Wolfgang Hauschild · Eberhard Lemke

High-Voltage Test and Measuring Techniques

Second Edition

Springer

High-Voltage Test and Measuring Techniques

Wolfgang Hauschild · Eberhard Lemke

High-Voltage Test and Measuring Techniques

Second Edition

Springer

Wolfgang Hauschild
Dresden, Germany

Eberhard Lemke
Dresden, Germany

ISBN 978-3-319-97459-0 ISBN 978-3-319-97460-6 (eBook)
https://doi.org/10.1007/978-3-319-97460-6

Library of Congress Control Number: 2018950215

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword to the First Edition

Most textbooks on high-voltage (HV) engineering published in the recent years are focused on general aspects of this field but not on the specifics of HV test and measuring techniques provided in this book. This topic is mainly experimentally based and essential for the wide range of present and future challenges, due to the increasing use of renewable power, the wider application of cable systems as well as the erection of long-distance ultrahigh voltage (UHV) lines using not only alternating but also direct transmission voltages.

Therefore, researchers and engineers engaged in HV test and measuring techniques are developing new equipment, instruments, and procedures. For a general basis, international organizations as CIGRE, IEC, and IEEE summarize the results of research work and provide commonly accepted rules, guides, and standards. Many researchers, designers, and technicians engaged in the field of HV engineering are not well familiar with the approaches prepared and introduced by the abovementioned organizations. In this situation, this book will close a gap and contribute to a better understanding of the advanced technique recently developed and adopted for quality assurance testing and diagnostics of HV insulation. Moreover, the book is a help for students to get well-understandable information on today's tools for insulation testing and diagnostics. Another main application will be the training, further education and individual learning of engineers.

In this context, it should be noted that great progress has been made in developing HV test systems including the associated measuring equipment which are the main topics of the book written by Hauschild and Lemke. In summary: The book gives a complete introduction and an overview of the state-of-the-art HV test and measuring techniques in close connection to practical aspects. For me, great work has been done by the authors, which I know since the beginning of the 1970s when I visited the HV Institute in Dresden for the first time. Thereafter we became good partners and close friends. I met the authors periodically, mainly when participating in various working groups of CIGRE and IEC where Wolfgang Hauschild was especially engaged in the field of HV test technique and Eberhard Lemke in the field of HV measuring technique. Their outstanding work and fruitful cooperation with the HV Institute of the Graz University of Technology has been recognized by awarding both with the degree of a "Doctor honoris causa" in 2007 and 2009, respectively.

Michael Muhr
Graz, Austria Graz Technical University

Paris, France Chairman of Cigre AG HV Test Techniques
November 2013

Preface to the First Edition

More than a century after its beginning, high-voltage (HV) engineering still remains an empirical field. Experimental investigations are the backbone for the dimensioning of electrical insulations and indispensable for quality assurance by type, routine and commissioning tests as well as for insulation condition assessment by monitoring and diagnostic tests. There is no change in sight for such empiric procedures. The application of higher transmission voltages, improved insulation materials, and new design principles require the further development of HV test and measuring techniques. The relevant bodies of experts in *CIGRE, IEC* and *IEEE* provide commonly accepted standards and guides of HV testing adapted to both, the needs and the level of knowledge.

Coming from the Dresden School of HV engineering of *Fritz Obenaus* and *Wolfgang Mosch*, the authors have been lucky to follow and to contribute to the development of HV test techniques for half of a century. This book is based on that experience and shall reflect the actual state of the art of HV test and measuring techniques. According to our intention, the book shall close a gap in the international literature of HV engineering and lead to a better understanding of the relevant IEC and IEEE standards. It is hoped our text will fill the needs of designers, test field and utility engineers as well as those of senior undergraduate and graduate students and researchers. Today, many engineers who are confronted with or even engaged in HV testing did not have an in-depth education in HV engineering. Therefore, the book is intended to support the individual learning as it is useful for further training courses, too.

After an introduction related to the history and the position of HV test techniques within electric power engineering, the general basis of test systems and test procedures, the approval of measuring systems and the statistical treatment of test results are explained. In separate chapters for alternating, direct, impulse, and combined test voltages, respectively, their generation, their requirements, and their measurements are described in detail. Because partial discharge and dielectric measurements are mainly related to alternating voltage tests, separate chapters on these important tools are arranged after that of alternating test voltages. The book closes with chapters on HV test laboratories and on-site testing.

The cooperation with many experts from all over the world has been a precondition for writing this book. We are grateful to all of them, but we can mention only a few: We got our stamping at the HV Laboratory of Dresden Technical University and acknowledge the cooperation of its staff, represented by *Eberhard Engelmann* and *Joachim Speck*. We consider our membership in the expert bodies of *CIGRE 33 (later D1), IEC TC 42* and *IEEE-TRC and ICC* as a school during our professional life. We have got numerous suggestions from this work on HV testing as well as from discussions with the members. We are grateful to *Dieter Kind, Gianguido Carrara, Kurt Feser, Arnold Rodewald, Ryszard Malewski, Ernst Gockenbach, Klaus Schon, Michael Muhr* and all others who are not mentioned here. Of course, the daily work in our companies has been connected with many technical challenges of HV test techniques. As they have always been mastered in our reliable teams, we would like to express our sincere thanks to both, the management and the staff of *Highvolt Prüftechnik Dresden GmbH* and *Doble-Lemke GmbH*. Thanks to *Harald Schwarz and Josef Kindersberger*, who appointed Wolfgang Hauschild to a lectureship on HV test techniques at Cottbus Technical University respectively on Munich Technical University. This required a suitable structure for the subject which is also used in this book. For the careful proofreading of the manuscript and the helpful advices, we thank our friends *Jürgen Pilling* and *Wieland Bürger*. We would be grateful for further suggestions and critics of the readers of this book.

Dresden, Germany
October 2013

Wolfgang Hauschild
Eberhard Lemke

Preface to the Second Edition

The recent years after the first edition of this book has been published are characterized by many developments in electric power generation, transmission, and distribution, e.g., the increasing application of renewable energy, the extensions of the AC transmission voltages to the UHV level >800 kV, the wider application of HVDC power transmission, also by using cable systems, and improved methods of diagnostics and condition assessment. All these advances are of consequence for the high-voltage test and measuring technique. The second edition of this book shall reflect the trend in HV testing and should be understood as a contribution to the present impetus of high-voltage engineering in general.

Also for this second Edition, we have been supported by many colleagues and mention *Dr. Ralf Pietsch, Günter Siebert* and *Uwe Flechtner*. Especially, we acknowledge the cooperation with *Dr. Christoph Baumann, Petra Jantzen* and *Sudhany Karthick* of Springer Nature.

Dresden, Germany
September 2018

Wolfgang Hauschild
Eberhard Lemke

Acknowledgement

Due to the generous aid by HIGHVOLT Prüftechnik Dresden GmbH, the book has got its colored appearance. Furthermore, all photographic figures and three-dimensional drawings without reference are supplied by the HIGHVOLT archives. Our sincere thanks are related to the management, especially to *Bernd Kübler, Thomas Steiner and Ralf Bergmann*, for their permanent support of our project.

Contents

Abbreviations

AC	Alternating current (in composite terms, e.g., AC voltage)
ACIT	HV units for feeding induced voltage tests
ACL	Accredited Calibration Laboratory
ACRF	HVAC series resonant circuit of variable frequency
ACRL	HVAC series resonant test circuit of variable inductance
ACT	HVAC test circuit based on transformer
ACTF	HVAC test circuit of variable frequency based on transformers
ADC	Analog–digital converter
AE	Acoustic emission
AMS	Approved measuring system
C	Capacitance
CD	Committee Draft (IEC)
CH	Channel
CRO	Cathode ray oscilloscope
DAC	Damped alternating current (in composite terms, e.g., DAC voltage)
DC	Direct current (in composite terms, e.g., DC voltage)
DCS	Directional coupler sensor
DNL	Differential nonlinearity
DSP	Digital signal processing
EMC	Electromagnetic compatibility
GIL	Gas-insulated (transmission) line
GIS	(1) Gas-insulated substation (2) Gas-insulated switchgear
GST	Grounded specimen test
GUM	ISO/IEC Guide 98-3:2008
HF	High frequency
HFCT	High-frequency current transformer
HV	High voltage (in composite terms, e.g., HV tests)
HVAC	High alternating voltage
HVDC	High direct voltage

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers (USA)
IGBT	Insulated gate bipolar transistor
INL	Integral nonlinearity
IVPD	Partial discharge measurement at induced AC voltage
IVW	Induced voltage withstand test
L	Inductance
LI	Lightning impulse (in composite terms, e.g., LI test voltage)
LIC	Chopped lightning impulse
LIP	Liquid-impregnated paper (insulation)
LSB	Least significant bit
LTC	Life time characteristic (or test)
LV	Low voltage
M/G	Motor–generator (set)
ML	Maximum likelihood
MLM	Multiple level method
MS	Measuring system
MV	Medium voltage (do not mix-up with the dimension “Megavolt”!)
NMI	National Metrology Institute
OLI	Oscillating lightning impulse
OSI	Oscillating switching impulse
PD	Partial discharge (in composite terms, e.g., PD measurement)
PSM	Progressive stress method
R	Resistor
R&D	Research and development
RF	Radio frequency
RIV	Radio interference voltage
RMS	Reference measuring system
rms	Root of mean square
RoP	Record of performance
RVM	Return voltage measurement
SFC	Static frequency converter
SI	Switching impulse (in composite terms, e.g., SI test voltage)
TC	Technical Committee (of IEC)
TDG	Test data generator
TDR	Time domain reflectometry
THD	Total harmonic distortion
TRMS	Transfer reference measuring system
UDM	Up-and-down method
UHF	Ultrahigh frequency
UHV	Ultrahigh voltage (in composite terms, e.g., UHV laboratory)
V	Voltage
VHF	Very high frequency
X	Reactance
XLPE	Cross-linked polyethylene
Z	Impedance

Symbols

A	Area
a	Distance
α	Phase angel
ß	Overshoot magnitude
C	Capacitance
C_i	Impulse capacitance
C_l	Load capacitance
c	Velocity of light
D	Dielectric flux density
d	Diameter
dV	Voltage drop (DC)
Δf	Bandwidth
ΔT	Error of time measurement
ΔV	Voltage reduction (DC)
δ	(1) Air density
	(2) Weibull exponent
	(3) Ripple factor
	(4) Loss angel (tan δ)
δV	Ripple voltage (DC)
E	Electric field strength
e	(1) Elementary charge ($e = 1.602 \times 10^{-19}$ As)
	(2) Basis of natural logarithm ($e = 2.71828\ldots$)
ε	Permittivity ($\varepsilon_0 = 8{,}854 \times 10^{-12}$ As/Vm)
ε_r	Relative permittivity
η	(1) 63% quantile (Weibull and Gumbel distributions)
	(2) Utilization or efficiency factor
F	(1) Scale factor
	(2) Coulomb force
F_p	Polarization factor
F(f)	Transfer function

$F(x)$	Distribution function
f	Frequency
f_m	Rated frequency
f_t	Test frequency
f_0	(1) Natural frequency
	(2) Centre frequency (narrowband PD measurement)
f_1	Lower frequency limit
f_2	Upper frequency limit
Φ	Magnetic flux
φ	Phase angle
G	Current density
g	Parameter for atmospheric corrections
$g(t)$	Unit step response
H	(1) Magnetic field strength
	(2) Altitude
h	Humidity
I	Current
I_m	Rated current
I_{sc}	Short-circuit current
i_L	Discharge current
K	Coverage factor for expanded uncertainty
K_t	Atmospheric correction factor
k	(1) Parameter for atmospheric corrections
	(2) Fixed factor
k_d	Constant in life time characteristic
k_e	Field enhancement factor
$k(f)$	(1) Test voltage factor
	(2) Test voltage function for LI evaluation
k_1	Air density correction factor
k_2	Humidity correction factor
κ	Conductivity
L	(1) Inductance
	(2) Likelihood function
M	Pulse magnitude (PD measurement)
m	Estimated mean value
μ	Theoretical mean value
μ	Permeability ($\mu_0 = 0.4\ \pi \times 10^{-6}$ Vs/Am = $1{,}257 \times 10^{-6}$ Vs/Am)
μ_r	Relative permeability
n	(1) Life time exponent
	(2) Number (e.g., of electrons)
ω	Angular frequency
P	Active test power
P_F	Feeding power
P_m	Dipole moment
P_N	Natural power of a transmission line

P_R	Loss power of a resonant circuit
p	(1) Probability
	(2) Pressure
p_0	Reference pressure
Q	(1) Charge
	(2) Quality factor (resonance circuit)
q	(1) Charge of a PD pulse
	(2) Charge of a leakage current pulse
R	(1) Resistance
	(2) Ratio between two results
R_d	Damping resistance
R_f	Front resistor
R_t	Tail resistor
r	(1) Ratio (e.g., divider or transformer)
	(2) Radius
S	(1) Reactive test power
	(2) Steepness (LI/SI test voltage)
S_f	Scale factor
S_{50}	50 Hz equivalent test power
s_g	Mean square deviation (estimation of standard deviation)
σ	Standard deviation
T	Duration (AC period)
T_C	Time to chopping
T_N	Experimental response time
T_R	Residual response time
T_T	Duration of overshoot
T_1	Front time of LI voltage
T_2	Time to half-value of impulse voltages
t	(1) Temperature
	(2) Time
t_s	Settling time
t_t	Test time
t_0	Reference temperature
τ	Time constant
U	Expanded uncertainty
U_{cal}	Expanded uncertainty of calibration
U_M	Expanded uncertainty of measurement
u	Standard uncertainty
u_A	Type A standard uncertainty
u_B	Type B standard uncertainty
V	Voltage
V_B	Maximum of base curve (LI voltage)
V_E	Extreme value of recorded curve (LI voltage)
V_e	PD extinction voltage
V_F	Feeding voltage

V_i	(1) PD inception voltage
	(2) Impulse voltage
V_k	Short-circuit voltage (test transformer)
V_m	(1) Highest voltage of equipment, rated voltage
	(2) Arithmetic mean (DC)
V_{max}	Maximum of DC voltage
V_{min}	Minimum of DC voltage
V_n	Nominal voltage
V_{peak}	Peak voltage
V_r	Return or recovery voltage
V_{rms}	Root mean square value of voltage
V_T	Test voltage value
V(v)	Performance function
$V_{\sum}$	Cumulative charging voltage
V_0	(1) Line-to-ground voltage
	(2) Initial voltage for a test
	(3) Charging DC voltage
V_1	Primary voltage of a test transformer
V_2	Secondary voltage of a test transformer
V_{50}	50% breakdown voltage
v	Variance
v(t)	Time-depending voltage
v_k	Short-circuit impedance of a test transformer
w	Number of turns of a winding
W	Energy
W_i	Impulse energy (of impulse voltage generator)
X	Reactance
X_{res}	Short-circuit reactance of a transformer
Z	Impedance
Z_L	Surge impedance of a transmission line

Chapter 1
Introduction

Abstract High-voltage (HV) test and measuring techniques are considered in most general HV text books (e.g. Kuechler 2009; Kuffel et al. 2007; Beyer et al. 1986; Mosch et al. 1988; Schufft et al. 2007; Arora and Mosch 2011). There are teaching books on HV test techniques for students (Marx 1952; Kind and Feser 1999) as well as few text books on special fields, e.g. on HV measuring technique (Schwab 1981; Schon 2010, 2016). It is the aim of this book to supply a comprehensive survey on the state of the art of both, HV test and measuring techniques, for engineers in practice, graduates and students of master courses. A certain guideline for this is the relevant worldwide series of standards of the Technical Committee 42 (TC42: "High-Voltage and High-Current Test and Measuring Techniques") of the *International Electrotechnical Commission (IEC),* largely identical with the corresponding standards of the Institute of *Electrical and Electronic Engineers (IEEE)*. This introduction contains also the relation between HV test and measuring techniques and the requirements of power systems with respect to the increasing transmission voltages and the principles of insulation coordination. Furthermore, HV testing for quality assurance and condition assessment in the life cycle of power equipment is investigated.

1.1 Development of Power Systems and Required High-Voltage Test Systems

Within the last 125 years, the development of transmission voltages of power systems from 10 to 1200 kV has required a tremendous development of high-voltage (HV) engineering. This includes, e.g. the introduction of many new insulating materials and technologies, the precise calculation of electric fields, the knowledge about the phenomena in dielectrics under the influence of the electric field and the understanding of electric discharge processes. Nevertheless, as an empirical technical science, HV engineering remains closely related to experiments and verifications of calculations, dimensioning and manufacturing by HV tests. The reasons for that are, e.g. unavoidable defects of the structure of technical insulating

W. Hauschild and E. Lemke, *High-Voltage Test and Measuring Techniques*,
https://doi.org/10.1007/978-3-319-97460-6_1

materials, imperfections of technical electrodes, but also failures of production and assembling. Therefore, in parallel to the development of HV engineering, national and international standards for HV testing have been developed, as well as equipment for the generation of test voltages and for measurements of (and at) these voltages.

Since the early beginning of the wider application of electrical energy, its transmission from the place of generation (power station) to that of consumption (e.g. industry, households, public users) influences the energy cost remarkably. The transportable power of a high-alternating voltage (HVAC) overhead line is limited by its surge impedance Z_L to a power transfer capability of approximately

$$P_L = V^2/Z_L. \tag{1.1}$$

Whereas the surge impedance ($Z_L \approx 250\ \Omega$) can only be influenced within certain limits by the geometry of the overhead line, the power transfer capability is mainly determined by the height of the transmission voltage, e.g. the power transfer capability of a 400 kV system is only a quarter of that of an 800 kV system. Consequently, increasing energy demand requires higher HVAC transmission voltages. Remarkable increases in the ratings *of HVAC transmissions are* to 123 kV in 1912 in Germany, to the 245 kV level in 1926 (USA), to 420 kV in 1952 (Sweden), to 800 kV in 1966 (Canada and Russia) and to UHV (1000–1200 kV in 2010, China) (Fig. 1.1).

Because at direct voltage, no surge impedance becomes effective; the limitation of the power transfer capability is mainly caused by the current losses. For identical

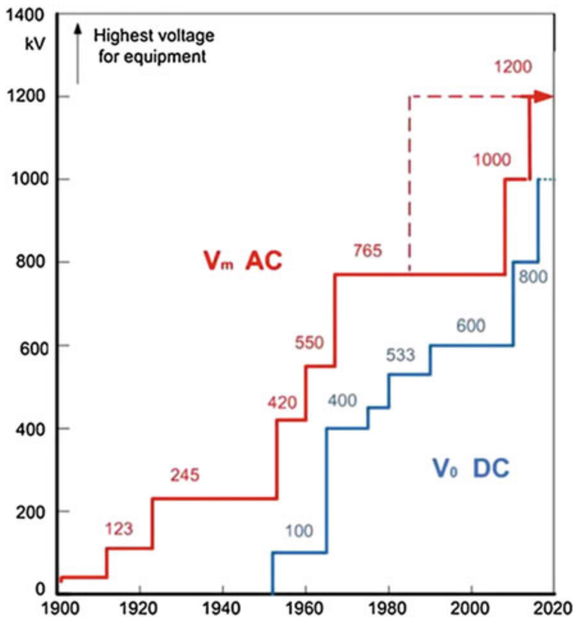


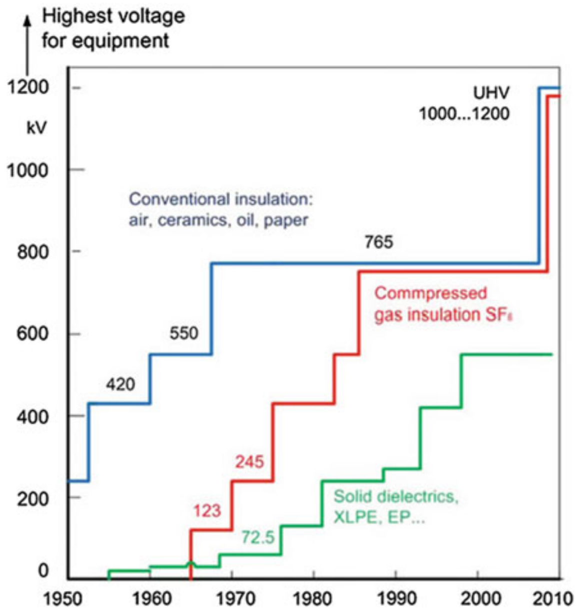
Fig. 1.1 History of HVAC and HVDC transmission systems

rated voltages, the HVDC power transfer capability is about three times higher than that at HVAC. This means that one 800 kV HVDC line with an efficiency of 94% replaces three 800 kV HVAC overhead lines with an efficiency of only 88% (Swedish Power Cycle 2009). But *HVDC transmission* requires expensive converter stations. Therefore, the application of HVDC transmission has been limited to very long transmission lines, where the cost reduction for the line compensates the higher station cost. The present cost reduction of power electronic elements, efficient HVDC cable production and other technical advantages of HVDC transmission has triggered worldwide activities in that field (Long and Nilsson 2007; Gockenbach et al. 2007; Yu et al. 2007). The historical development (Fig. 1.1) shows that the 1000 kV level is reached in China now, but the next levels above 1000 kV or more are under preparation (IEC TC115 2010).

The HV test and measuring techniques have to be able to test components which belong to both HVAC and HVDC power systems. But additionally, also the kind of insulation to be tested determines the kind of the test equipment. The "classical" insulating materials (air, ceramics, glass, oil, paper) are completed by insulating gases, e.g. SF_6 for gas-insulated substations and transmission lines (GIS, GIL) (Koch 2012), and synthetic solid materials, e.g. epoxy resin for instrument transformers and polyethylene for cables (Fig. 1.2) (Ghorbani et al. 2014). In the future, environmental viewpoints require a wider application of cables and GIL for power transmission of both, AC and DC voltages.

It is assumed that the present technology of *UHV DC transmission* would even allow the erection of a global-spanning supergrid to interconnect regional networks (Fig. 1.3) (Gellings 2015). This enables the world-wide exchange of electric power,

Fig. 1.2 History of the application of insulating materials



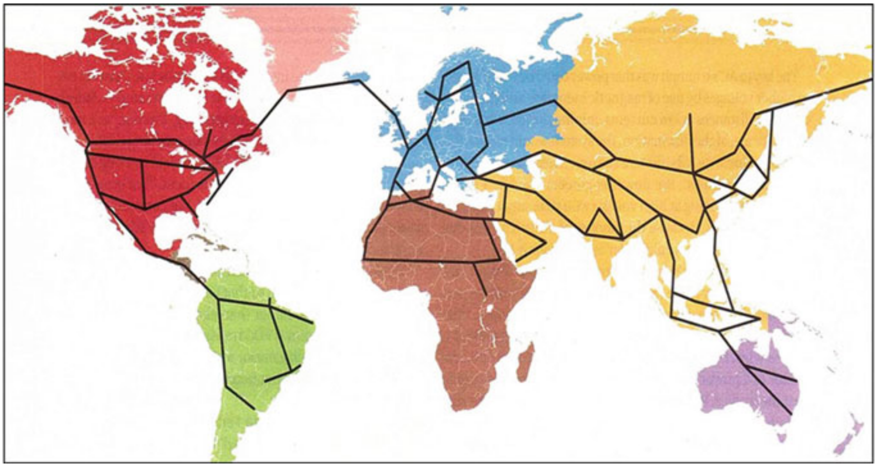


Fig. 1.3 The idea of a global-spanning super-grid

maintains the balance between supply and demand as well as secures grids against electronic and physical attacks. Planned and even constructed EHV/UHV regional networks, e.g. in China, Europe or around the Mediterranean can be understood as first steps to a supergrid which would also be a challenge to UHV testing!

The basic principle of HV testing expresses that test voltages stresses shall represent the characteristic stresses in service (IEC 60071-1). When electric power transmission started, not all these stresses were known. Furthermore, the kind and height of stresses depend on the system configuration, the used apparatus, the environmental conditions and other influences. The historical development of HV testing is closely related to the development of and the knowledge on power systems. It can be characterized by the following steps:

HV testing started in the first decade of the twentieth century with *alternating test voltages* of power frequency (50 or 60 Hz) (Spiegelberg 2003). The test voltages have been generated by test transformers, later also by transformer cascades (Fig. 1.4a, see also Sect. 3.1). It was assumed that suited *HVAC tests* would represent all possible HV stresses in service. Of course, HVDC equipment has been tested with DC voltages generated by DC generators (Fig. 1.4b, see also Sect. 6.1).

But independently on the performed HVAC tests, equipment has been destroyed in power systems, e.g. as a consequence of lightning strokes, which caused *external over-voltages*. These overvoltage impulses are characterized by front times of few microseconds and tail times of several ten microseconds. Based on that knowledge, tests with *lightning impulse (LI) test voltages* (front time ≈ 1…2 µs, time to half-value ≈ 40…60 µs) have been introduced in the 1930s. For LI voltage testing, suited generators have been developed (Fig. 1.4c, see also Sect. 7.1).

Another 30 years later, it has been found that *internal over-voltages* lead to lower breakdown voltages of long air gaps than LI or AC voltage stresses. They are caused by switching operations in the power system. Their durations lay between

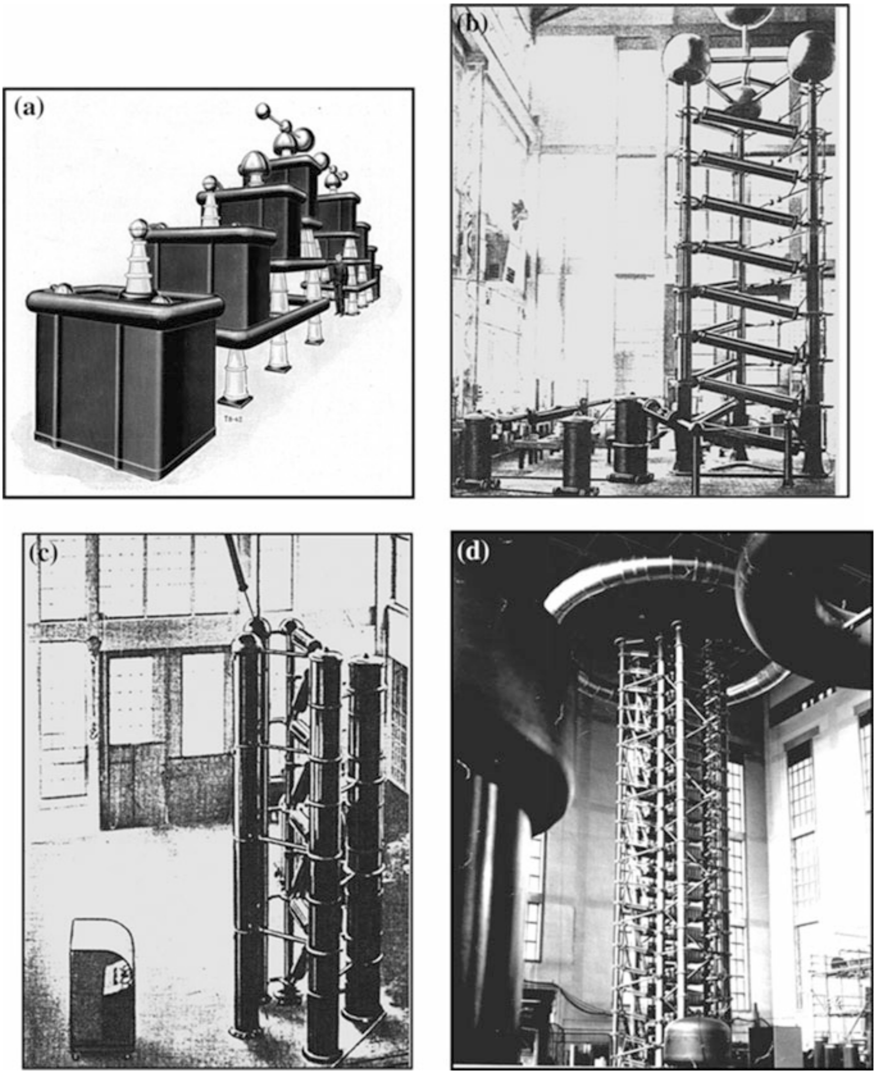


Fig. 1.4 Historical test voltage generators **a** world's first 1000 kV cascade transformer (Koch and Sterzel Dresden 1923) **b** 1000 kV DC test voltage generator (Koch and Sterzel Dresden 1936) **c** 2000 kV LI test voltage generator (Koch and Sterzel Dresden 1929) **d** 7000 kV LI/SI test voltage generator (TuR Dresden 1979)

some hundreds of microseconds and few milliseconds. As a consequence, *switching impulse (SI) test voltages* have been introduced in the 1960s. *SI test voltages* can be generated by the same type of generators as *LI test voltages* (but with larger HV electrodes for better control of the electric field, Fig. 1.4d, see also Sect. 7.1) or by test transformers.

Again 30 years later, it has been found that disconnector switching of gas-insulated substations (GIS) causes oscillating *over-voltages of very fast front* (VFF, several ten nanoseconds) which may harm the GIS insulation itself, but also attached equipment. Whereas a test with *very fast front (VFF) test voltage* has been introduced for GIS, it is under discussion for other components of power systems (Sect. 7.1.5).

The mentioned overvoltages are superimposed on the operational voltages. The traditional HV testing of components of HVAC power systems must not consider the operational voltage, only for special cases, e.g. disconnectors or three phase GIS busbars, the superposition plays a role. Therefore "*mixed voltages*" of two voltage components have been introduced. Depending on the position of the insulation in a test, one distinguishes between "*combined test voltages*" for three-pole test objects (e.g. disconnectors) and "*composite test voltages*" for two-pole test objects (e.g. polluted insulators), for details see Chap. 8. In case of HV testing of components of HVDC power systems, composite test voltages, play a very important role because of the space charge generation at DC voltages.

1.2 The International Electrotechnical Commission and Its Standards

The International Electrotechnical Commission (IEC) is the worldwide organization for international standards on electrical engineering, electronics and information technology. It has been founded in 1906, and its first president was the famous physicist Lord Kelvin. Today, about 60 national committees are IEC members. During its first years, IEC tried to harmonize the different national standards. But now, more and more national committees contribute to maintaining existing or establishing new IEC standards which are later overtaken as national and regional standards (e.g. CENELEC Standards of the European Union). This book refers mainly to IEC Standards and mentions also relevant standards of the US organization "*Institute of Electrical and Electronic Engineers*" (*IEEE*) which play an important role in some parts of the world. IEEE publishes also "*IEEE Guides*" which may overtake the role of missing text books. The IEEE Guides supply only recommendations and no requirements as standards are doing. The actual trend shows a closer cooperation between IEC and IEEE for the harmonization of IEC and IEEE Standards.

The structure of IEC (in 2014) is given in Fig. 1.5: The national committees send delegates to the IEC Council which is the IEC parliament and controls the IEC activities performed by the IEC Executive Committee. The Executive Committee is supported by three management boards, one of them related to IEC Standards. For the different fields of the IEC activities, the Management Board is supported by special groups. The active standardization work is done by Technical Committees (TC) and Subcommittees (SC). Each TC or SC is responsible for a certain number of standards of a special field. Existing IEC Standards are observed by Maintenance

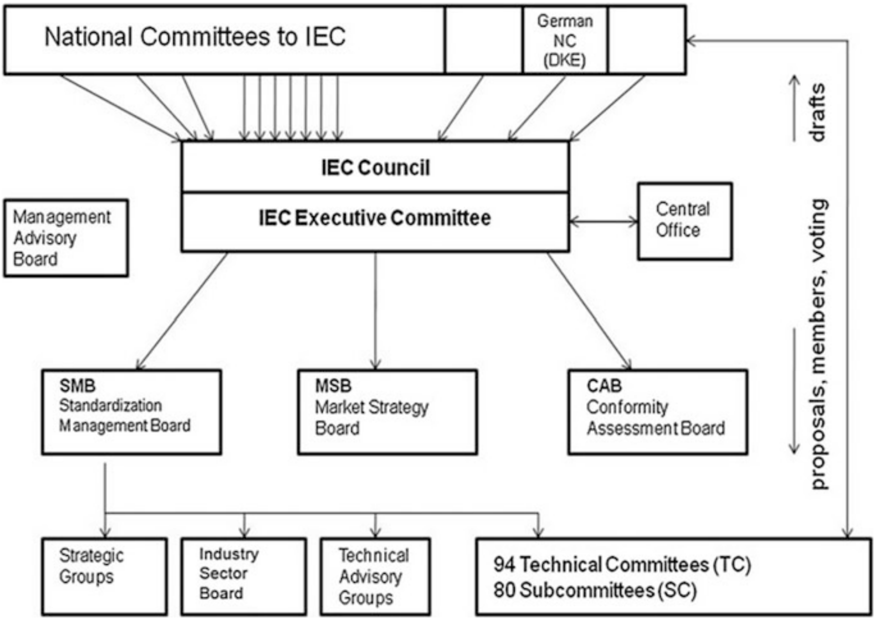


Fig. 1.5 Structure of the International Electrotechnical Commission (IEC)

Groups (MG); new IEC Standards are established by Working Groups (WG) based on proposals of National Committees. Each National Committee can be a TC/SC member or observer (or not attend the activities of certain TCs and SCs) and sends members to the active WGs.

There are TCs which have to maintain IEC Standards important for power systems and all types of apparatus. These are so-called *horizontal standards* (e.g. on insulation coordination or HV test techniques); the related TCs are shown in the first column of Table 1.1. IEC Standards related to apparatus or equipment (e.g. tests on transformers, GIS ore cables) are called "*vertical*" *(or apparatus) standards*. When a vertical standard is developed, all relevant horizontal standards shall be considered. Vice versa, during the development of a horizontal standard, the requirements of different apparatus should be known. The co-operation between horizontal TC's and vertical (apparatus) TC's requires improvement. Vertical TC's should better contribute to the activities of the horizontal committees and then apply horizontal standards consequently.

This book is closely related to the tasks of the TC 42 "High-voltage and high-current test techniques". It explains the scientific and technical background of the TC 42 standards, but cannot replace any of them. Rather, it should be understood as an application guide to the relevant IEC Standards and stimulate their application.

Table 1.1 The technical committees for horizontal and vertical standards

Horizontal Technical Committees for systems and basic tasks	Vertical Technical Committees TC / SC for apparatus and equipment								
	Rotating Machi nes TC 2	Power Trans-formers TC 14	Switch-gear TC 17	Cables TC 20	Power Electronics for T & D SC 22F	Capa-citors TC 33	Insu-lators TC3 6	Arres-ters TC 37	Instrument Trans-formers TC38
TC 1 Terminology									
TC 8 System Aspects									
TC 28 Insulation Coordination									
TC 42 HV Test Techniques									
TC 77 Electrom. Compatibility									
TC 104 Environment. Conditions									
TC 115 HVDC Transmission									
TC 122 UHV AC Transmission									

1.3 Insulation Coordination and Its Verification by HV Testing

In service, an electrical insulation is stressed with the *operational voltage* (including its temporary increase, e.g. in case of a load drop) and with the over-voltages mentioned above. The reliability of a power system has to be guaranteed under all possible stresses of its insulations. This is realized by the *insulation coordination* and described in the relevant group of IEC Standards (IEC 60071).

Insulation coordination is the correlation of the *withstand voltages* of different apparatus in a power system among each other and with the characteristics of *protective devices*. Today, protective devices (IEC 60099-4 2009) are *mainly metal oxide arresters (MOA)*, and partly conventional silicon carbide arresters with internal gaps and protection air gaps are still in use. An ideal protective device conducts electric current for voltages above the *protection level* and is an insulator below that voltage (A MOA is near to that characteristic). In the design of a power system, protective devices are installed at sensitive points, guaranteeing the protection level and protecting the insulation from excessive over-voltages.

The *insulation level* of the apparatus is selected in such a way that it is—under consideration of economic viewpoints—by a safety margin above the protection level. The insulation levels are defined by values of the relevant test voltages. The insulation under test must withstand the test voltage in a certain procedure. Usually, the AC or DC test voltage procedure is a 1-min stress (see Sects. 3.6 and 6.5); an