Design & Application of Power Circuit Breakers

Tutorial

Industry Standards which govern the design, testing and application of power circuit breakers have undergone significant changes throughout the years since their original publication. This natural evolution of standards follows changes in both the advancing technology of the equipment as the increasing demands imposed on them due to the complex environment which they are applied. This never-ending process makes it critical for system design engineers and planners to be aware of the current status of, and recent changes to, these standards in order to properly specify and apply this equipment.

This tutorial will begin with a historical review of the standards, describe the evolution of various rating methods used, and review the significant changes made in the current publications. This will be useful to those engineers faced with the task of specifying new circuit breakers that will be used to replace equipment that was manufactured to previous editions of the standards.

A review of the most common types of circuit breaker interrupter technologies will be conducted. Transient recovery voltage (TRV) application considerations and specific switching duties will be presented. These include terminal faults, short line faults, and out-of-phase switching. Changes to the TRV envelope specifications which are in the process of being implemented into the IEEE Standards will be reviewed. Unique characteristics of switching capacitive and inductive loads are also presented.

A review of the methods used to test high power circuit breakers is part of this tutorial. Considerations that are necessary for proper design and selection of equipment destined for installations in seismic areas are also covered.

It is recognized that time constraints limit the scope of this tutorial to provide summary information on the topics presented. However, sufficient background and reference material will be identified to enable the attendees to probe further in each topic covered.

The contributions of the authors for each section are gratefully acknowledged. They are each recognized experts in the field which they have written and presented, as well as in the related fields of circuit breaker design, ratings and applications.

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Summary of Topics

HISTORY OF CIRCUIT BREAKER STANDARDS — Jeff Nelson

This chapter traces the evolution of standards for alternating current high-voltage circuit breakers in the IEEE, formerly AIEE, from approximately 1900 to 2007. It reviews differences in rating principles and application methods in the original "total current" and the presently used "symmetrical current" basis of rating standards and outlines some of the new areas of circuit breaker standardization recently completed or currently under development in industry committees.

INTERRUPTING MEDIUMS — Rich York

This chapter will describe and show the method of operation of the various technologies of interrupters that have been and currently are being used in medium and high voltage circuit breakers. These include air magnetic, 2-pressure air, 2-pressure SF_6 and various types of single pressure SF_6 breakers.

VACUUM INTERRUPTERS: — Mietek Glinkowski

Vacuum Switching part of the tutorial will include topics on: vacuum as dielectric, vacuum as interrupting medium, brief comparison of vacuum with other switching media, fundamental design characteristics of vacuum interrupters, basic characteristics of vacuum-interrupter-based devices, issues related to applications and maintenance of vacuum switchgear.

TRANSIENT RECOVERY VOLTAGES — Denis Dufournet & Kirk Smith

Transient recovery voltages (TRV's) associated with short-circuit current interruption are presented, starting with general considerations that explain the different shapes of TRV's and how they are influenced by several parameters. TRV's are then presented in detail for terminal faults, short-line faults and out-of-phase breaking operations. The last part presents application considerations and the selection of circuit breakers for TRV's.

CAPACITIVE & SMALL INDUCTIVE CURRENT SWITCHING — John Brunke

Transient phenomena associated with the switching capacitive and small inductive currents are covered in this section. Special emphasis is on specification and application considerations of circuit breakers for these duties which include switching shunt capacitors and reactors, transformers, and no-load transmission lines. Surge control methods are covered, including controlled switching.

INSULATION COORDINATION Steve Lambert

Insulation element and design factors to handle overvoltages (60 Hz, lightning, and switching surges) and respective insulation withstand levels are reviewed. Various ANSI, IEEE and IEC standards are applied and discussed in relation to studies, test procedures, and results on insulation design studies for high voltage circuit breakers.

HIGH POWER TESTING OF CIRCUIT BREAKERS Harm Bannink

Testing of switchgear/circuit breakers is the last but crucial step in the quality assurance of such equipment. In this presentation, test-methods for switchgear regarding the withstand to and the interrupting capability of fault current will be highlighted:

1) Fault current withstand: basic fundamentals and short-time current test topics will be highlighted;
2) Fault arc withstand: internal arc ("arc resistance") test-methods and evaluation of results, as well as KEMA's experiences will be discussed;
3) Verification of fault current interruption capability: the so-called "synthetic test method" and some selected topics of testing under various service conditions, as simulated in the testlab, will be explained.

SEISMIC DESIGN Willie Freeman

IEEE Std 693-2005, 'Recommended Practice for Seismic Design of Substations" is reviewed. This standard primarily covers the seismic design and test qualification of electrical equipment, excluding nuclear Class 1E equipment used in substations. It does not cover the civil and structural design of the substation.

This chapter will present the seismic levels and qualification process as specifically applied to high voltage power circuit breakers, which can require either analysis or test, depending on the voltage rating.

The tutorial will show how to select the seismic qualification level and then apply the appropriate sections of the document to define the qualification analysis or test procedure for the equipment. A power circuit breaker example will be used to illustrate process.

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Agenda

Introduction	Rich York
History of Circuit Breaker Standards	Jeff Nelson
Review of Interrupting Mediums:	
Air, Oil, SF6	Rich York
Vacuum	Mietek Glinkowski
Break	
Transient Recovery Voltages & Fault Current Application Considerations	Denis Dufournet & Kirk Smith
Lunch Break	
Switching of Capacitive & Inductive Loads	John Brunke
Insulation Coordination	Steve Lambert
Break	
High Power Testing of Circuit Breakers	Harm Bannink
Seismic Considerations of Circuit Breakers	Willie Freeman

Speaker Biographies

Harm Bannink

Harm Bannink was born in Oosterbeek, The Netherlands (NL) in 1972. He received his Bachelor's Degree in Electrical Power Engineering from the Hogeschool Enschede, Enschede, NL in 1998 Harm Bannink has been with KEMA for the past 9 years of which 7 years working as a Test Engineer in the High Power Laboratory in Arnhem, NL. Because of his thorough knowledge of ANSI and IEC standards as well as related testing procedures he is currently on a two year assignment at KEMA-Powertest in Chalfont, Pennsylvania to optimize and standardize the testing procedures and methods between the two high power laboratories. He is also a member of the IEC SC17A/MT47 Working Group of IEC switchgear Technical Subcommittee on automatic reclosers.

John H. Brunke

John H. Brunke (F'94) was born in Portland Oregon. He attended Portland State University where he received a B.S. in Applied Science and Engineering in 1974 and a MS in Applied Science in 1980. He received the degree of Doctor of Technical Science from the Swiss Federal Institute of Technology in Zurich Switzerland (ETHZ) in 1998 writing his dissertation on controlled switching of large power transformers. Dr. Brunke was employed by the Bonneville Power Administration in Portland Oregon from 1975 through 2005 in various positions including Chief of the Test and Development Section, Chief of the Specifications Section, and Principal Engineer for High Voltage Equipment. He has taught graduate courses in power systems and high voltage engineering at Portland State University. He is presently a consultant for Siemens PT&D. John is a past Chairman of the IEEE Switchgear Committee and past Chairman of CIGRE Study Committee 13 (Switching Equipment). John is a Fellow of the IEEE, Distinguished and Honorary Member of CIGRE and a Registered Professional Engineer in Oregon and Washington. He is also a retired Naval Reserve Engineering Duty Officer.

Denis Dufournet

Denis Dufournet graduated from ENSEM Nancy in Electrical engineering, in 1975. He joined AREVA T&D (then Delle Alsthom) in 1977 as a research engineer. He is currently Senior Expert, Head of research in AREVA T&D, Villeurbanne, France. Since 1983 he is member of Working groups and Technical Committees in IEC, IEEE and CIGRE. While participating in these activities, he received several awards from CIGRE: Distinguished Member in 2002, Diplôme d'Honneur from the Technical Committee in 2001.

In IEC, he is Chairman of IEC TC 17 (Switchgear and Controlgear) and SC17A (High Voltage Switchgear and Controlgear) since April, 2004, he is member of Maintenance teams 36 and 37.

In CIGRE, he is presently member of WG A3-19 and A3-22. Previously he has been a member of CIGRE WG 13-01 (Practical applications of arc physics), CIGRE-CIRED

CC03 (TRV in Medium voltage networks)and CIGRE WG A3-11 (Application Guide for IEC 62271-100 and 62271-1)

He has been elected Fellow of the IEEE in 2005, and is chairman of IEEE WG C37.011. He received the IEEE Standardization Association International Award in 2005.

Willie Freeman

Willie Freeman is Engineering Manager at ABB High Voltage Products in Mt. Pleasant. He has over 35 years of experience in the design and development of high voltage switchgear and other equipment. Previously, he held design engineering positions at the Westinghouse Power Circuit Breaker and Machinery Technology Divisions. He holds MSME and BSME degrees from the University of Pittsburgh and Georgia Tech and is a licensed professional engineer.

Mietek T. Glinkowski

Mietek T. Glinkowski was born in Czestochowa, Poland on December 29, 1956. He received his M.S. degree (cum-laude) in Telecommunication Engineering from Poznan Polytechnic, Poznan, Poland, in 1980, the M.E. degree in Electric Power Engineering from Rensselaer Polytechnic Institute, Troy, NY, in 1985, and his Ph.D. in Electric Power Engineering in 1989. He was a Fulbright Scholar in 1984-1985. Between 1989-1997 Dr. Glinkowski was a Professor of Electric Power Engineering at Rensselaer. His area of expertise included power switchgear (especially vacuum switching), electrical discharges, power systems, system protection, mathematical modeling of power system components, electrical transients in power systems, as well as novel AI (Artificial Intelligence) techniques applied to power engineering. Dr. Glinkowski has also taught power engineering courses, graduate and undergraduate, as well as core engineering courses in dynamic systems. At his private consulting practice he has worked with many industrial and utility customers world-wide concerning operation, design, and analysis of power equipment. His major customers included General Electric, Cooper Power Systems, Con Edison of New York, S&C Company, TVA, SCE, ABB, Alstom, and many others.

Dr. Glinkowski joined ABB Inc. in June 1997 where he was first a Technology Team Leader for Electric Systems Technology Institute's Switchgear and Insulation Systems and later a Program Manager for Equipment and Application Technologies. Since 2000 Dr. Glinkowski has been a Director of Engineering for the ABB North America Technology Center (NAM TC) and more recently he is also a Global Technology Manager for MV Outdoor Equipment coordinating global business development projects and technologies of ABB outdoor distribution equipment worldwide. In this capacity his main business focus is on United States, Canada, India, and China. During 2002-2004 Dr. Glinkowski has been on an international business assignment working in two business locations ABB Raleigh (USA) and ABB Dalmine in Italy.

Mietek Glinkowski is a Senior Member of IEEE Power Engineering Society, full voting member of the Switchgear Committee, Chairman of the ERP (Education, Recognition

and Publication) Subcommittee. He is a member of CIGRE, Chairman of CIGRE Joint Working Group JWG 12/13/23.21, member of the CIGRE WG A3.13, member of the Current Zero Club (CZC), member of New York Academy of Sciences, and member of SEP (Society of Polish Electrical Engineers). He is also a member of the Technical Advisory Board of the International Symposium on Short Circuit Currents (IS SCC). Dr. Glinkowski is a registered Professional Engineer (PE) in the State of New York and a member of the Sigma Xi research society. In February 2003 Dr. Glinkowski has been awarded a 2002 IEEE Outstanding Engineer of the Year from the IEEE Eastern Section. In January 2006 he received a 2005 CIGRE Technical Committee Award in recognition for outstanding contribution to the work of study committee A2.

Dr. Glinkowski is a member of the peer review board for IEEE Transactions on Power Delivery (IEEE TPWD), and is a member of the balloting pool for ANSI and IEEE Switchgear standards.

Dr. Glinkowski co-authored one technical book and wrote over 50 technical papers and chapters of books and encyclopaedias on power equipment and systems. He holds 6 US Patents. He has completed Six Sigma QA program and graduated from the Duke University ABB Leadership Management Program.

Stephen R. Lambert

Stephen R. Lambert (M'69, SM'78, F'91) received both a BSEE and MS from the University of Illinois in 1969. After teaching at the University he joined Commonwealth Associates, Inc. in 1970, and in 1973 he joined Power Technologies, Inc. In July of 1997, he founded Shawnee Power Consulting, LLC.

Mr. Lambert is a Registered Professional Engineer and a Fellow of the IEEE. He is past chairman of the TRV Working Group, the High Voltage Circuit Breaker Subcommittee and the IEEE Switchgear Committee, and served as Vice-President, Technical Activities for the Power Engineering Society

Jeffrey H. Nelson

Jeffrey H. Nelson, P.E. (S'1987, M'1990, SM'1993) was born in Montgomery, AL. He received a Bachelor of Electrical Engineering degree from Auburn University, in Auburn, AL USA, in December 1989.

Mr. Nelson has been employed by the Tennessee Valley Authority since 1990 in various roles. His current position is Principal Electrical Engineer, in the Substation Projects Group, responsible for substation equipment applications and standards, technical management of substation equipment and material contracts, substation design standards, and technical and design process support.

Mr. Nelson has been actively involved in IEEE/PES activities for over fifteen years. He is Past-Chair of the Switchgear Committee, Past-Chair of the Capacitor Subcommittee, Past-Chair of the High Voltage Circuit Breaker Subcommittee, Past-Char of the Chattanooga IEEE Section, Past-Chair of the Chattanooga PES Chapter, WG Chair of IEEE 18 Standard for Shunt Power Capacitors, WG Chair for IEEE C37.04 Standard for High Voltage Circuit Breakers, an Editor for Transactions on Power Delivery, and a member of the PES Technical Committee Advisory Board. He is a recipient of the IEEE Third Millennium Medal and the 2002 PES Walter Fee Outstanding Young Engineer Award.

R. KIRKLAND SMITH

(IEEE Membership, Student Member'73-Member'75-Senior Member'90)

Kirk Smith was born in Camden, New Jersey, USA in 1948. He received the B.S.E.E. ('70 degree in electrical engineering from Drexel University, Philadelphia, PA, and the M.S.E.E. ('71) and Ph.D. ('74) degrees in electrical engineering from the University of Pittsburgh, Pittsburgh, PA, with the specialization in electrical power engineering. Dr. Smith has 33 years of research and product development experience in a wide range of technologies in the switching of electric current. He is presently the Manager of the Power Test Laboratory at the Eaton Electrical Vacuum Interrupter Business Unit in Horseheads, NY, USA. Dr. Smith is a member of the Power Engineering Society and participates in several working groups of the IEEE Switchgear Committee. He is the chair of the TRV working group of that committee. He was also the Convenor of IEC SC17A/WG23 a working group on power test procedures for high voltage circuit breakers of the IEC Switchgear Technical Subcommittee.

Richard A. York

Richard A. York (IEEE Student Member-1980, Member-1982) has been employed with the ABB Power T&D Co. Inc., Mount Pleasant & Greensburg PA, since 1987. He has been responsible for control's engineering, and since 1990, assigned to the Development Engineering Department. As Sr. Development Engineer, he is responsible for test programs for new product development and breaker applications for all product lines. These include all single pressure SF_6 circuit breakers with rated maximum voltages through 800 kV. Mr. York is a member of IEEE Power Engineering Society, the Switchgear Committee and is currently Chair, High Voltage Circuit Breaker Subcommittee.

Richard graduated from the University of Pittsburgh in 1982 with a B.S in Electrical Engineering. Prior to joining ABB, he was employed by the Stone & Webster Engineering Corporation, being assigned to various power plant design and construction projects.