Eastern Economy Edition

Second Edition

An Introduction to High Voltage Engineering

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PHI

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High Voltage Engineering

SECOND EDITION

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To

My Mother

For giving me the courage to fight against odds

My wife, Sumita

For showing me the virtue of sobriety

My daughter Suchandra and son Sudipto

For teaching me the essence of patience

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Preface

The first edition of this book was intended to provide a basic concept of high voltage engineering to the undergraduate students of Electrical Engineering. The topics dealt with four major components—breakdown mechanism, generation and measurement of high voltage, high voltage testing and high voltage phenomenon in transmission systems. Over the last decade, electric field analyses using digital methods are extensively practiced for insulation design. A new chapter on electric field estimation is being added in the second edition. Instead of going into the details of field theory, the chapter has been devoted to its application to high voltage systems. Techniques for measurement of partial discharges have undergone a lot of changes. The fundamentals of partial discharges were adequately addressed to in the first edition. An appendix is being added to provide the readers with modern concepts of partial discharge and its detection.

I am thankful to my daughter-in-law, Jayeetri for helping with the manuscript typing. Thanks are due to ex-Professor N. Chatterjee, Jadavpur University and Professor S. Sen of IIT Kharagpur for their constructive suggestions. I must express my gratitude to the management of M.V.J. College of Engineering, Bangalore, especially Dr. K.S. Badrinarayan, Principal, for allowing me to bring out the second edition. I am also thankful to my publishers PHI Learning for bringing out the second edition.

SUBIR RAY

Preface to the First Edition

Since the first public power station established in London more than 120 years ago, the electric utility system has witnessed revolutionary changes. To meet the ever-increasing demand of electric energy at locations spread over vast territories, the power system has grown into an integrated one interconnecting generating stations by gigantic transmission networks. Tapping of hydel energy at places far remote from load centres in certain countries has necessitated long transmission lines intended to carry bulk power. Accordingly, the transmission voltage levels have increased rapidly. High voltage dc links (sometimes hundreds of kilometres in length) are now being successfully used for providing a channel for power flow.

Voltage levels of 1000 kV and above have been achieved over the last few decades in some countries. Such high transmission voltages necessitate a proper design of the insulation system. Not only should the insulation system be capable of withstanding such high normal system voltages, it should also be capable of withstanding transient overvoltages associated with external lightning discharges or internal switching operations without any outage. To achieve this, the system engineers need to have an understanding of the properties of insulating materials to be used as well as knowledge of the characteristics of the overvoltages appearing in the system.

Insulations may be solid, liquid, or gaseous. In electrical systems a combination of these insulating media is used. The properties of gases, as well as those of liquid and solid insulating materials, are of fundamental significance to high voltage engineering—a field of electrical engineering which is concerned with the physical phenomena and technical problems associated with high voltages. While we have now a reasonably satisfactory idea of breakdown characteristics of several gaseous media supported by theoretical treatment, the same cannot be said of the other two media. So, experiment constitutes the backbone of research in this area. Our idea of overvoltages appearing in power systems and their effects on the system is also not supported by accurate theoretical treatment. This is because of the statistical nature of overvoltages and the complications involved in quantization. One has to depend on national or international standards which are essentially based on experiments and statistical inferences, for equipment insulation design. Accordingly, it is necessary to test high voltage equipment during its development stage and prior to commissioning, to verify if the insulation can withstand the overvoltage as recommended in the standards.

From what has been said in the preceding paragraph it is clear that research and development in the field of high voltage technology cannot be carried out without expensive high voltage laboratories. For the purpose of effective teaching in this area, students need to be exposed to such laboratory practices. Such laboratory facilities are not available at all the technical institutes, and only the institutes having such facilities offer specialized courses on high voltage technology.

A qualitative change is taking place as regards manpower requirement in power systems since 1990. Flexible ac transmission systems (FACTS) technology employing power electronic devices is gaining popularity and the process of unbundling of generation and transmission areas (to be managed by separate companies) has started all over the world. So, more and more technical personnel drawn from specialized areas other than high voltage engineering are being exposed to high voltage systems. It is, therefore, being felt that an introductory course on high voltage engineering should be included in the curriculum at the undergraduate level in electrical engineering and may also form a part of the package of power system courses.

The present book is intended to address the situation by providing a basic concept of high voltage engineering qualitatively, and wherever possible quantitatively. The book will be useful not only to students studying the first course on high voltage engineering, but also to practicing engineers who are not exposed to formal training on high voltage technology.

The book deals with the following broad topics: (i) breakdown mechanisms and characteristics of insulating media, (ii) generation and measurement of high voltages, (iii) high voltage phenomenon in electric power systems, and (iv) high voltage testing of equipment.

Chapters 1 to 4 are devoted to the study of breakdown of gaseous insulation. While Chapters 1 and 2 deal with the breakdown mechanisms and characteristics in uniform field, Chapter 3 discusses the same topic under a non-uniform field. In Chapter 4, lightning discharges have been dealt with as a special case of breakdown of a long non-uniform air-gap. Breakdown mechanisms of liquid and solid dielectric materials have been covered in Chapter 5. Chapters 6 and 7 describe the principles of generation of high voltages in the laboratory for testing purposes and the measurement of such high voltages, respectively. In Chapter 8, the transient overvoltage phenomenon in power systems is discussed and the necessity of high voltage testing has been emphasized. Finally, Chapter 9 describes some important high voltage tests performed on power system equipment.

It is expected that the reader will have the following pre-requisites to appreciate the contents of the book: (i) elementary concepts of atomic models and electric field, (ii) concepts of circuit theory including transient analysis, (iii) knowledge of electric power transmission and electrical measurements.

I would whole-heartedly welcome constructive criticism and appraisal of this book from students and faculty alike. I sincerely invite their comments and suggestions for improving this book.

I am deeply indebted to Dr. P.L. Gautam, Vice-Chancellor of Govind Ballabh Pant University of Agriculture and Technology and Dr. C.S. Jaiswal, former Dean, Faculty of Technology, for their constant encouragement, constructive suggestions, and valuable comments during the writing of this book.

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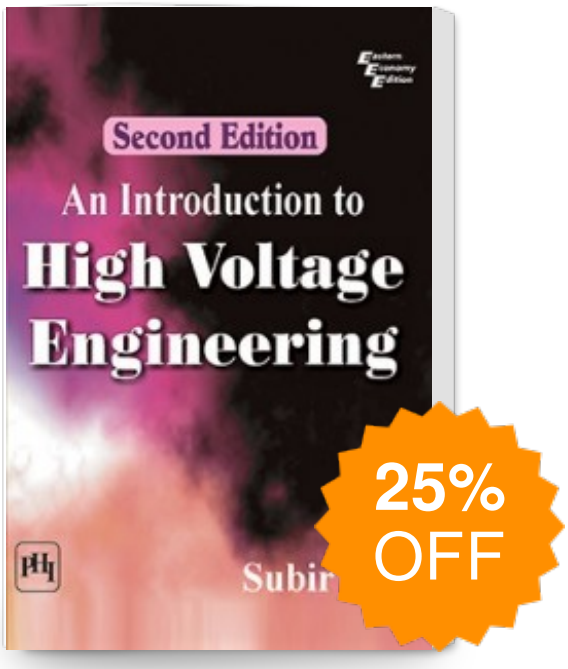

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Dear Readers, Welcome to High Voltage Engineering multiple choice questions and answers with explanation. These objective type High Voltage Engineering questions are very important for campus placement test, semester exams, job interviews and competitive exams like GATE, IES, PSU, NET/SET/JRF, UPSC and diploma. Specially developed for the Electrical Engineering freshers and professionals, these model questions are asked in the online technical test and interview of many companies. Introduction High voltage engineering has very wide range of application in many areas of modern industry. High voltage engineering occupies an important place in power engineering development all over the World. Problem of sta-ble work supply of any electric energy system is solved by means of high voltage technology using: reliable external and internal insulation perfor-mance 6 High Voltage Engineering: Fundamentals. to several tens of microseconds and then slowly decreasing to zero. The stan-dard impulse voltage has been accepted as an aperiodic impulse that reaches its peak value in 1.2 Âµsec and then decreases slowly (in about 50 Âµsec) to half its peak value.