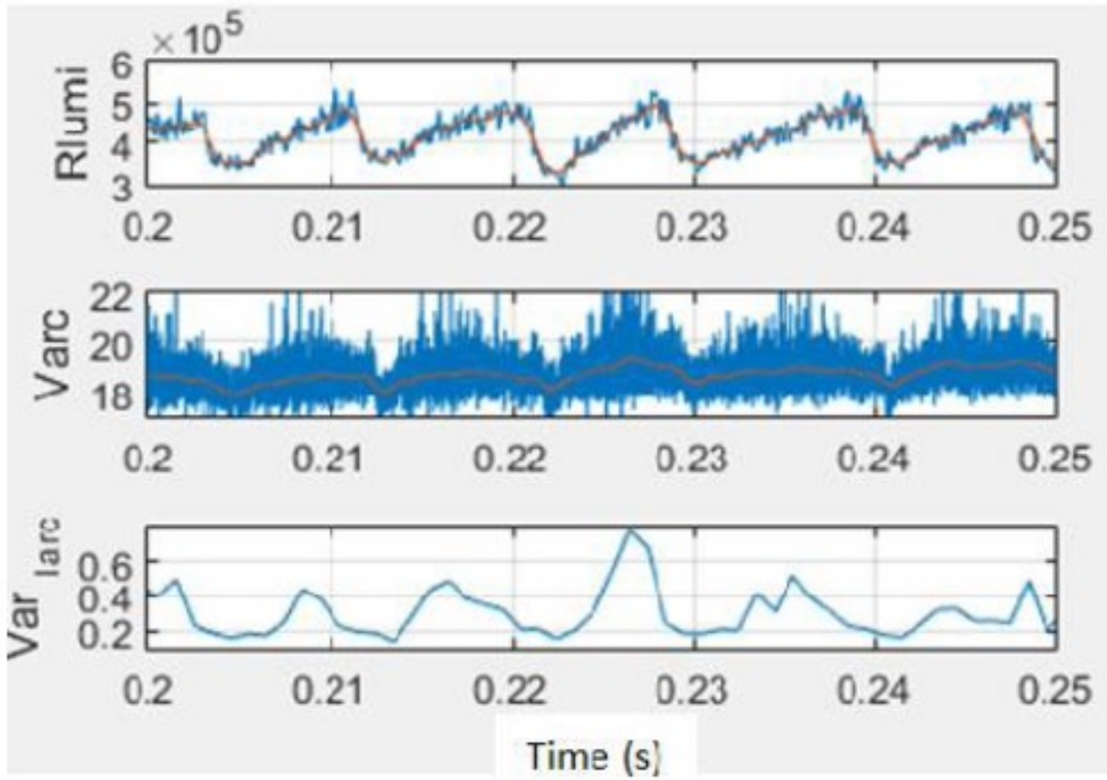


Fig. 3 Measurement of brightness and electrical levels of the discharge

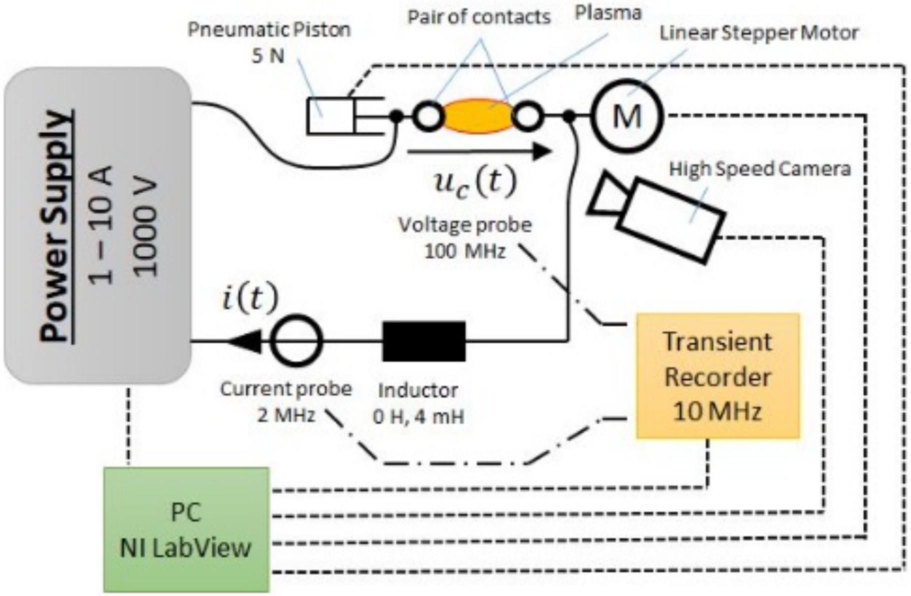


Fig. 2 Measurement equipment of the experiment; voltage sensor: differential probe, limiting frequency 100 MHz; current sensor limiting frequency 2 MHz; signal recording a transient recorder (sampling frequency 10 MHz); colour filming of the plasma with 10000 to 20000 frames per second.

For a direct correlation of the spectrum with the recorded voltage and current signals in a time plot, an auxiliary value, the "(total) harmonic content" (HC) of the spectrum (up to 10 kHz) was calculated according to equation (3).

$$\mathrm{HC} = \sqrt{\textstyle\sum_{i=2}^{N} {u_i}^2} \qquad (3)$$

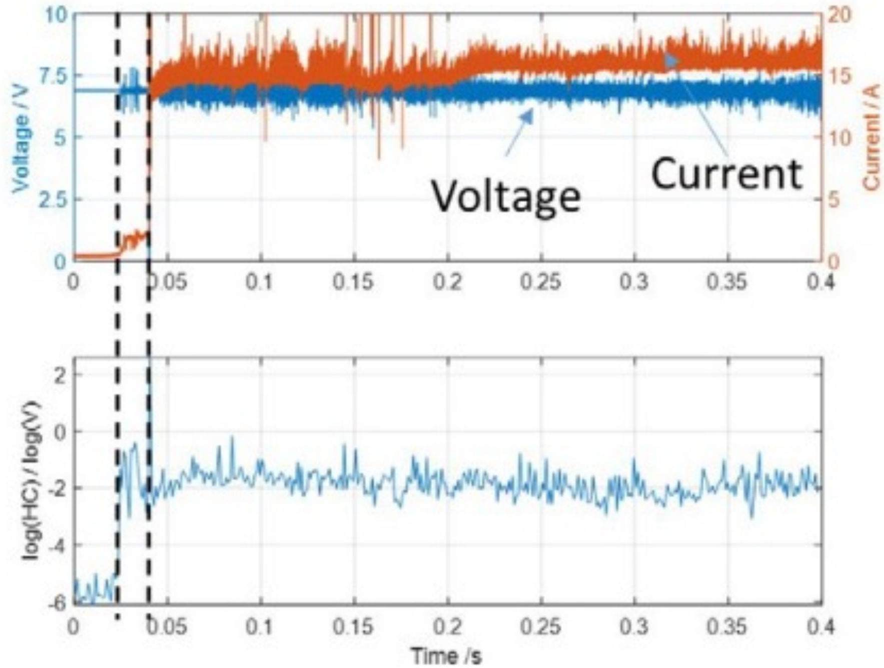


Fig. 6 Correlation of subsequent 1 ms period spectrum HC corresponding to **Fig. 3**.

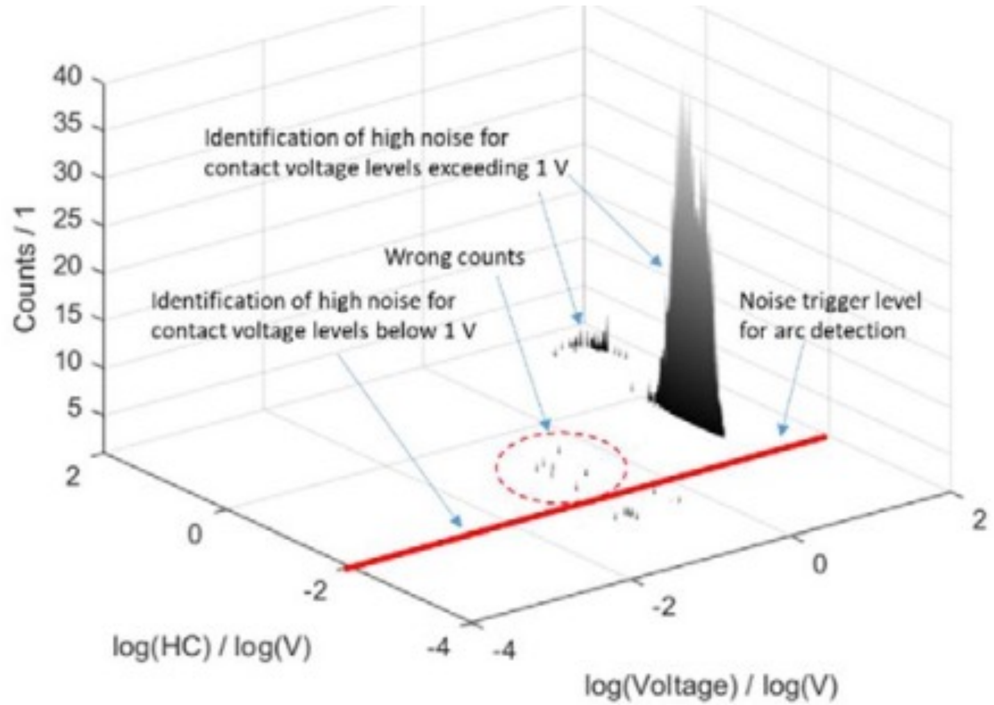


Fig. 15 Counts versus the HC and voltage classes for all experiments with copper and no series inductor according to **Table 1**.

Measurement and study of arc noise fluctuation by fast camera observations

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Abstract

As part of this work, we seek to study more precisely the formation of an arc and its behaviour at the opening of a circuit in conditions close to those of avionics (altitude, atmosphere, etc.). Our work is carried out on an HVDC 270VDC type electrical network at various pressures. The phenomenon is observed by a PHOTRON FASTCAM SA5 model 775K-M3 camera at a rate between 20000 and 100000 frames per second. Our observations show a repetitive behaviour in electrical measurements (current and arc voltage) depending on the experimental conditions. In this paper, we propose an analysis of the noise oscillation phenomenon present in an arc of moderate intensity (<20A) through a fast camera study and then a diagnostic method of the phenomenon observed by camera only from the measurement of line current.

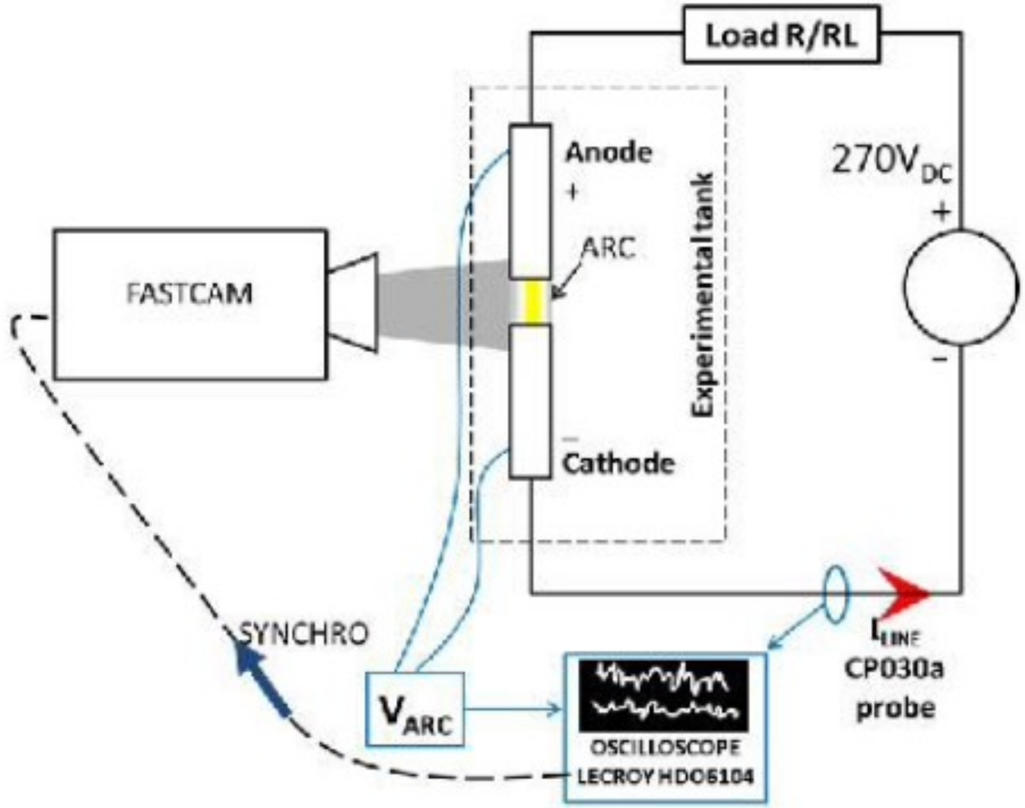
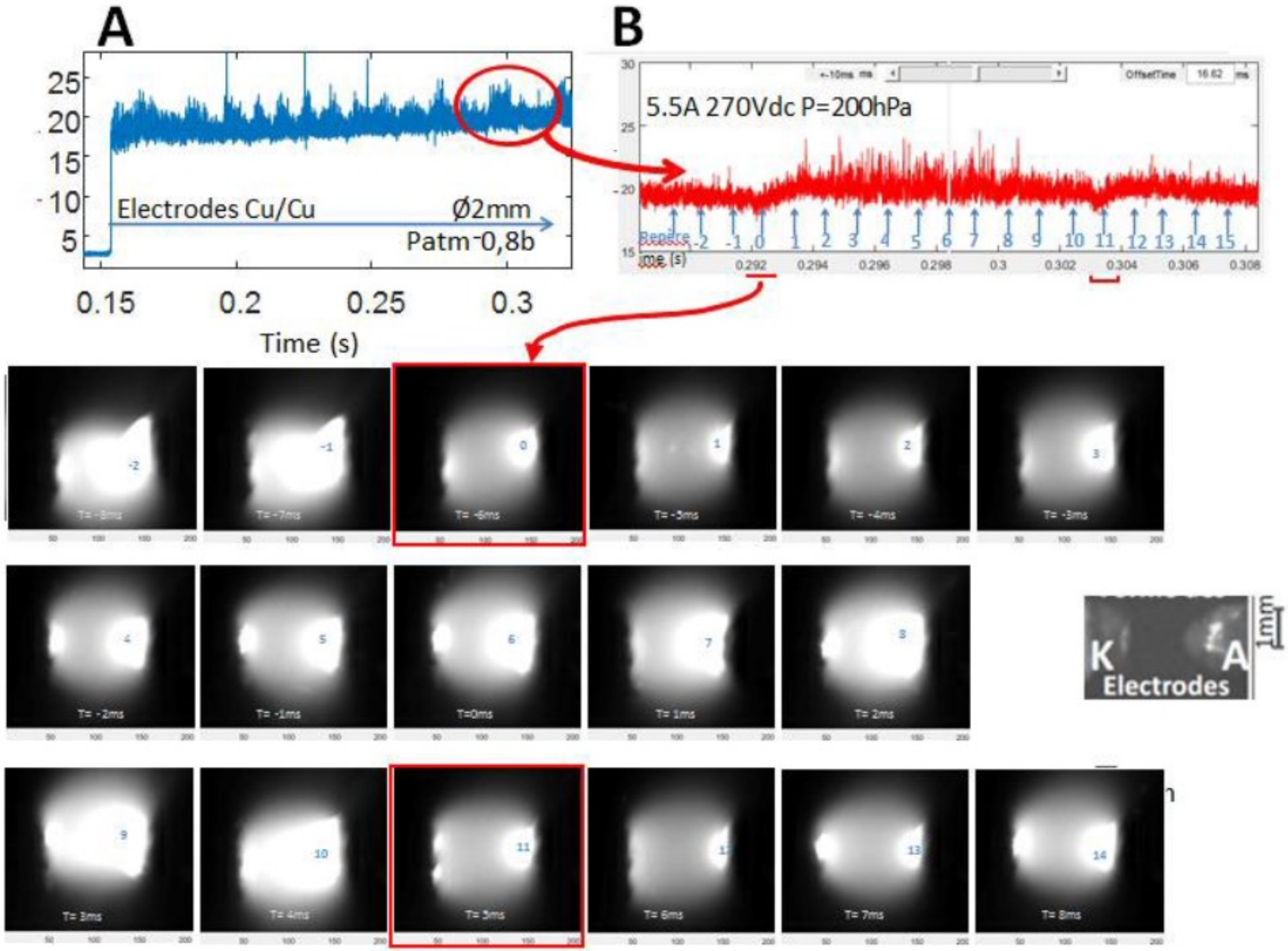


Fig. 1 Experimental test bench


A
B
Electrodes Cu/Cu
Ø2mm
Patm ̃0,8b
Time (s)
5.5A 270Vdc P=200hPa
K
A
Electrodes
1mm

Session 2: Switching Behaviour A

Recovery of Short AC Switching Arcs – An Old Principle Newly Investigated
Manfred Lindmayer (TU Braunschweig) and David Elmiger (Rockwell Automation Switzerland).

Arc Re-striking Phenomena in Break Operations of AgSnO2 Contacts in Inductive DC Load Conditions up to 20V-17A under External Magnetic Field
Makoto Hasegawa (Chitose Institute of Science and Technology) and Seika Tokumitsu (Chitose Institute of Science and Technology)

Effects of arc during mechanical bounces on contact material for different power supply frequencies
Asma Ramzi (Université de Rennes1), Erwann Carvou (Université de Rennes1) and Alexis Schach (Safran Group)

Determination of dielectric recovery characteristic of a pyro switch in commutation circuit
Christian Drebenstedt (TU Ilmenau) and Michael Rock (TU Ilmenau)

Influence of Load Current and Breaking Velocity on Arc Discharge at Breaking of Electrical Contacts
Koichiro Sawa (Nippon Institute of Technology), Kiyoshi Yoshida (Nippon Institute of Technology) and Kenji Suzuki (Fuji Electric FA Components & Systems Co., Ltd).

Spectroscopic investigation of the DC-arc in gas filled contactors under external magnetic fields regarding the effects on the arc-plasma properties

Diego Gonzalez (Leibniz Institute for Plasma Science and Technology), Ralf Methling (Leibniz Institute for Plasma Science and Technology), Sergey Gortschakow (Leibniz Institute for Plasma Science and Technology), Steffen Franke (Leibniz Institute for Plasma Science and Technology), Shun Yu (TDK Electronics) and Frank Werner (TDK Electronics).

Study of Arcing Processes in Circuit Breakers by Means of Spatially Resolved Magnetic Field Recordings

Christian Reil (Ostbayerische Hochschule Amberg-Weiden), Hans-Peter Schmidt (OTH - Technical University of Applied Sciences), Michael Anheuser (Siemens AG) and Frank Berger (Technische Universität Ilmenau).

Recovery of Short AC Switching Arcs – An Old Principle Newly Investigated

Manfred Lindmayer, TU Braunschweig/D and David Elmiger, Rockwell Automation Switzerland, Aarau/CH
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Abstract

It has been known from Slepian since 1928 that the recovery of AC arcs burning between simple contacts without additional quenching aids depends on the formation of a thin space charge sheath in front of the new cathode after polarity change. Already in the 1950s/1960s it has been found that arcs of sub-millimeter length behave superior in comparison with longer gap distances. In his 1968 thesis Schmelzle in addition to systematic experiments treated this phenomenon theoretically, and found that there exists an immediate recovery voltage after polarity reversal, followed by a further increase due to flattening of the temperature gradient between the cooler cathodic contact and the still hot column. Based on this theory, new simulations were now carried out using the COMSOL® Multiphysics program. Additionally to arcs in the contact center, arcs on contact edges were considered. This theoretical work was accompanied by switching experiments. In both ways it is shown that the shorter the gap length the faster the withstand voltage increases. This is due to the better column cooling by the closer counter-electrode. Arc roots on edges are characterized by a slower growth of the sheath thickness around the edge, leading to a deteriorated quenching behavior. The application of this interruption principle lies in AC arcs in currents between a few Amperes and a few hundred Amperes, such as smaller contactors, or auxiliary switches.

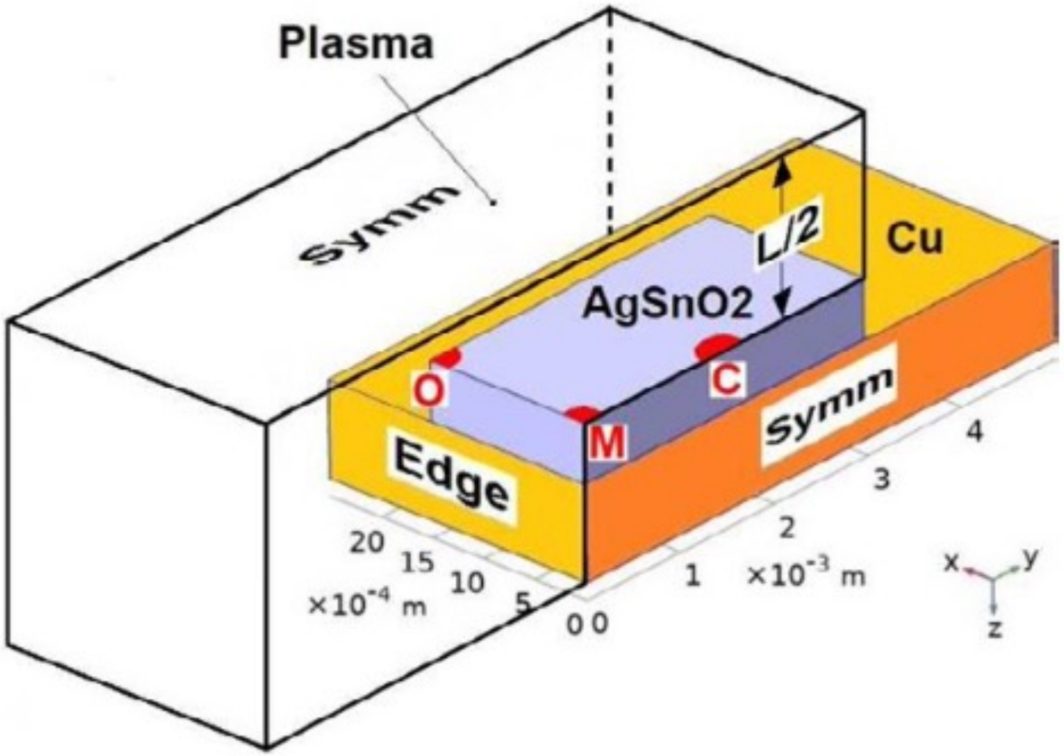

Fig. 6 Simulation Geometry

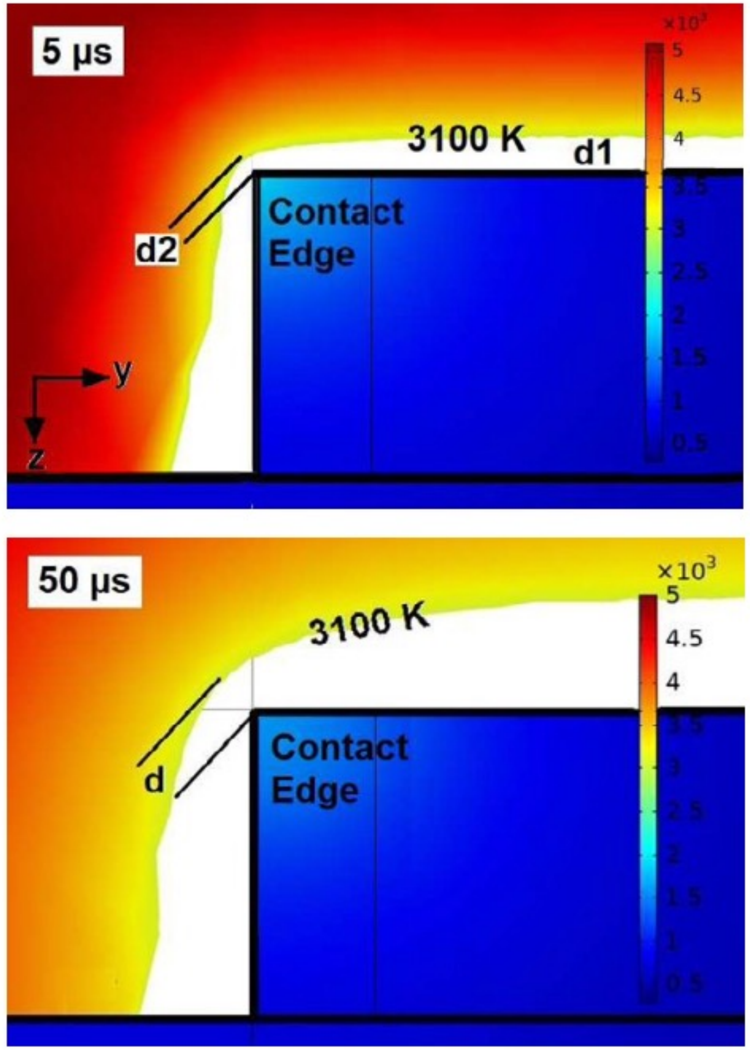

Fig. 13 Example of Growth of Sheath Thickness d around a Contact Edge
Arc Spot (**M**), $I_{RMS} = 150$ A, $t_v = 10$ ms, $L/2 = 1$ mm

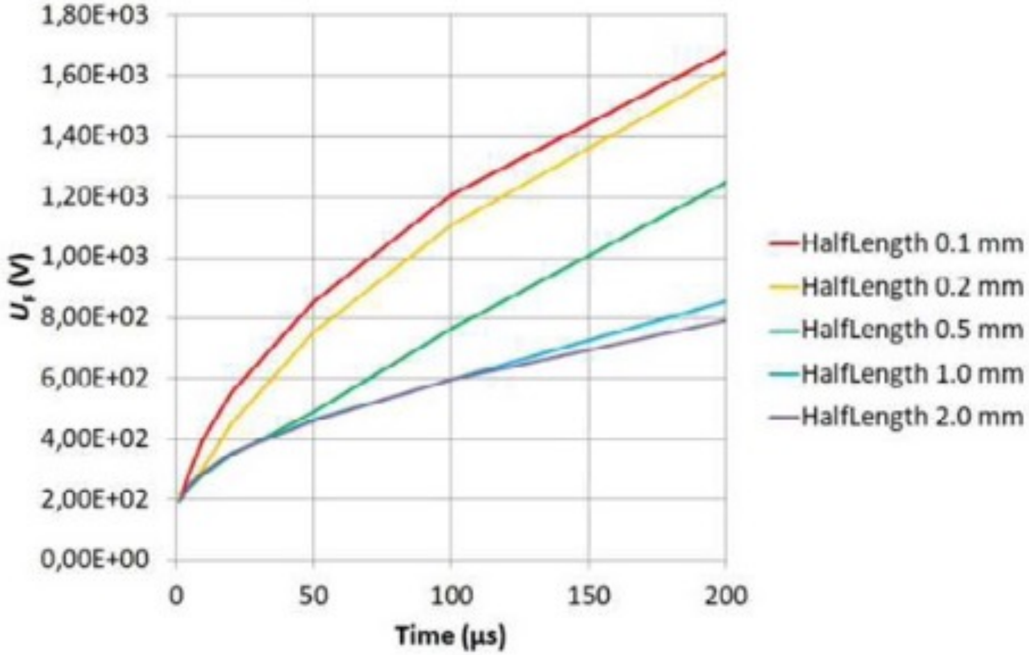

Fig 14 Recovery Voltage U_F as a Function of Cooling Time after Current Zero. $I_{RMS} = 150$ A, $t_v = 10$ ms, Parameter $L/2$.

Arc Re-striking Phenomena in Break Operations of $AgSnO_2$ Contacts in Inductive DC Load Conditions up to 20V-17A under External Magnetic Field

*Makoto Hasegawa and Seika Tokumitsu, Chitose Institute of Science and Technology, Chitose, Japan
*hasegawa@photon.chitose.ac.jp

Abstract

Arc re-striking phenomena of break arcs are sometimes observed with applied external magnetic field even at small or middle load levels. In this study, $AgSnO_2$ contacts were operated to break an inductive DC load circuit of 14V-7A, 14V-12A, 20V-7A, or 20V-17A with an applied external magnetic field of about B=120mT at contact opening speeds of 1 to 200mm/s. Movements of break arcs were observed with a high-speed camera, while arc voltage/current waveforms were also obtained. Arc energy was later calculated based on the obtained voltage/current waveforms. Arc re-strikes were likely to be observed with larger load current levels and faster contact opening speeds. The number of arc re-strikes was sometimes two or more. Arc energy calculations revealed that the total arc energy from ignition to extinction reached almost the same level irrespective of re-striking incidents. Thus, occurrence of the arc re-striking phenomena during break operations of inductive DC load currents up to 20V-17A is believed to be influenced by the amount of energy to be supplied into a contact gap and to be consumed as arc energy. Even when arc is blown out of a contact gap due to an applied external magnetic field, arc re-strikes may occur and repeat until a certain amount of arc energy is finally consumed.

Effects of arc during mechanical bounces on contact material for different power supply frequencies

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Abstract

During a make operation in an electromechanical switching device, an electrical arc could occur because of mechanical bounces and can cause serious damages, such as contact welding and electrodes erosion. The characteristics of this arc are influenced by several parameters such as the level of voltage and current, the load of circuit, the nature of contact materials and, a parameter that we will focus on, the voltage frequency.

Indeed, for frequencies equal or greater than 50 Hz, the current can go through zero several times during typical mechanical bounce. The energy transferred to the electrodes, which will condition the welding, depends on the total arc duration, and so on the reignition of the arc.

In order to investigate this phenomenon, the contacts welding in relation with the re-ignition of arc have then been studied for different frequencies. The make tests were done for 115 Vrms/750 Arms with a mechanical bounce of 2 ms, with different frequencies 50 Hz/ 400 Hz/ 500 Hz and with $AgSnO_2$ contact material and silver contacts as reference. The welding characteristics, such as welding occurrence and force were measured as a function of arc characteristics (voltage/current/energy).

Finally, this investigation showed the importance of the voltage frequency on contactors reliability.

Determination of dielectric recovery characteristic of a pyro switch in commutation circuit

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Michael Rock, Technische Universität Ilmenau, Ilmenau, Germany, michael.rock@tu-ilmenau.de

Abstract

Pyrotechnic switches are used for overcurrent protection, e.g. in low-voltage DC circuits (battery disconnector). At fault current interruption, arc voltage built up by the switch must be sufficiently high to drive the current to zero (DC switching principle). Compared to AC interruption, the switch does not experience a transient recovery voltage (TRV). With increasing breaking capacity, comparatively large construction volumes are necessary. Possible reduction in design effort of the switch is found by using the commutation principle where the pyrotechnic switch is integrated as commutation switch in the low-impedance main current path.

This publication presents an experimental method for recording the dynamic dielectric recovery characteristics of a pyrotechnical switch for commutation circuits. An electrically equivalent network without a switch-off element in the commutation path was installed in the synthetic test circuit and stressed with currents up to 10 kA. From the moment of successful commutation by the pyrotechnical switch, the switch was loaded with voltages up to 4 kV using an RC circuit for recording the dynamic dielectric recovery characteristic. With the resulting dielectric recovery course and the verification of the switching capacity required for successful commutation, an optimally adapted switch-off element can be selected for realizing the overcurrent protection device based on the commutation principle.

Influence of Load Current and Separation Velocity on Arc Discharge at Breaking of Electrical Contacts

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Kiyoshi Yoshida, Nippon Institute of Technology, Miyashiro-cho, Japa, yoshida@nit.ac.jp
Kenji Suzuki, Fuji Electric FA Components & Systems Co., Ltd, Konosu-shi, JAPAN, suzuki-knj@fujielectric.com

Abstract

DC interruption is more difficult than AC interruption even at DC low voltage. So, magnetic blow-out is usually used to quickly extinguish arc discharge. However, magnetic blow-out is less effective at low current so, the arc duration becomes the maximum at lower current called "critical load current". In the previous paper, this phenomenon was examined in the current range of 1 to 30 A with the source voltage of DC 100 V and at the magnetic flux density of 0, 5 and 10 mT with the breaking velocity of 100 mm/s.

In this report the above phenomenon is examined at the breaking speed of 25, 50 and 100 mm/s with the magnetic flux density of 10 mT and the same voltage and current conditions as the previous report.

Consequently, the same phenomenon of maximum arc duration at lower current is found at three velocities. In addition arc energy is examined and Lorentz force working on arc column is discussed

Keywords— electrical contacts, arc discharge, arc duration, arc energy, magnetic blow-out, separation velocity

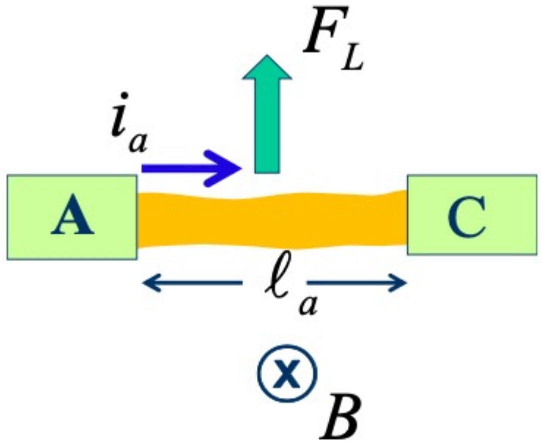

Fig.14 A model of Lorentz force working on arc column.

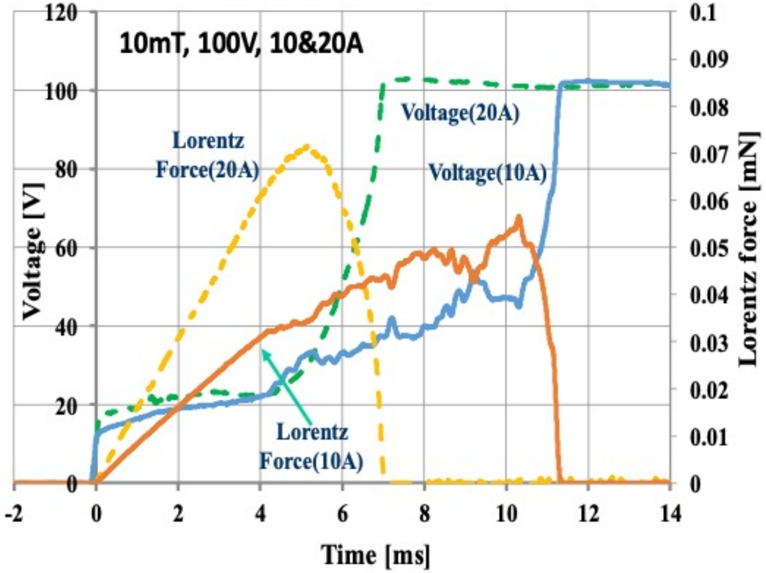

Fig.15 Time dependence of Lorentz force during arc ignition.

Spectroscopic investigation of DC-arcs in gas filled contactors under external magnetic fields regarding the effects on the arc-plasma properties

Diego Gonzalez[1], Ralf Methling[1], Sergey Gortschakow[1], Steffen Franke[1], Shun Yu[2], Frank Werner[2]
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Abstract

The spectral characteristics of switching DC-current arcs in hydrogen containing gas mixtures under several bar pressure was investigated using a model chamber and optical emission spectroscopy. The switching device consists of a model of a real double breaker DC-contactor with copper contacts. High-speed imaging and spectroscopy permit to observe and to characterize the properties of the switching arc plasma. The experiments show the influence of the external magnetic fields on the resulting arc voltage and on the current-limiting performance of the switching device. Strong widened H-alpha and H-beta lines characterize the arc-plasma.

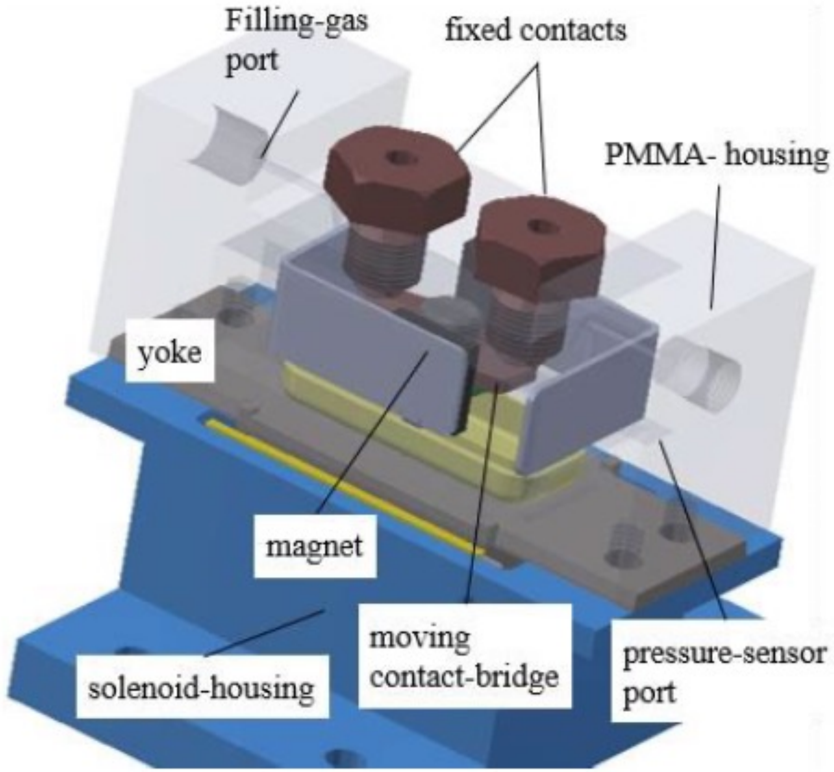

Fig. 1 CAD-schematic of the model switch

Further characteristics of the experimental setup are as follows: The contact-bridge and fixed contacts are

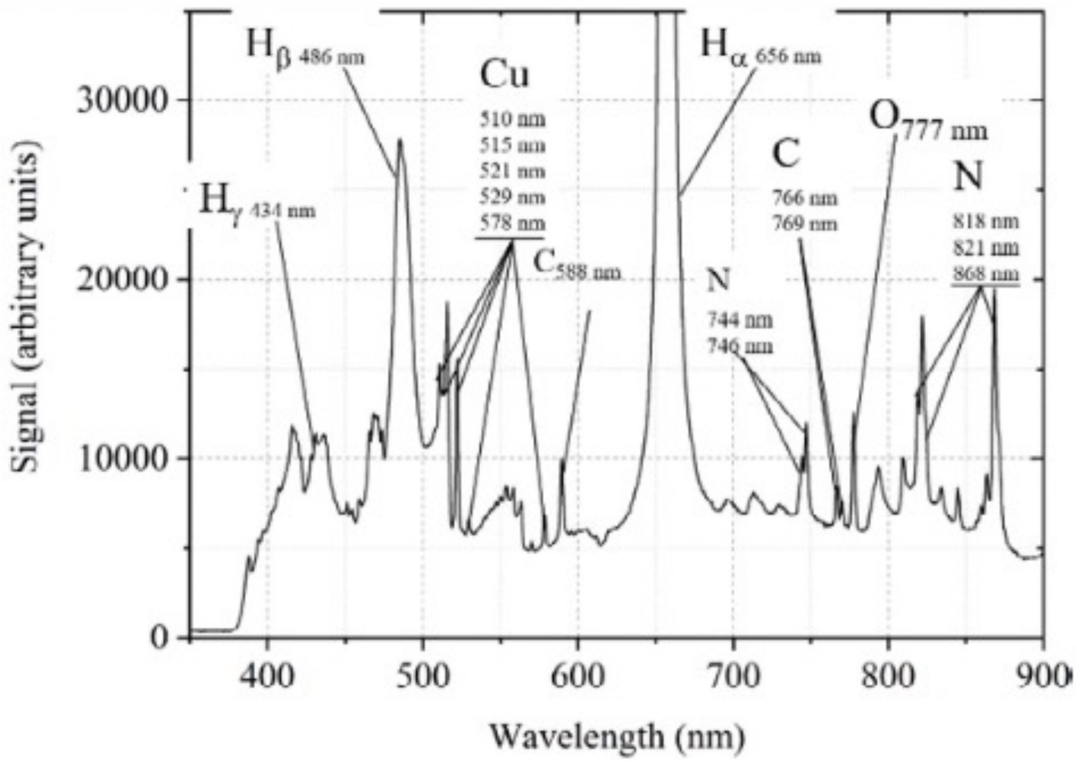

Fig. 6 Spectral distribution of the switching 80 A arc in H_2/N_2 overriding the effect of the H_α line.

Study of Arcing Processes in Circuit Breakers by Means of Spatially Resolved Magnetic Field Recordings

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Hans-Peter Schmidt, OTH-Technical University of Applied Sciences, Amberg, Germany, hp.schmidt@oth-aw.de
Michael Anheuser, Siemens AG, Amberg, Germany, michael.anheuser@siemens.de
Frank Berger, Technische Universität Ilmenau, Ilmenau, Germany, frank.berger@tu-ilmenau.de

Abstract

Magnetic field measurements performed on a circuit breaker in order to study the switching arc processes are presented. Characteristic for these measurements is the spatial two-dimensional recording of the magnetic field with simultaneous high temporal resolution. A sensor head was developed for this purpose, which records the magnetic flux density in an area of 42 mm x 60 mm with a spatial resolution of 12 x 24 measuring points. A highly integrated sensor chip based on the Hall effect was used for the design. The configurability of this sensor chip makes it possible to adapt the time resolution to the measurement task, always in compromise with the amplitude resolution and the number of field components to be measured. Measurements with a sampling rate of 80 kHz were conducted. Also, with the sampling rate reduced to 25 kHz, three axis measurements could be performed. By combining two sensor heads into one measuring system, it was possible to perform simultaneous measurements at the two contacts of a low-voltage circuit breaker with double breaker. As a result, both slow and fast changes in the magnetic field caused by the arcing process were recorded and visualized. The changes in the field distribution measured with the two sensor heads correlated well with the respective arc voltage. With the help of such magnetic field measurements, study of the arcing processes in low-voltage switchgear should be made possible without interference of the arc itself.

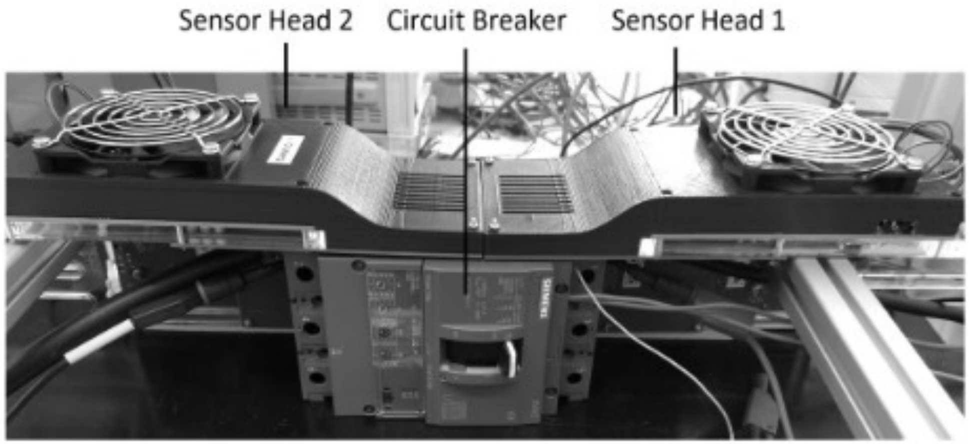

Fig. 3 Picture of the measurement setup.

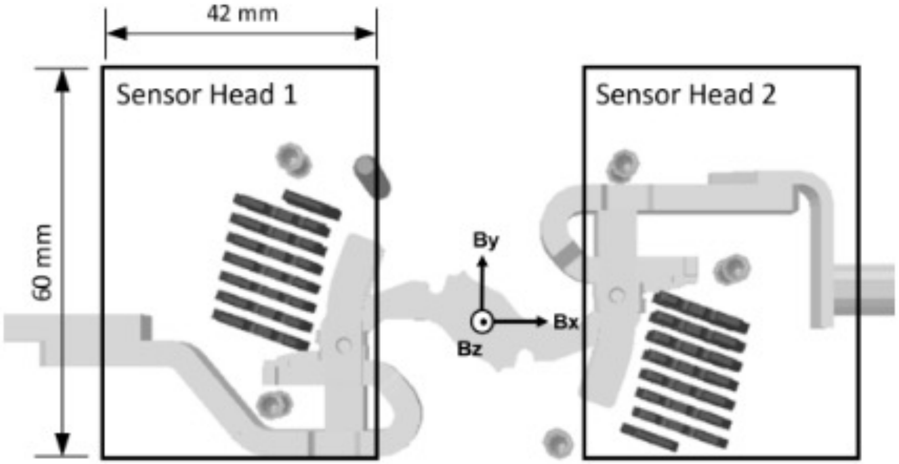

Fig. 4 Location of the measurement areas of the two sensor heads.

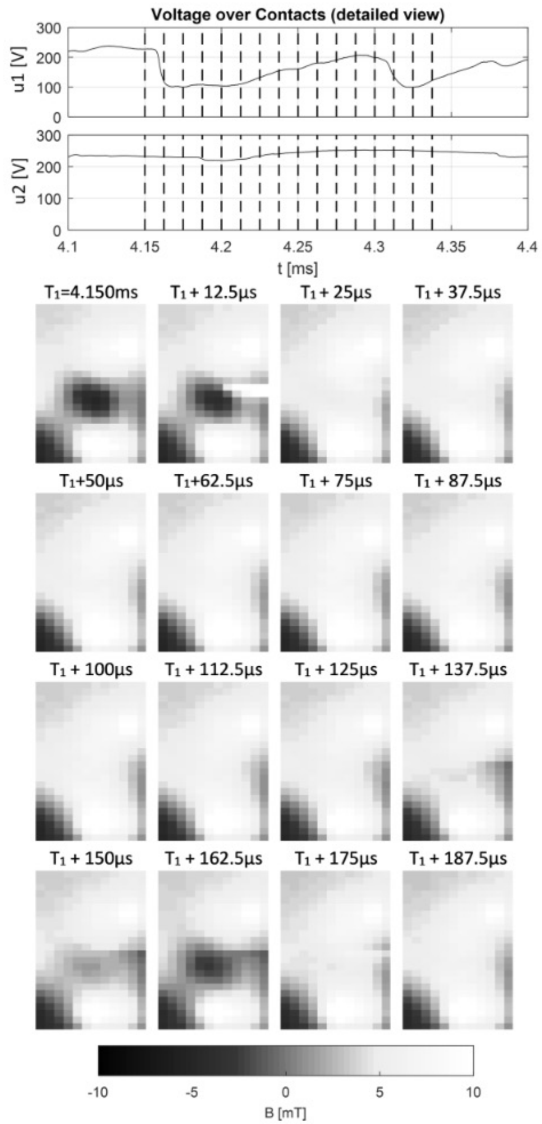

Fig. 7 Magnetic field distribution Bz of sensor head 1 from t = 4.150 ms to t = 4.3375 ms.

Session 3: Switching Behaviour B

Influence of electrode material properties on the anode phenomena in switching vacuum arcs
Sergey Gortschakow (Leibniz Institute for Plasma Science and Technologyy), Diego Gonzalez (Leibniz Institute for Plasma Science and Technology), Dirk Uhrlandt (Leibniz Institute for Plasma Science and Technology), Mike Boening (PLANSEE Powertech AG) and Sabine Boening (PLANSEE Powertech AG).

Investigations of the Possibility of Limiting the Hazard due to Internal Arc Faults in Medium Voltage Switchgears
Bogdan Miedzinski (Wroclaw university of Science and Technology), Bartosz Polnik (KOMAG Gliwice), Julian Wosik (KOMAG Gliwice), Grzegorz Wisniewski (Wroclaw University of Science and Technology), Marcin Habrych (Wroclaw University of Science and Technology) and Stanislaw Wapniarski (ELEKTROBUDOWA S.A.).

Impact of pre-strike arc on contacts degradation after short circuit current making operation in medium voltage air load break switches
Naghme Dorraki (Norwegian University of Science and Technology (NTNU)), Marius Strand (Norwegian University of Science and Technology (NTNU)) and Kaveh Niayesh (Norwegian University of Science andTechnology (NTNU)).

Research on Arc Characteristics of Different Arc Extinguishing Medium Used in DC Contactor
Xuebing Yuan (School of Automation, Northwestern Polytechnical University) and Hu Zhao (School of Automation, Northwestern Polytechnical University)

Influence of electrode material properties on the anode phenomena in switching vacuum arcs

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Diego Gonzalez, Leibniz Institute for Plasma Science and Technology, Greifswald, Germany, diego.gonzalez@inp-greifswald.de
Dirk Uhrlandt, Leibniz Institute for Plasma Science and Technology, Greifswald, Germany, uhrlandt@inp-greifswald.de
Mike Boening, PLANSEE Powertech AG, Seon, Switzerland, Mike.Boening@plansee.com
Sabine Boening, PLANSEE Powertech AG, Seon, Switzerland, Sabine.Boening@plansee.com

Abstract

Powder metallurgical manufactured CuCr electrodes made from materials with different Cr morphology have been studied under the AC current load up to 6.5 kA. Special attention was paid to the appearance of various anode modes. Arc dynamics has been acquired by high-speed camera. NIR spectroscopy was used for determination of the time- and space-resolved anode surface temperature. Broadband absorption spectroscopy was applied for determination of the vapour density with respect to different anode modes. Existence ranges of various anode modes, as well as the results of anode surface temperature and Cr I density measurements for two electrode materials are presented and discussed.

Investigation of the Possibility of Limiting the Hazard due to Internal Arc Faults in Medium Voltage Switchgear

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Grzegorz Wisniewski, Marcin Habrych, Bogdan Miedziński, Wrocław University Of Science and Technology, Wrocław, Poland, bogdan.miedzinski@pwr.edu.pl
Stanislaw Wapniarski, ELEKTROBUDOWA S.A., Konin, Poland, eskwap@op.pl

Abstract

This paper proposes and discusses a method of fast quenching of arc faults, inside the switchgear, by forced transformation into solid three-phase faults with earth. This is achieved through the use of an independent system of three open vacuum chambers connected in an earthed star and included in the medium voltage network. This system is activated (closed) under the influence of the increased internal gas pressure of the switchgear (due to the electric arc) over the respective value. The results of laboratory tests of the effectiveness of such a system during simulated arc faults in a medium voltage network of 6kV are presented and discussed. Appropriate practical conclusions are formulated.

Impact of pre-strike arc on contacts degradation after short circuit current making operation in medium voltage air load break switches

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Abstract

Medium voltage load break switches are required to perform a number of making operation while passing of short circuit current that could be more than tens of kiloamperes. Using air-filled devices as an alternative to SF_6, which is a high impact greenhouse gas, makes the switch more environmentally friendly but leads to more challenging making operation due to higher arcing times and dissipated energies between the contacts. In this case, the pre-strike arc could lead to contacts welding and degradation, which is highly undesirable. This paper reports on an investigation of the pre-strike arc impact on erosion and welding of copper/tungsten (20/80) arcing contacts during short-circuit making operations. For this purpose, a synthetic test circuit consisting of a high current source in combination with a high voltage one is used. Experiments are conducted for different operation voltages, while the short circuit current is kept constant at 22 kA. Mass loss measurement and visual inspection of eroded/welded contacts are examined with regard to pre-strike arc impact on their degradation. The contacts are welded by three times repeating the test at operation voltage of 20 kV and short-circuit current of 22 kA and failed to re-open. Besides, an increase in the contacts' mass loss with arcing time is observed while the making current is constant. This is an indication that the pre-strike arc energy highly impacts the switch reliability and service life.

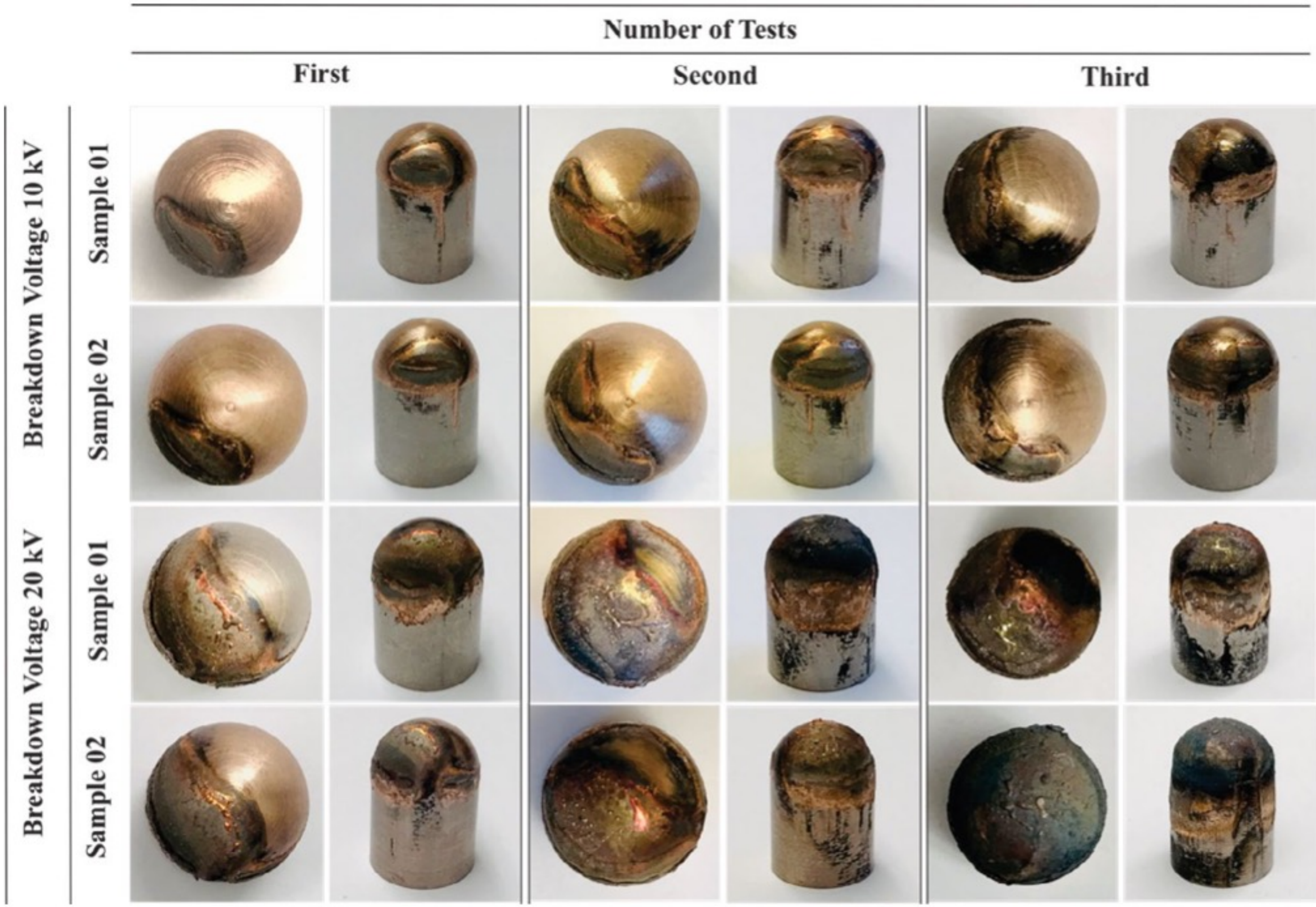

Fig 4. Eroded contacts' surface after each three times repeating the test at test voltage of 10 kV and 20 kV when a short circuit current of 22 kA passed through the contacts.

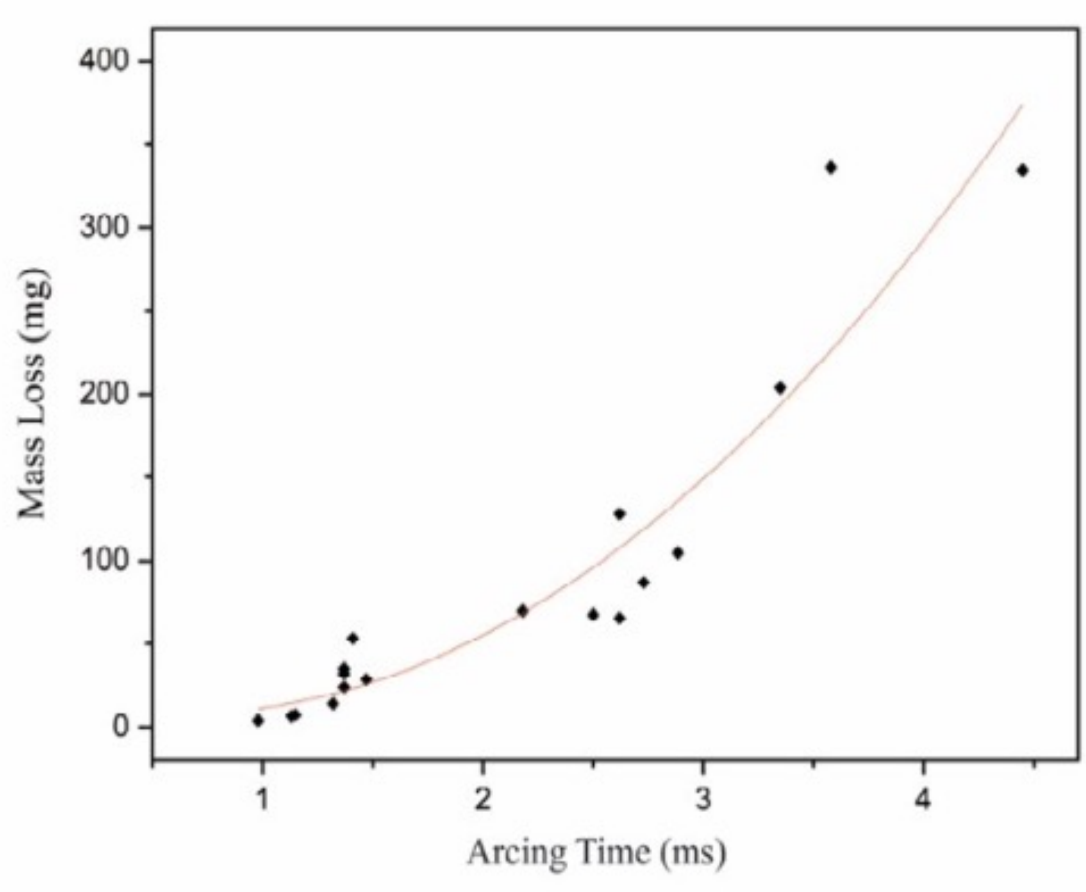

Fig 5. Mass loss as a function of arcing time when the short circuit current is kept constant (22 kA)

Research on Arc Characteristics of Different Arc Extinguishing Gases Used in DC Contactor

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Hu Zhao, School of Automation, Northwestern Polytechnical University, Xi'an, China, hzhao@nwpu.edu.cn

Abstract

In recent years, the new energy fields such as electric vehicles, photovoltaic power generation and electric aircraft develop so rapidly that DC contactor demand has been increasing dramatically. Under the development trend of high voltage and large current for contactor, it is more difficult to improve the arc extinguishing performance only from the structural design. It is necessary to study the performance and selection of different arc extinguishing gas. However, the various arc extinguishing gases, their mixing ratio and their arc quenching characteristics are not quite clear. In this paper, the arc properties of insulation gases such as H_2, N_2, CO_2, air, and different mixture ratio of N_2-H_2 have been researched through experimental tests. The results are as follows: The thermal conductivity of H_2 arc is high, which is good for energy dissipation when small current, however, the N_2 arc is more unstable, which is benefit for dissipation when large current. Better comprehensive 20%N_2 has better comprehensive properties including arcing time, heat dispersion and heat recovery rate than others.

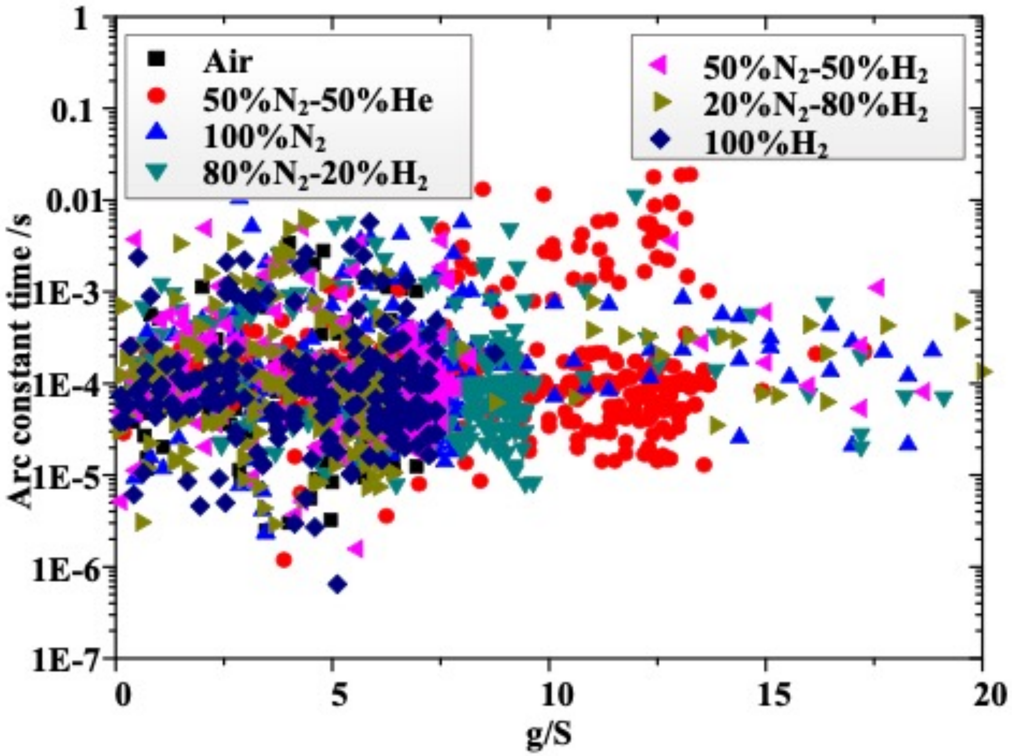

Figure 10 Arc time constant of different gases

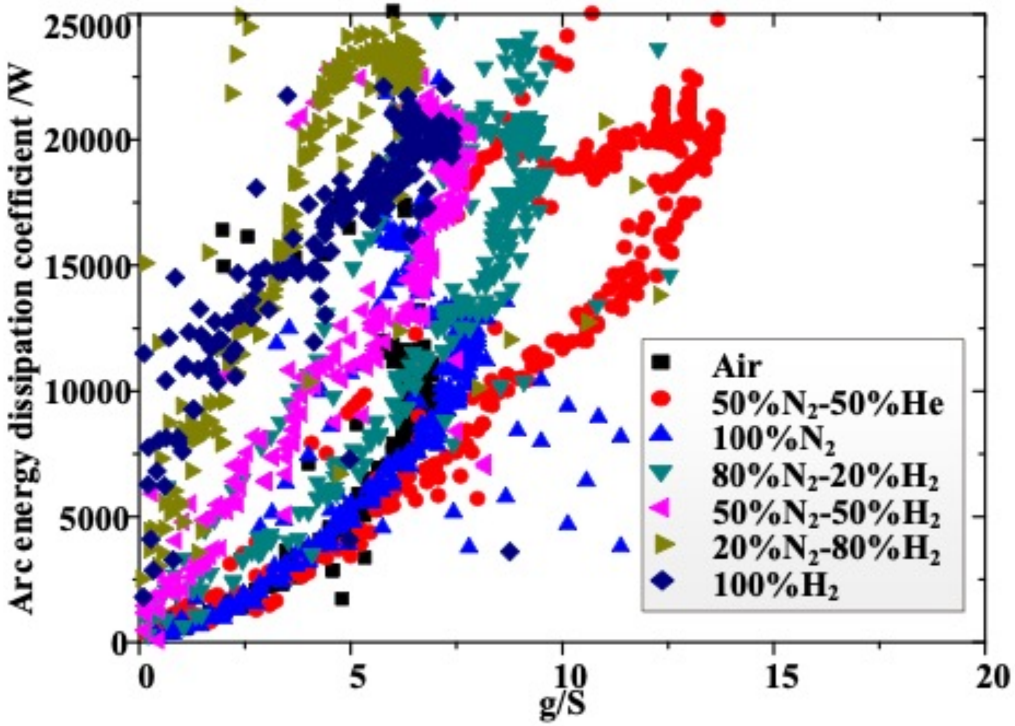

Figure 11 Arc energy dissipation coefficient of different gases

Session 4: Arc Interruption and Design

PV Arc Fault Diagnosis and Modeling Methods: State of the Art and Perspectives
Xingwen Li (Xi'an Jiaotong University), Silei Chen (Xi'an University of Technology) and Jing Wang (Shenzhen Power Supply Bureau Shenzhen, P.R.China).

Threshold Current of Arc-Free Commutation For Copper-Carbon Contact in a DC Hybrid Switch
Chomrong Ou (Department of Electrical and Electronic Engineering, Tokyo Institute of Technology), Huang Yinming (Department of Electrical and Electronic Engineering, Tokyo Institute of Technology) and Koichi Yasuoka (Department of Electrical and Electronic Engineering, Tokyo Institute of Technology).

Investigation and optimization of a hybrid circuit breaker for low- and medium-voltage DC-Grids
Frederik Anspach (TU Braunschweig), Patrick Vieth (TU Braunschweig), Lars Claaßen (TU Braunschweig, Institute of Highvoltage Technology and Electrical Power Systems), Ernst-Dieter Wilkening (TU Braunschweig) and Michael Kurrat (TUBS).

New Switching Technology for DC Grids
Wolfgang Hauer (Eaton Industrie Austria GmbH), Michael Bartonek (Eaton Industrie Austria GmbH) and Hartwig Stammberger (Eaton Industrie Germany GmbH).

Switchgear Combination of Pyrotechnic Switch and Fuse
Arnd Ehrhardt (DEHN SE + Co KG) and Sven Wolfram (Technische Universität Ilmenau).

PV Arc Fault Diagnosis and Modeling Methods: State of the Art and Perspectives

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Abstract

The global photovoltaic (PV) power capacity is growing exponentially. However, the undetected arc faults would pose a severe fire hazard to PV systems, so various advanced diagnosis techniques have been proposed especially in the last few years. This talk presents a comprehensive review of state-of-the-art techniques for arc fault diagnosis and modeling methods in PV systems, and the development trend of future diagnosis methods is also discussed. Diagnosis methods viewed from physical and electrical signals of PV arc faults have been proposed for a few decades. Their capabilities and limitations are discussed, compared, and summarized in detail. By acquiring electromagnetic radiation and sound characteristics of arc faults, diagnosis methods based on physical signals have the advantage of the accurate identification. However, these methods show limitations for large-scale PV systems due to the increasing interference factors in the exposed environment. Through signal processing methods such as time-domain methods, fast Fourier transform and time-frequency transforms, much more works focus on diagnosis methods based on electrical signals. Recently, diagnosis methods with good switching noise and system transition immunity have been introduced. For instance, the existing Db9-based features would cause nuisance trip for the arc fault detection in grid-connected PV systems. The Rbio3.1-based features are proposed to achieve better arc fault recognition ability. Since the field testing is costly and time consuming, precisely modeling arc faults becomes more critical. Different types of arc fault models including dynamical state model, stationary state model, and high-frequency component model have been reviewed and compared. In addition, future trends about PV arc fault diagnosis methods are outlined. It is predicted that facing more complex arc fault conditions, the data processing chip development and machine learning based classifier are of great significance to improve the detection accuracy of diagnosis methods. Also, the detection reliability of diagnosis methods would be significantly improved without increasing the computation time significantly.

Threshold Current of Arc-Free Commutation For Copper-Carbon Contact in a DC Hybrid Switch

Chomrong Ou, Huang Yinming, and Koichi Yasuoka,
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Abstract

Hybrid DC switches (HDCSs) have attracted considerable attention due to the low on-state loss and fast current interruption. With low current interruption, there is no arc generation between the contacts. However, arc discharge occurs between the contacts after the contact opens for a high circuit current. Arc discharge erodes the surface of the contacts and decreases the insulation strength between the contacts. This paper presents a new configuration of contacts that can increase the threshold current for arc-free commutation. The contact has a cuboid shape with a join of copper and carbon. When the contacts are in the closing position, the copper and carbon materials of the contacts come in contact. When the contacts start opening, the contact spots of the copper start decreasing until rupture, but carbon, which has a higher resistivity than copper, still remains in contact. With a higher resistance of the contacts, the current is further commutated to the semiconductor device until the current at the contacts becomes low. After the contacts rupture, the low surge voltage from the inductance in the circuit cannot ignite arc discharge. Thus, arc-free commutation can be achieved.

Keywords– Hybrid DC switch, coper-based carbon contact, arc discharge, threshold current, arc-free commutation.

Investigation and Optimization of a Hybrid Circuit Breaker for Low- and Medium Voltage DC-Grids

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Abstract

In previous investigations the result was found that the hybrid switch is the most suitable switchgear topology for low- and medium voltage DC-grids. The hybrid switch has the best performance in all operation modes except in the short circuit range. The investigations are part of the research project Smart-Modular-Switchgear-II. In this contribution the focus is set to the optimization of the hybrid switching performance. Therefore, the switch-off behaviour of two types of hybrid switches were investigated to determine the optimization potential. The hybrid switches were investigated in a current range from 10 A up to 600 A and three ohmic-inductive time constants were used: 0 ms, 1 ms and 3 ms. The highest optimization potential was detected in the improvement of the actuator. The new actuator causes a reduction of the switch-off time from 30 ms to 8 ms. Further results of the switch-off performance will be discussed in detail to describe the impacts to the switching process.

New Switching Technology for DC Grids

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Abstract

This paper discusses hybrid switching technology in general and the practical implementation in particular. A novel low voltage DC hybrid circuit breaker (HCB) and its components are introduced. The HCB is rated for up to 100 A / 700VDC and can interrupt currents with a rise rate up to 5 A/µs. Particular attention was given to the power stage of the HCB including the ultra-fast bypass relay and the semiconductor switch. Its design considerations are discussed. The mechanical construction of the bypass relay and the current commutation process from the bypass relay to the semiconductor switch are emphasized. Short circuit interruption and selectivity test results which were performed at an industrial DC model installation in the course governmental funded DC-Industrie project are discussed.

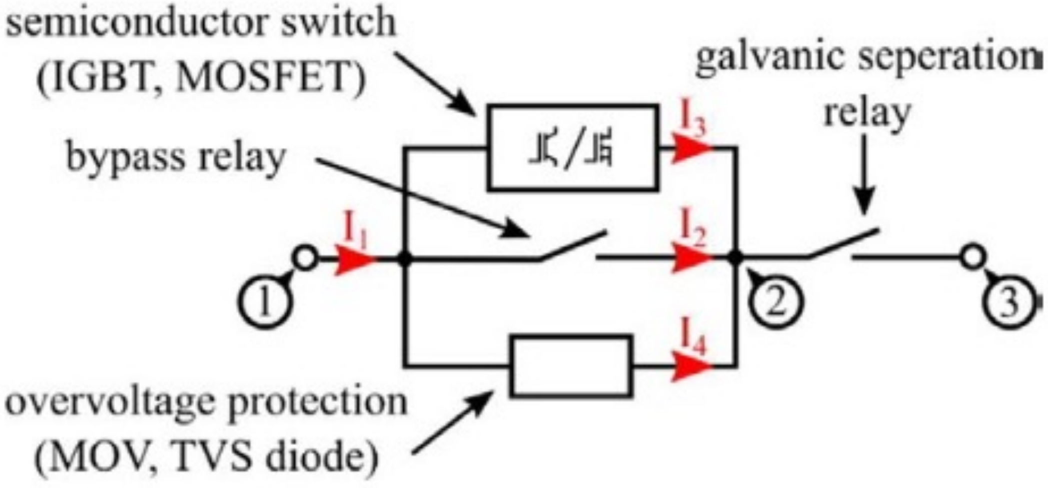

Fig. 1 Basic schematic of a hybrid breaker. The current I_1 to I_4 correspond to the total current through the hybrid breaker, current through bypass relay, current through semiconductor switch and current through overvoltage protection device as shown in Figure 2.

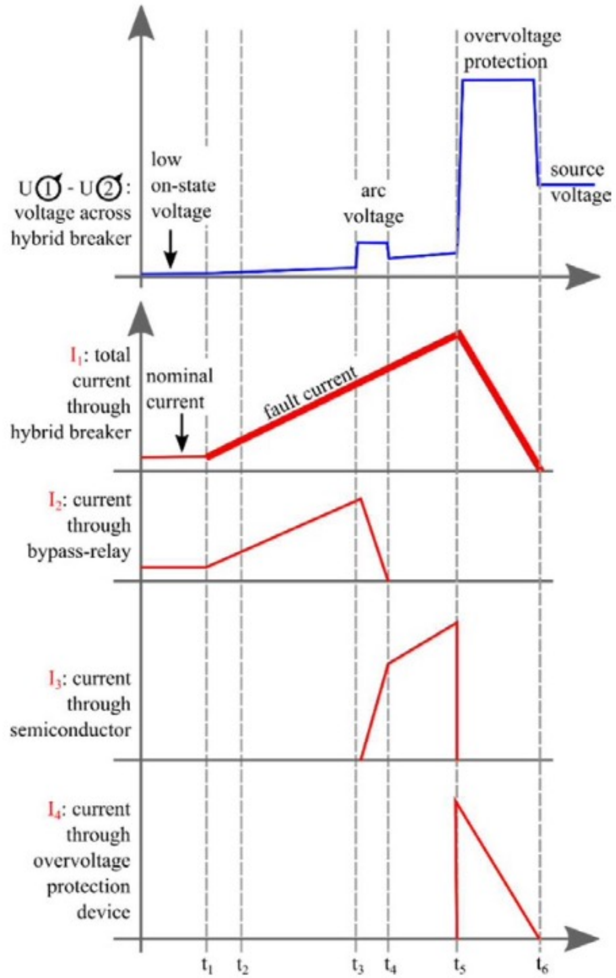

Fig. 2 Typical current-voltage waveforms of a hybrid circuit breaker during switch off operation. Here, t_1 indicated the start of the short circuit, t_2 is the detection time, t_3…start of commutation, t_4…end of commutation, t_5…semiconductor switches off, t_6…short circuit is cleared

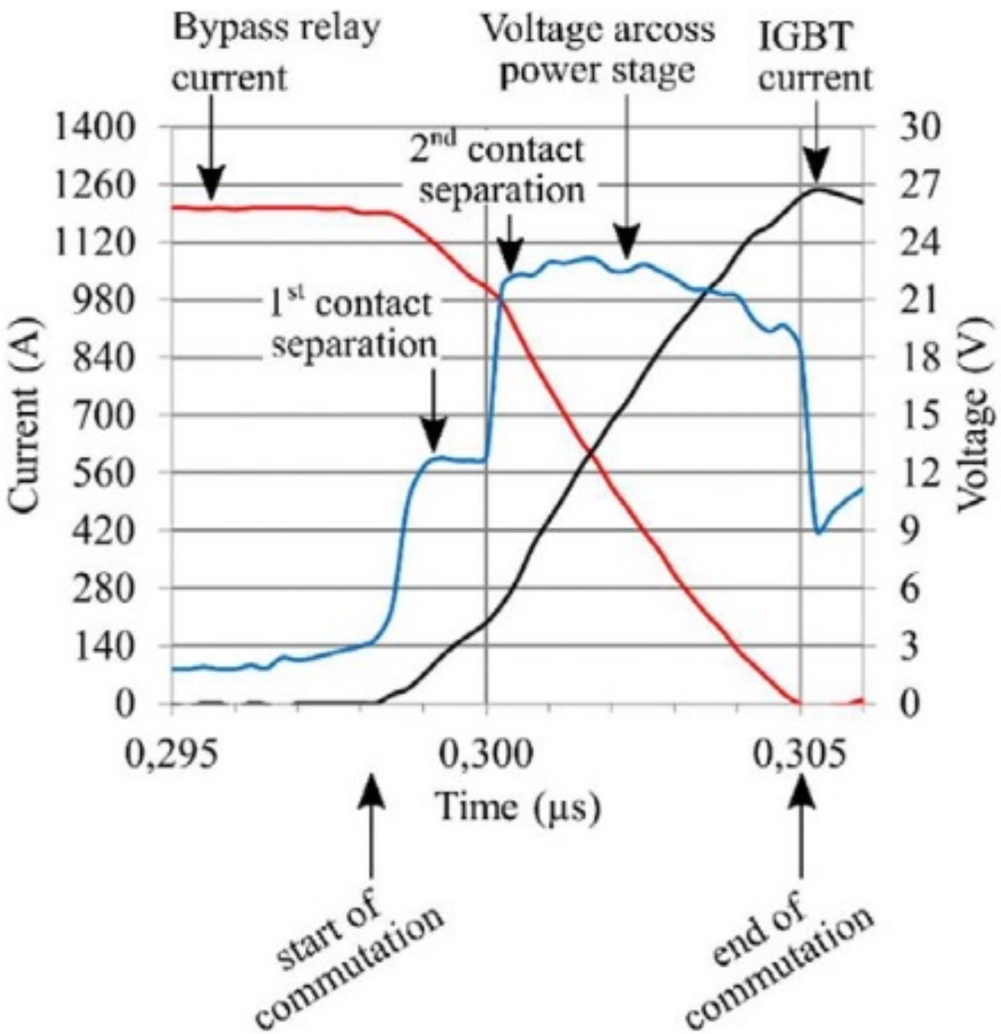

Fig. 8 Detailed view of the current commutation

Switchgear Combination of Pyrotechnic Switch and Fuse

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Abstract

The article presents the combination of a low-voltage fuse with a pyrotechnic switch in a compact design. Different circuit concepts will be discussed, and their scope of application demonstrated with the aid of simulations and experiments based on two sample arrangements. Besides having a passive over-current protective characteristic, both arrangements allow active triggering and fast disconnection. The protective behaviour of both variants from the over-current to the short-circuit range is described for purely passive behaviour and especially for active triggering.

Session 7: Contact Materials and Design II A

The Impact of Arcing (AC3) on the Contact Resistance Behavior of Ag/SnO2

Timo Muetzel (SAXONIA Technical Materials GmbH), Christian Hubrich (SAXONIA Technical Materials GmbH) and Johannes Tasch (SAXONIA Technical Materials GmbH).

The Impact of Arcing (AC3) on the Contact Resistance Behavior of Ag/SnO_2

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Hubrich Christian, SAXONIA Technical Materials GmbH, Hanau, Germany
Tasch Johannes, SAXONIA Technical Materials GmbH, Hanau, Germany

Abstract

For medium and high power rated contactors silver tin-oxide (Ag/SnO_2) materials doped with different types of additives are state-of-the-art contact materials. AC3 endurance tests were performed with a commercially available contactor type (45 kW). By novel approach, arcing voltages during make and break operation throughout endurance testing as well as individual contact voltage drops during temperature rise test sequences were studied.

Focus of the studies was set on the evaluation of contact resistance for individual pairs of contacts and correlating it to individual arcing stresses during endurance switching (within a double-breaking device design). Several types of silver metal-oxides were examined and deeper insights into the interaction between contact material and device could be achieved. Experimental contact resistance results are further explained by post-switching analysis of the contacts via metallurgical routines.

Session 9: Automotive Applications

Future of Electromechanical Switchgear
Frank Berger (Technische Universität Ilmenau).

Study on the Arc Erosion Characteristic and Mechanism of $AgSnO_2$ Used in the Simulated Conditions of Automotive Relay
Li Jie (Fuda Alloy Materials Co., Ltd), Yan Xiaofang (Fuda Alloy Materials Co., Ltd) and Bai Xiaoping (Fuda Alloy Materials Co., Ltd).

Modelling the switching behavior of pyrofuses for the protection of electric cars based on measurement data
Dietmar Haba (Hirtenberger Automotive Safety).

Future of Electromechanical Switchgear

Frank Berger, TU Ilmenau, Ilmenau, Germany, frank.berger@tu-ilmenau.de

Abstract

The current development of the electrical networks towards a DC system imposes certain changes in the design and functionality of several network components. This paper aims to offer an overview of the challenges and the opportunities that are raised by the DC system over the electromechanical switchgear in order to identify its future path in the electrical network. The paper starts with a review process of the previous statements regarding the future of the low-voltage (LV) electromechanical switchgear. In the second part, the existing developments in the LV technology towards a mixed (centralized and decentralized) DC grid are presented. The third part presents the main influencing factors and the developments in the classic electromechanical switchgear as well as in the relatively new switchgear technologies represented by the hybrid and power electronic switches. Following, several questions concerning the standardization and the DC ageing behaviour of the insulating materials will be presented and discussed. The last part will present the conclusions of the current overview.

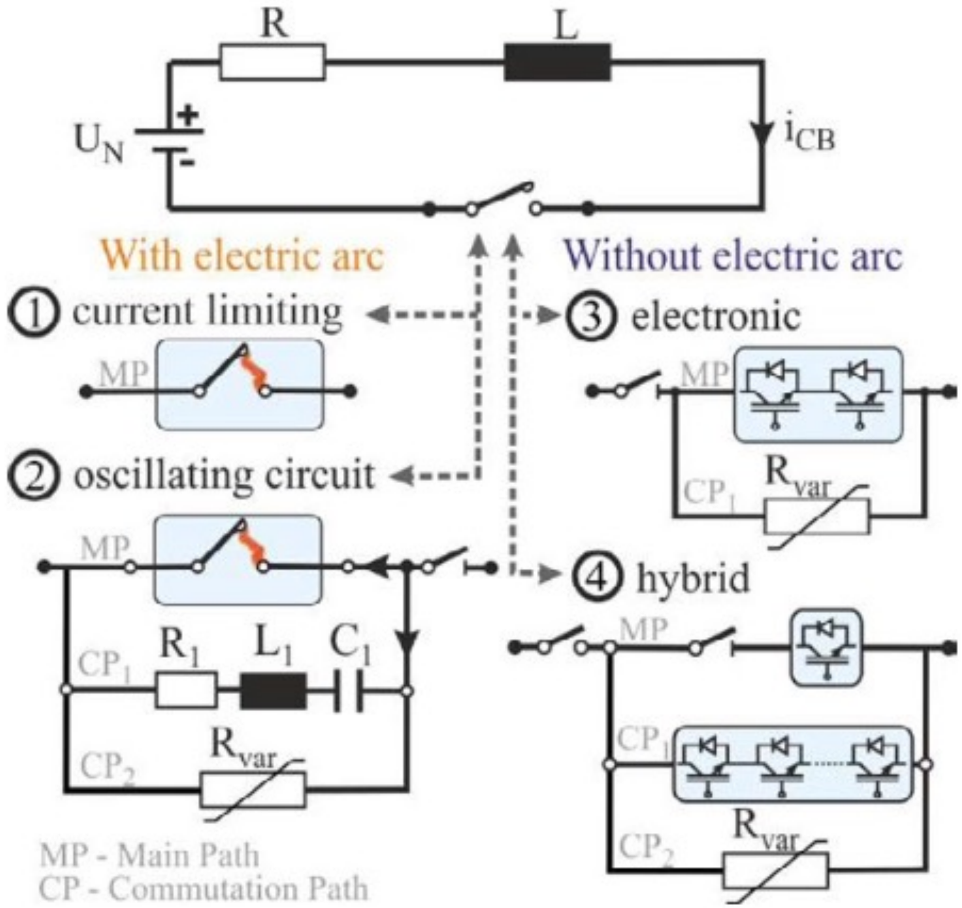

Figure 5: Systematization of the DC switching principles

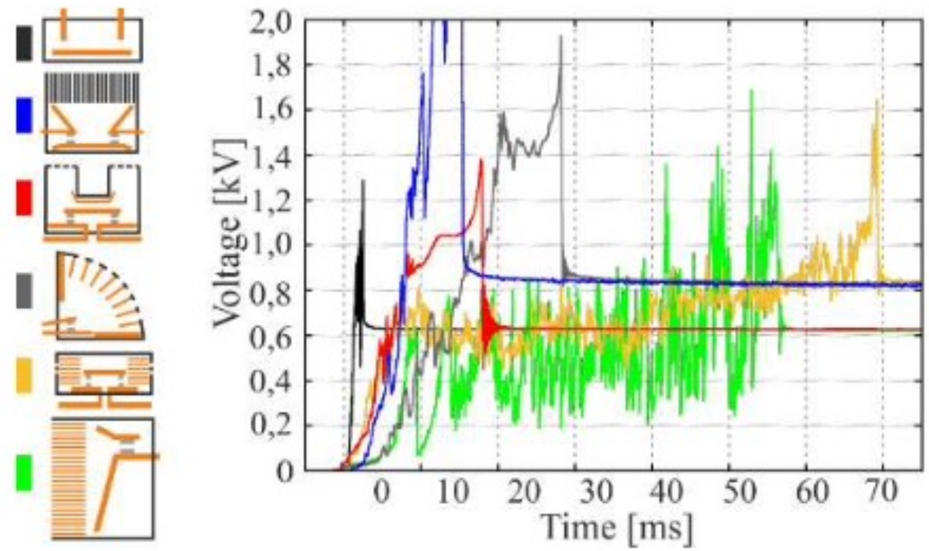

Figure 7: Arc voltage structure with different contactor designs

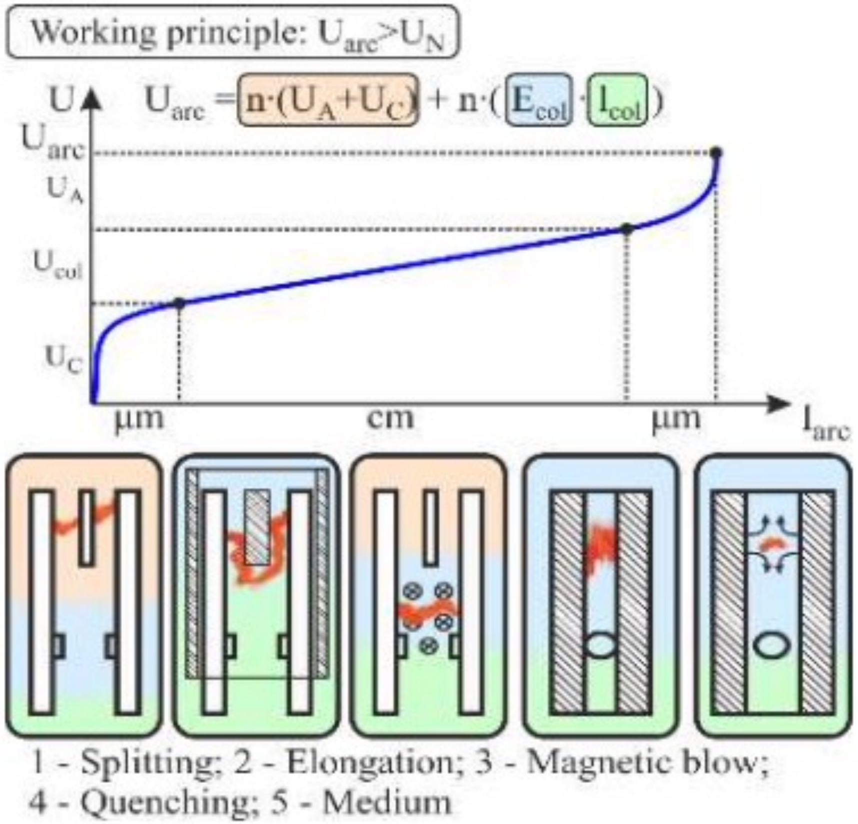

Figure 6: Arc quenching principle

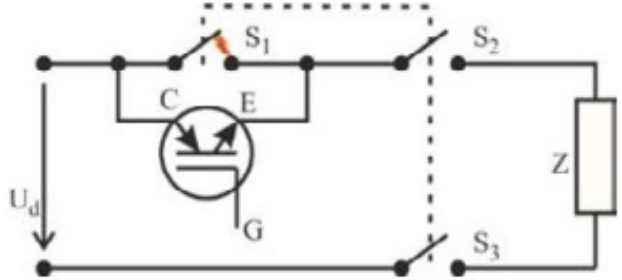

Figure 9: Hybrid Switch with arcing switching [16]

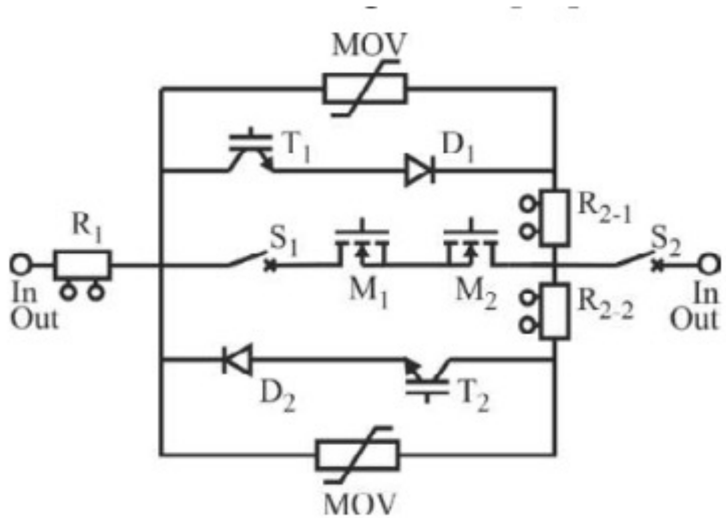

Figure 10: Hybrid Switch with arc-free switching

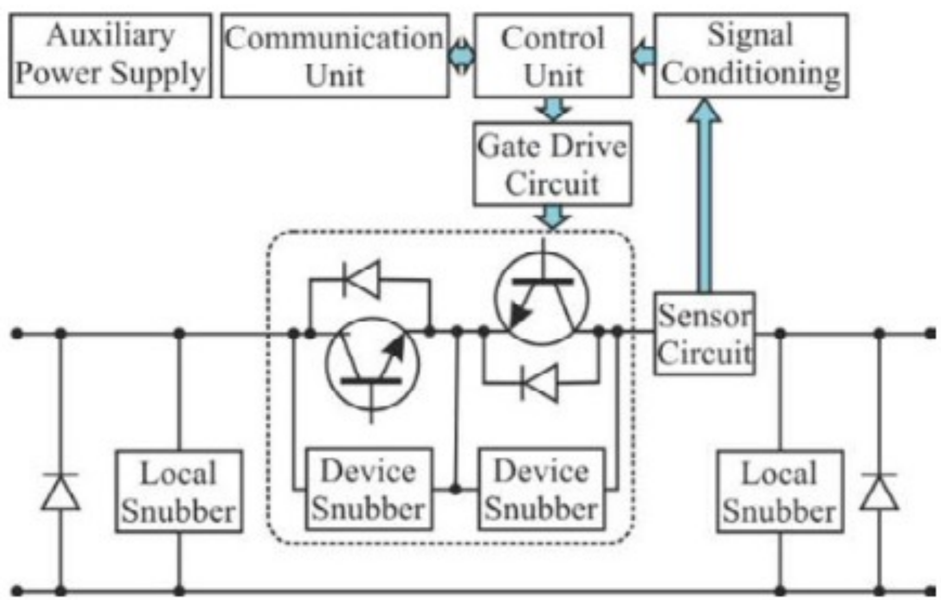

Figure 12: Solid State Circuit Breaker

Study on the Arc Erosion Characteristic and Mechanism of $AgSnO_2$ Used in the Simulated Conditions of Automotive Relay

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Abstract

Automotive relays, which are widely used in the control of automotive starting, preheating, air condition, lighting and other systems, play an important role in controlling electrical systems. When the relay is under lighting load, a surge current (5-10 times of the steady-state current) will be produced, which is easy to welding and leading to serious contact material transfer. When the electric contact is eroded seriously, the reliability of the contact will be decreased. This paper has focused on the study of the arc erosion performance of different electric contact materials under the simulated lighting load. Arc energy, arc time, welding force, rebounding times and other characteristic parameters of different $AgSnO_2In_2O_3$ electric contact materials, as well as arc erosion mechanism, were investigated by using electrical performance simulated device. It was expected to provide an important reference for the development and application of electrical contact materials.

Key words
Arc Erosion, Electric Contact, $AgSnO_2$, Automotive Relay

Modelling the switching behavior of pyrofuses for the protection of electric cars based on measurement data

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Abstract

The rapid development in electric car batteries allows steadily increasing operating currents with low power losses thanks to decreasing internal resistances. This challenges the electric protection on board: Accidental short-circuit currents can reach over 20 kA within milliseconds, bringing conventional protection systems to its technical limits, particularly at high on-board voltages. This problem limits the development of electric car architecture significantly. Pyrotechnically activated circuit breakers are a suitable solution. These *pyrofuses* actively cut a busbar triggered by an ignition signal. They respond very fast, have low resistance before activation and high resistance thereafter, good aging characteristics and high reliability. Other than melt fuses, the separation time hardly depends on the overcurrent, the temperature or the product's age. Moreover, the active triggering allows separating even without any overcurrent, e.g., after a car crash. Upon activation, a switching arc forms within the product. Depending on the current and the inductivity, up to 6 kJ of inductive energy must be dissipated for this arc to be extinguished, which transforms into high pressure and temperature. Development focuses on controlling this energy and limiting its harmful effects, thus providing a safer solution for steadily increasing demands.

Session 12: Modeling/Simulation A

Simulations of switching devices with the example of a circuit breaker: the knowns, the unknowns, and the way ahead.
Henrik Nordborg, Roman Fuchs, Mario Mürmann (OST Eastern Switzerland University of Applied Sciences, Rapperswil, Switzerland)

Remarks Concerning Arc Roots in CFD Modeling of Switching Arcs
Manfred Lindmayer (TU Braunschweig).

Arc Evolution Process Considering the Motion of Moving Contact in DC Circuit Breaker
Jianning Yin (Xi'an University of Technology), Tian Tian (Xi'an Jiaotong University), Qian Wang (Xi'an University of Technology) and Xingwen Li (Xi'an Jiaotong University).

Surge protection device digital prototyping
Olga Schneider (DEHN SE + Co KG), Arnd Ehrhardt (DEHN SE + Co KG), Bernd Leibig (DEHN SE + Co KG), Sebastian Schmausser (DEHN SE+Co KG), Andrey Aksenov (Capvidia NV) and Elena Shaporenko (Capvidia NV)

Numerical arc simulations of radiatively-induced PMMA nozzle wall ablation
Roman Fuchs (HSR University of Applied Sciences Rapperswil).

Simulations of switching devices with the example of a circuit breaker: the knowns, the unknowns, and the way ahead.

Henrik Nordborg, Roman Fuchs, Mario Mürmann,
OST Eastern Switzerland University of Applied Sciences, Rapperswil, Switzerland

Abstract

Numerical simulations of gas discharges have long been considered too challenging for routine use in product development. There are two reasons for this: the complex physics involved and the lack for suitable software tools. The physical complexity requires us to be judicious in in the choice of models as we are constantly forced to compromise between speed and accuracy. The challenge is to find approximations good enough for specific applications and there will never be one universal simulation model for all kinds of arc discharges.

The lack of suitable software tools is partly due to lack of interest from software vendors and partly due to the difficulty of coupling the equations involved. Whereas the flow equations are best solved using a finite volume formulation, the electromagnetic equations are best solved using finite elements. Currently, the perfect algorithm for coupling the equations only exists on paper.

Despite these difficulties, significant progress has been made in recent years. This paper tries to outline the state-of-art in simulations of electric arcs and gas discharges with a detailed discussion of the approximations made and their impact on convergence and accuracy. We emphasize that arc simulations, if correctly used and interpreted, are useful tools for product development today. In particular, simulations can deliver results that are only indirectly related to the arcing process, such as pressure build-up and mechanical stresses on enclosures.

In addition, we argue that a paradigm shift will be required to develop better software simulation tool. Rather than first developing theoretical models and implementing them, we need to start by establishing an efficient computational framework and fill in the details later. An efficient and parallelizable code is required to validate the simulations in rigorous manner.

Remarks Concerning Arc Roots in CFD Modeling of Switching Arcs

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Abstract

This paper reviews arc root models used to represent the processes at anode and cathode of arcs in a simplified way. From the electrical potential distribution, there are the voltage falls V_A and V_C across thin sheaths in front of both electrodes. Their product with the current and current density, respectively, characterize the power (power density) generated in these areas. The powers (power densities) that flow to the electrodes and thus determine their heating and erosion are often expressed by equivalent voltages V_{eqA}, V_{eqC}. A frequent approach to model arc roots within computational fluid dynamics (CFD) models of switching arcs is to replace the root region within the CFD volume by a thin layer adjacent to the electrodes of voltage drops $V_A(J)$, $V_C(J)$, depending on the current density there. An equivalent "contact resistance" is an alternative. The power generated in this region is the product of voltage and current density. Its partition between the electrodes and the arc column then follows the rules of the CFD differential equations ("Navier-Stokes" equations). However, the physics of the fall regions is completely different, with charge carriers freely falling without collisions, and hitting the electrodes. It is therefore better to separate both effects. For this, the knowledge of V_A, V_C, V_{eqA}, and V_{eqC} is necessary. After a summary of the methods used so far by the author's own research group, experimental work is considered to determine the required values, and additionally the current density at the roots. Two ways can be differentiated: Comparison of experiments with simulations of fall regions, and with simulations of the electrode heating. Based on voltage data from the literature, a modified model of the power flows in the electrode fall regions is derived. It also holds for zero length of the arc column. Finally, an implementation into CFD programs suitable for complete simulations is suggested.

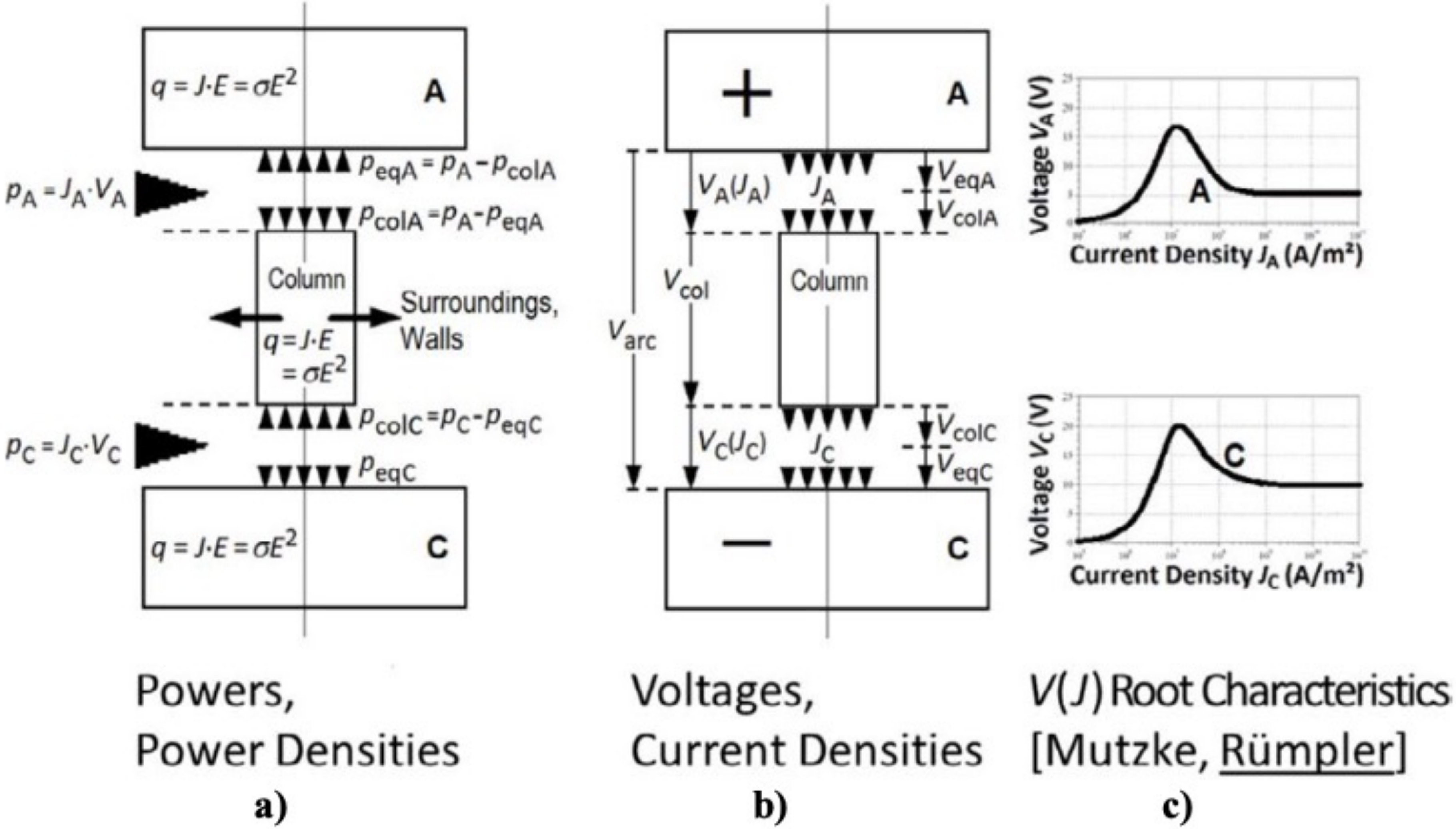

Fig. 1 Power Flows (a) and Voltages (b, c) in Switching Arcs

Arc Evolution Process Considering the Motion of Moving Contact in DC Circuit Breaker

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3 State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, China
qianwang@xaut.edu.cn

Abstract

Direct current (DC) circuit breaker is a crucial component for controlling and protecting the DC power system, especially in photovoltaic power generation system. It should switch off the DC load current. The motion process of the moving contact (arm) greatly affects the arc voltage and arc evolution process. Therefore, this paper focuses on the arc evolution process considering the motion of moving contact in a DC circuit breaker. A 2-D magneto-hydro-dynamic (MHD) model of a miniature circuit breaker is built. Based on this model, the temperature distribution and airflow field distribution are obtained. The arc evolution process with two different structures is analyzed. At the same time, the results with arm motion and without arm motion are compared and analyzed. In addition, the related experiments are carried out. It turns out that the arc evolution considering arm motion is closer to the experimental results.

Surge protection device digital prototyping

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Andrey Aksenov[2] and Elena Shaporenko[2]
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Abstract

The market requirements for surge protection devices (SPD) call for improvements of their technical parameters, characterized by; higher impulse currents, higher short-circuit currents and at the same time reduced size. This leads to a significantly increased level of complexity for the tools used in design, simulation, and production. Another very crucial business aspect is time to market, forcing shorter development cycles. Implementing the SPD digital prototyping workflow into design cycle reduces both the development time and development costs. This paper presents virtual spark gap model development steps and simulation results of the real physical processes occurring in a spark gap-based SPD device. The virtual spark gap simulation is based on the full compressible Navier-Stokes equations, the energy conservation law, the radiation heat transfer and Maxwell equations. Presented simulation results include arc behaviour, gas flow dynamics and electromagnetic forces. The results are validated using a high-speed camera for arc visualization and compared with experimental data. This virtual simulation technology shows the ability for the further increase of product reliability, performance and size optimization.

Numerical arc simulations of radiatively-induced PMMA nozzle wall ablation

Roman Fuchs, HSR University of Applied Sciences Rapperswil,
IET Institute for Energy Technology, Rapperswil, Switzerland, rfuchs@hsr.ch

Abstract

An axially-blown arc in a PMMA nozzle is analyzed with numerical simulations. Previous experiments showed that wall ablation is observed for current values larger than a threshold and absent otherwise, and it has recently been found that PMMA is optically thick in the ultraviolet (UV) frequency range. An appropriate definition of radiation bands for the UV range has recently been published that allows for evaluating irradiance on the nozzle surface. In this contribution, it is shown that copper vapor affects the spatial temperature profile of the arc column and increases wall irradiance towards the upstream nozzle section. A caloric estimate for radiation-induced wall ablation is presented, which sheds some light on the experimental findings.

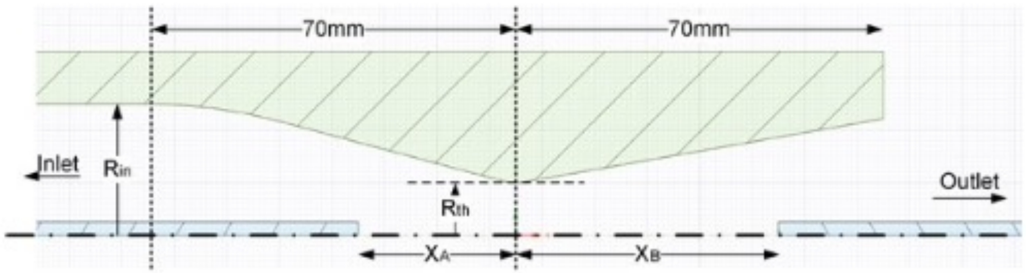


Figure 1: Axisymmetric view of the PMMA nozzle and electrodes.

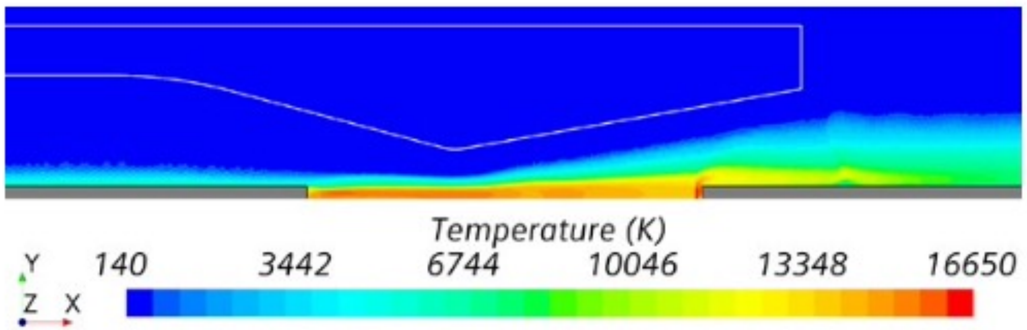
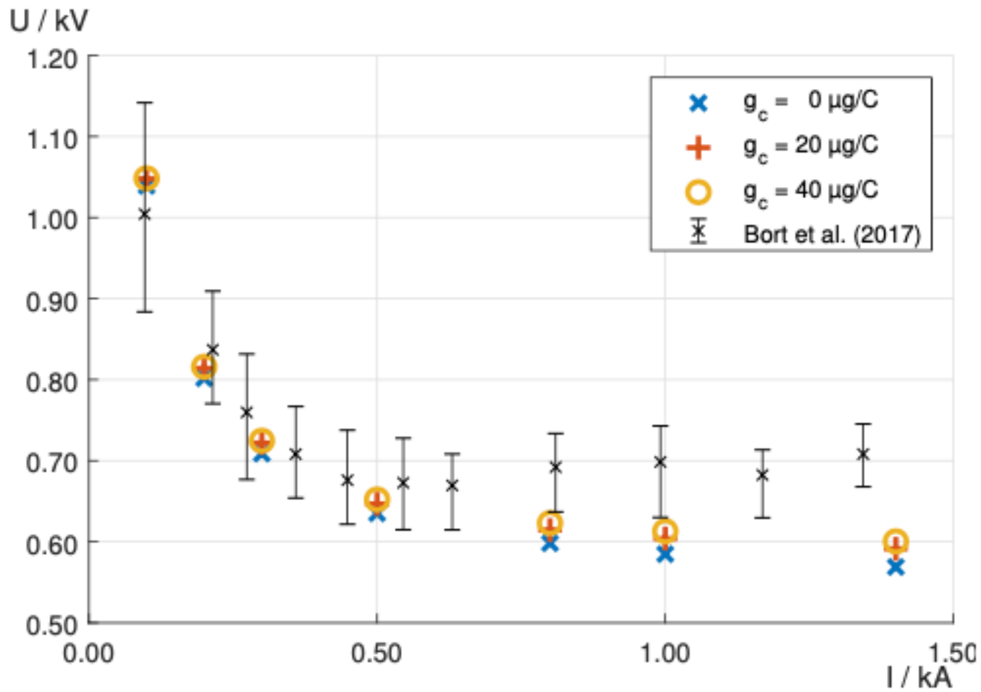


Figure 3: Temperature field for $I = 1400\,\mathrm{A}$ and $g_c = 40\,\mu\mathrm{g\,C^{-1}}$.



Session 13: Modeling/Simulation B

The mathematical model of a short arc at the blow-off repulsion of electrical contacts during the transition from metallic phase to gaseous phase
Stanislav Kharin (Kazakh-British Technical University).

Series Arc Fault Modelling in Photovoltaic Resistive Systems
Silei Chen (Xi'an University of Technology), Xingwen Li (Xi'an Jiaotong University) and
Jing Wang (Shenzhen Power Supply Bureau Shenzhen, P.R.China).

The mathematical model of a short arc at the blow-off repulsion of electrical contacts during the transition from metallic phase to gaseous phase

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Abstract

The mathematical model describing the dynamics of temperature field in electrical contacts at the initial stage of a blow-off repulsion is presented. It is based on the Stefan problem for the disk of a short arc and two spherical domains for the liquid and solid zones. All coefficients in the equations such as the thermal and electrical conductivities, density, thermal capacity are dependent on the temperature. The analytical solution of this problem is obtained using the similarity principle. The results of calculation are compared with the data obtained in published papers and with the experimental data.

$$c_A(\theta_A)\gamma_A(\theta_A)\frac{\partial \theta_A}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(\lambda_A(\theta_A) r \frac{\partial \theta_A}{\partial r}\right) + \frac{j^2}{\sigma(\theta_A)} - W_r(\theta_A) - P(r,t) \quad (1)$$

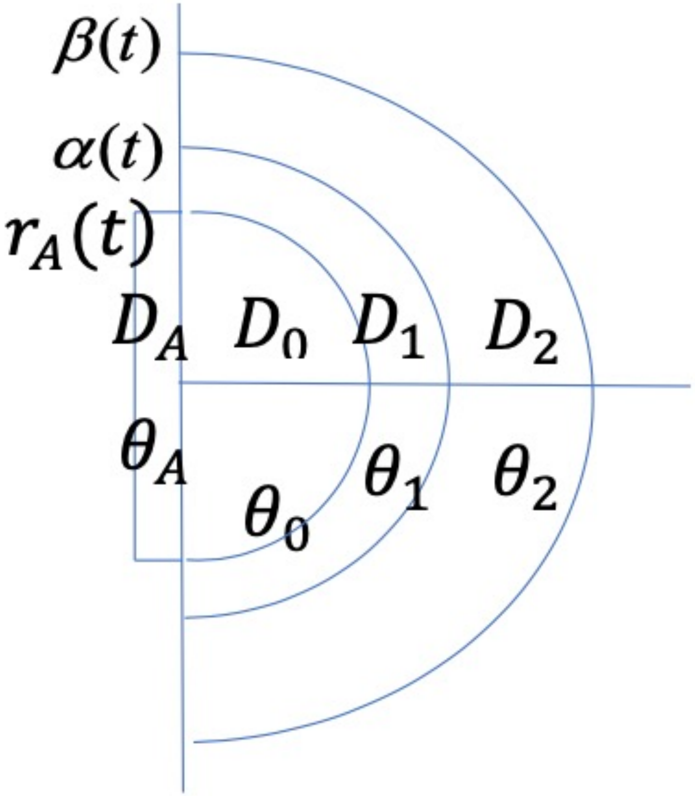

Fig.1. The axial contact cross-section of the spherical domains. D_A - the disk occupied by the arc, D_0 - the Holm sphere of the ideal conductivity, D_1 - the sphere of metallic vapours, D_2 - the sphere of liquid metal, $r > \beta(t)$ - the solid zone

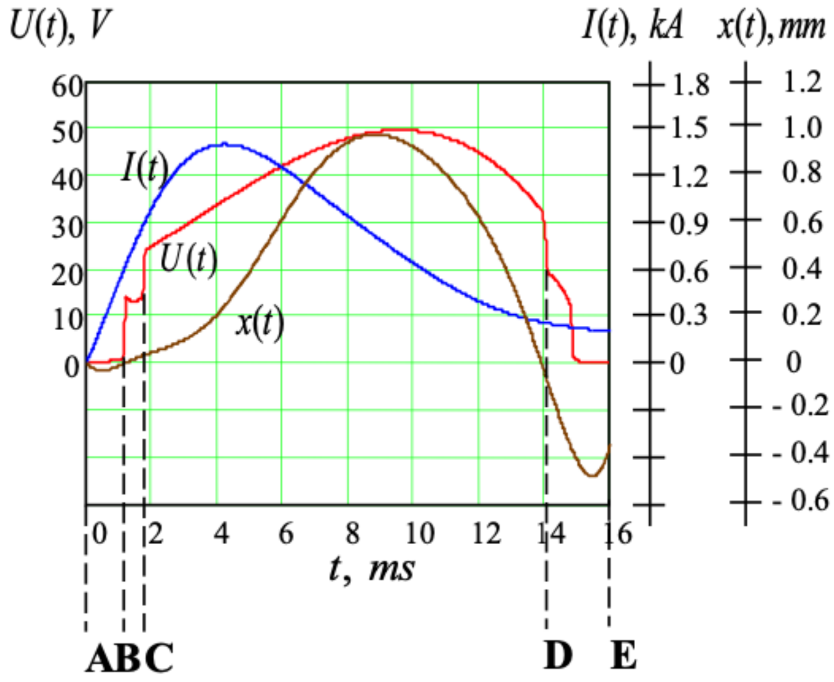

Fig. 4. Dynamics of voltage $U(t)$, current $I(t)$, and contact displacement $x(t)$

Series Arc Fault Modelling in Photovoltaic Resistive Systems

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Abstract

Series arc fault modelling provides an effective simulation approach for understanding arc fault characteristics in photovoltaic (PV) systems. However, the measured arc fault signals are synthetic results between arc faults and many system interference factors, which makes the modelling process complicated. This paper aims at providing an effective arc fault model for the simulation research in PV resistive systems. In this paper, various arc fault data are acquired through the designed experiment platform firstly. Then the establishment direction is summarized for the arc fault modelling in PV resistive systems. Next, the series arc fault model is proposed by combining the U-I model and pink noise model. Finally, the simulation analysis of series arc fault is carried out in PV resistive systems. By comparing with the obtained experimental data, the effectiveness of the arc fault model is verified.

$$V_{arc} = \frac{32.83 + 12.79 L_{arc}}{I_{arc}^{0.223+0.02445 L_{arc}}} \qquad (1)$$

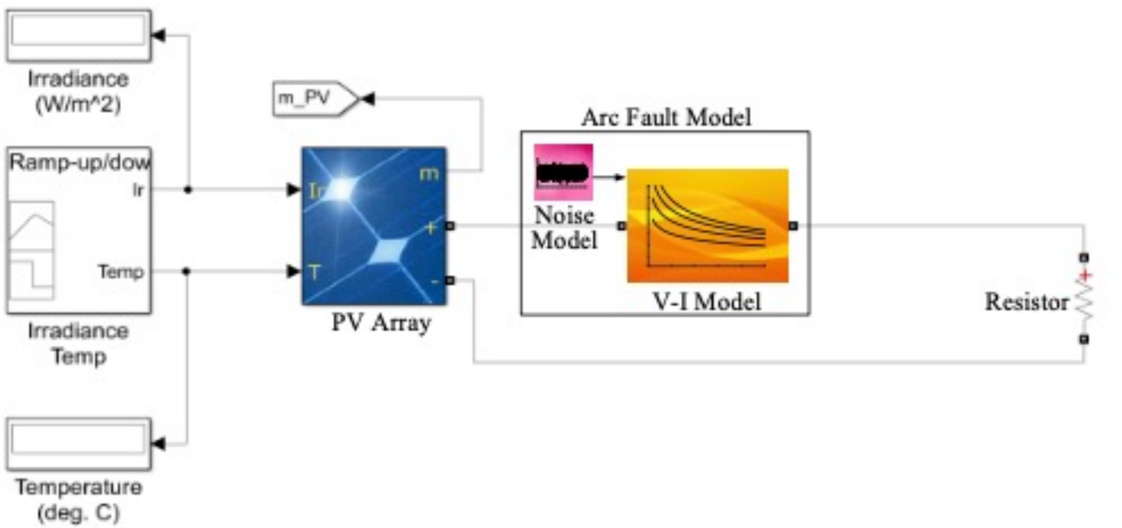

Fig. 3.1 Simulation of series arc faults in the PV resistive system.

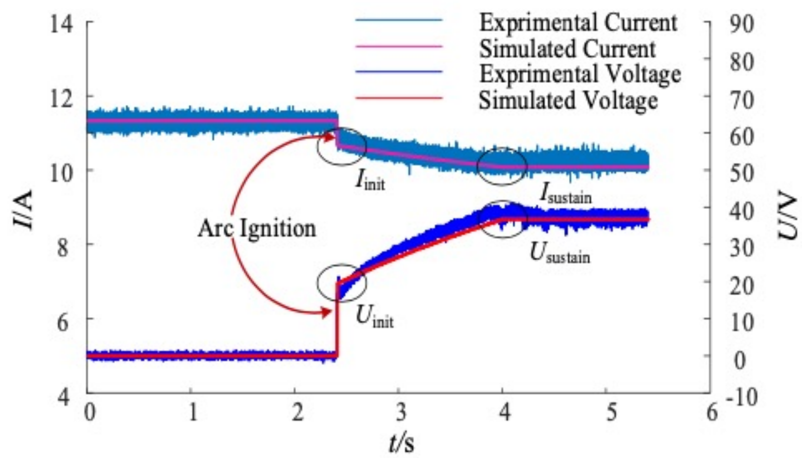

Fig. 3.2 The simulation and experiment comparison of arc fault current and voltage in time domain.

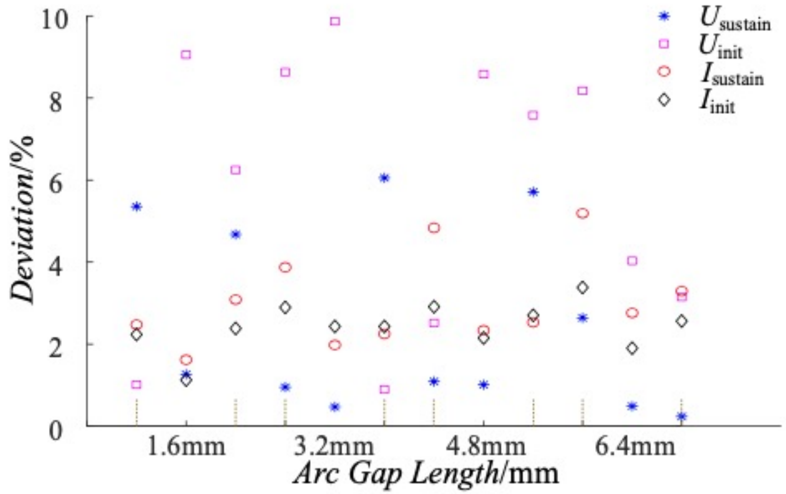

Fig. 3.3 Time-domain relative error analysis between simulation and experiment with different arc gap lengths and current levels.

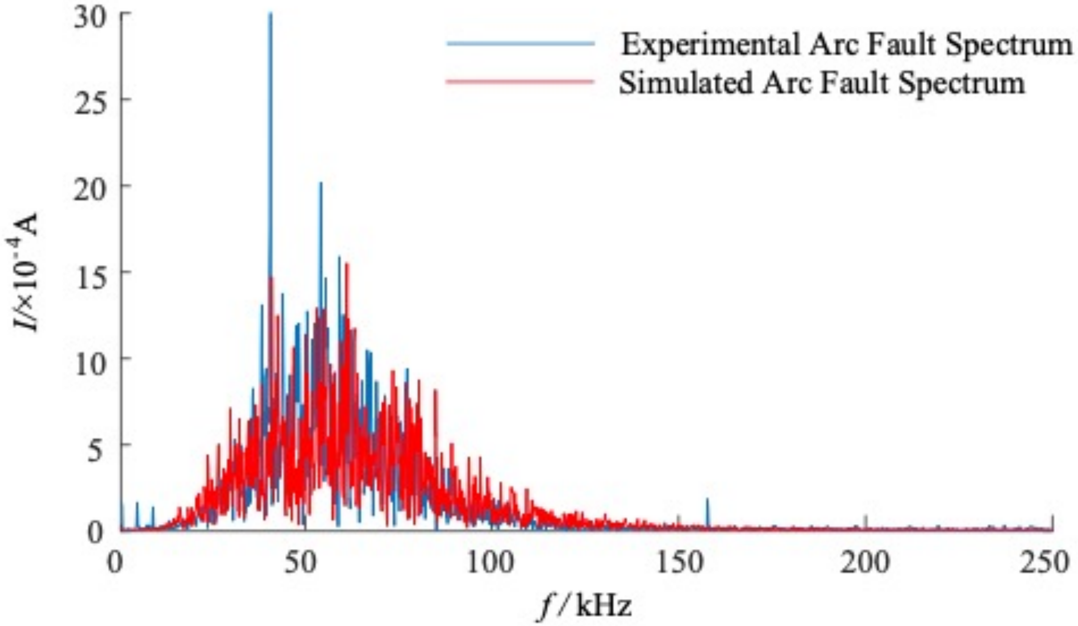

Fig. 3.4 Frequency-domain comparison between simulated and experimental spectrum results with different arc gap lengths and current levels.

Session 14: New Technologies

SF6 alternative gases and future switching arc research
Christian Franck (ETH Zürich)

Electric Arc Reconstruction from Magnetic Field
Jinlong Dong (Xi'an Jiaotong University), Luca Di Rienzo (Politecnico di Milano),
Guogang Zhang (Xi'an Jiaotong University) and Jianhua Wang (Xi'an Jiaotong University).

Innovative switching concept to shutdown circuit currents in DC operating systems up to 1000VDC/30kA or 3600VDC/12kA based on ultrafast Powerfuse (PF) technology without outgasing.
Peter Lell (PyroGlobe GmbH).

SF_6 alternative gases and future switching arc research

[«Invited Presentation, ICEC 2020 Switzerland, Christian M. Franck»]

In the past decades, circuit breakers in medium and high voltage networks have been dominated by vacuum and SF_6 gas technology, respectively. The increasing awareness of the high global warming potential of SF_6, the related national and international regulation and legislation efforts, and the consequential increasing objection to use this technology have triggered substantial R&D-efforts to find environmental friendly alternatives. This invited presentation will give an overview on the ongoing and planned activities and recent advancements associated with finding alternative high voltage circuit breaker technologies [1].

Electric Arc Reconstruction from Magnetic Field

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Abstract

The knowledge of current density distribution gives important information for the study of the electric arc in low-voltage circuit breakers. At present, available experimental approaches to investigate the electric arc behavior include electrical measurements, optical and magnetic diagnostic techniques where electric arc shapes and movement can be obtained by these approaches. However, non-invasive experimental methods able to obtain the electric arc current density cannot be found in literature. This paper presents a non-intrusive diagnostic technique which is able to reconstruct the three-dimensional electric arc current density from its magnetic field measurements by solving a magnetic inverse problem. This inverse problem is known to be ill-posed and therefore Tikhonov regularization is used together with the L-curve method to deal with the ill-posedness. Zero-divergence condition on the current density and boundary conditions are incorporated into the formulation of the inverse problem with the help of Whitney elements. A magnetic field measurement system is developed based on a Hall effect magnetic sensor array and a data acquisition board. The sensor array is composed of 64 mono-axial analog-bipolar sensors distributed in eight columns and eight rows. The data acquisition board consists of eight analog-to-digital converters with a maximum sampling rate of 200 kHz and a 16-bit resolution. Experimental tests are carried out using the proposed method in order to study the arc dynamics. The three-dimensional arc current density reconstruction are obtained with the experimental magnetic field data. The reconstructions are compared with the optical images of the arc by using an optical diagnostic technique based on a charge-coupled device camera.

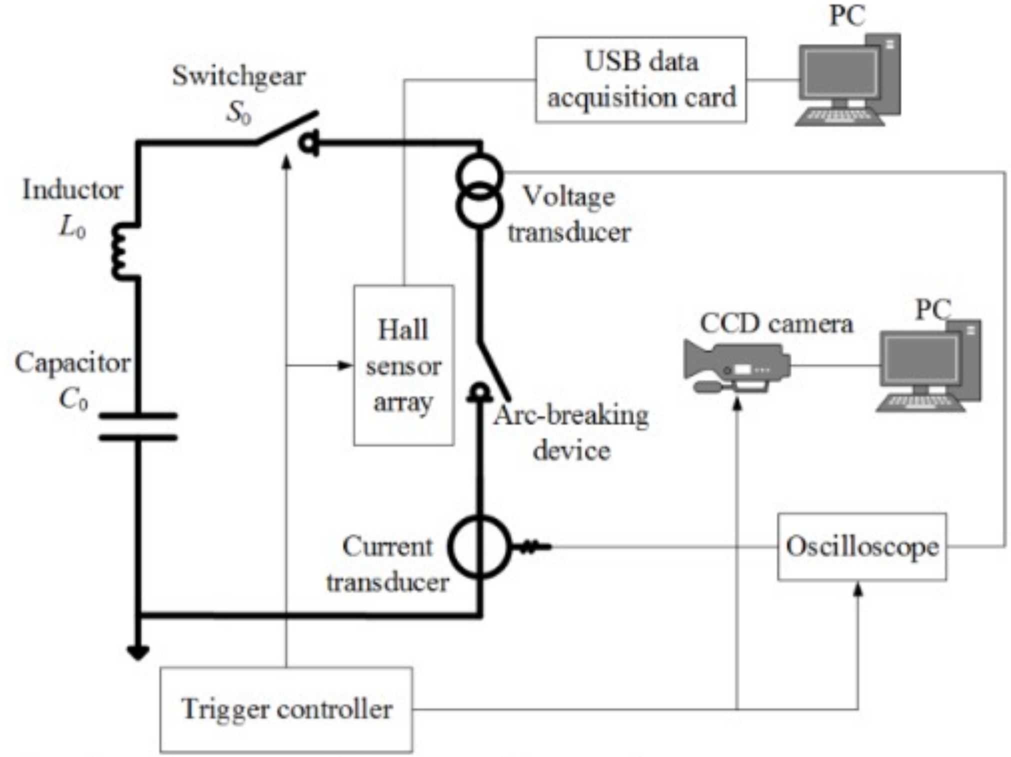

Fig. 1 Diagram of the experimental system.

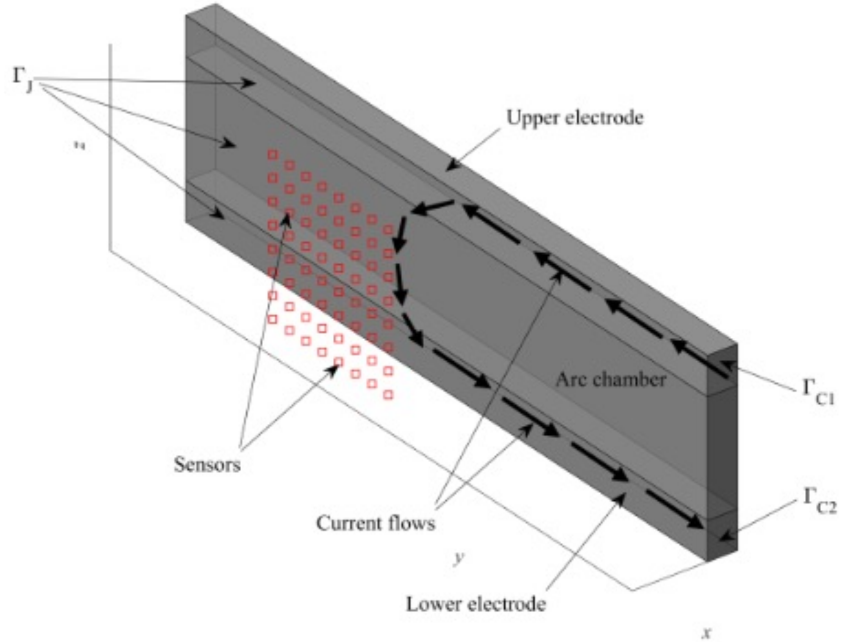

Fig. 4 Geometric model of the simplified arc chamber and location of the sensor array.

voltage U_c is 1000 V, with its corresponding peak current I_p equal to 9000 A.

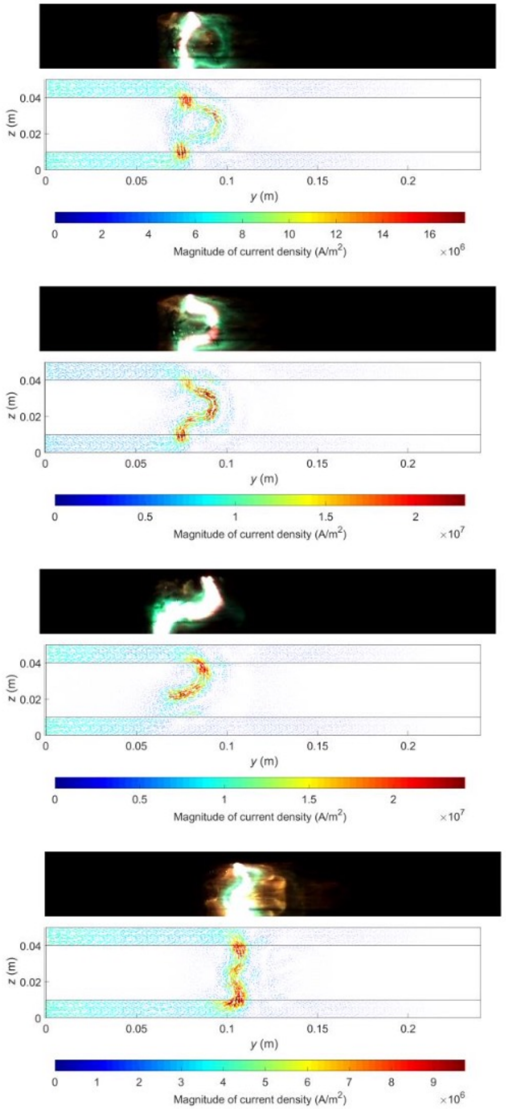

Fig. 6 Example of 2D projections of the reconstructed electric arc current density in different experimental tests compared with the optical image.

Innovative switching concept to shutdown circuit currents in DC-operating systems up to 1000VDC / 30kA or 3600VDC / 12kA based on ultrafast Powerfuse (PF) technology without outgasing.

Dr. Peter Lell, PyroGlobe GmbH, Hettenshausen, Germany, p.lell@pyroglobe.de

Abstract

In almost all technology areas direct current replaces the alternating current circuits at voltages far over 100V. In order to avoid unquenchable electric arcs, the switching of DC-circuits is now the most important issue. These DC-circuits must be galvanically separated from the rest of the electrical system in case of thermal overload or a short circuit condition, as it may occur after an accident or in other emergency situations, or to switch-away short circuit loops, as it is important i.e. in electromobility or control-cabinets. In existing protecting circuits, melting fuses and mechanical circuit breakers have been the choice for overcurrent protection at higher voltages. But challenging new applications have brought conventional current breaking devices to their limits. Mechanical circuit breakers and fuses are too slow to prevent the starting of an electrical arc, nor can they quench these arcs once started. In this article we outline the newest development of cutters for active and passive triggering with pyrotechnic-driven-elements, so called Powerfuses. Powerfuses are actively controllable via a current pulse and can switch-off currents of 30kA at 1000VDC or 12kA at 3600VDC in the range of a few milliseconds. The principle of Powerfuses, their applications and the last test-results are shown and discussed.