ELECTRIC SAFETY

Practice and Standards



Mohamed El-Sharkawi

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This textbook is dedicated to my wife, Fatma, and my sons, Adam and Tamer.
The book is also dedicated to linemen heroes who undertake
dangerous jobs to keep our light shining.

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Preface

Electricity is one of the best forms of energy known to man; it is clean, readily available, quiet, and highly reliable. Equipment powered by electricity is pollution free and is more compact than those powered by other forms of energy such as gas or oil. Because of the overwhelming advantages of electricity, it has now become widely available by just the flip of a switch.

Since the early days of the electrical revolution, electricity was recognized as hazardous to humans and animals. Today, in spite of the safety products available in the market, more than 1000 people are killed every year in the United States alone due to electric shocks and several thousands more are disabled or injured.

Performing maintenance work on an electric grid is a daring job that demands a high degree of skill and attention. It is therefore handled by highly trained linemen who deserve great appreciation for their dedication to maintain our light even under harsh and hazardous conditions.

To protect the public and workers from the hazards of electricity, several regulations and standards have been developed to address every electric safety issue known to man so far. On December 29, 1970, President Nixon signed into law the Occupational Safety and Health Act. The purpose of the legislation was to "assure so far as possible every working man and woman in the Nation safe and healthful working conditions." Before this legislation was implemented, about 15,000 job-related fatalities (not all related to electricity) were reported every year in addition to 2.5 million disabilities and 300,000 cases of illnesses.

To administer the act, the secretary of labor created a new division in the Labor Department called the Occupational Safety and Health Administration (OSHA). Its mission was to assure the safety and health of America's workers by developing and enforcing standards, providing safety training, and improving safety and health in the workplace. On May 29, 1971, the first group of standards was adopted to provide baseline for safety and health protection in American workplaces.

Today, OSHA and its state partners have over 2000 inspectors and more than 200 offices throughout the United States. In addition, it uses the service of engineers, scientists, standards writers, attorneys, and other technical and support personnel.

OSHA's Code of Federal Regulation (CFR) is a set of standards that deals with several job-related issues such as electric, mechanical, and chemical safety. The electric safety code can be found in OSHA's standard 29 CFR 1910 in sections such as 1910-137, 1910-269, and 1910-302.

The Institute of Electrical and Electronic Engineers (IEEE) has several working groups and standard committees devoted to electric safety.

This organization has an international outlook, and its work is the collective judgment of its members. It is therefore considered the source of all standards worldwide. As a matter of fact, OSHA rules, in most cases, are direct extractions from IEEE standards.

Based on my experience as a safety consultant and expert witness, I find that electric safety at worksites is often left to field workers whose experience is transferred from one generation to the next. Furthermore, the safety procedures are often based on having workers memorize a set of rules. Logical explanation of these rules may not be provided to field workers or be fully understood by them. When a rule is forgotten or incorrectly extrapolated, hazardous conditions occur at the worksite. To address this problem, electrical engineers must acquire more knowledge in the area of electric safety and must be able to enhance the training modality of field workers and to communicate instructions clearly to them. This cognitive learning will certainly improve the safety at worksites. However, unfortunately, most power engineers are not familiar with the electric safety practices governing site works.

The goal of this book is to provide electrical power engineers with the knowledge and analysis they need to be well versed in electric safety and to effectively transfer their skills to the relevant workers in their organizations. This book is very practical and can be used as a textbook worldwide, since electric safety codes are very similar everywhere.

Chapter 1 covers the fundamentals of electric circuits as well as electric and magnetic fields. Chapter 2 describes the main components of substations and transmission lines. Chapter 3 deals with the biological impact of electric current. Chapter 4 covers the ground resistance calculation and measurement. In Chapter 5, the hazards of electricity are discussed. Chapter 6 covers the induced voltage on metallic objects due to electric fields. It describes a computation method to evaluate the severity of the problem. Chapter 7 is dedicated to the impact of magnetic field on the induced voltage. De-energized line work is discussed in Chapter 8. Chapter 9 covers the energized line work, while Chapter 10 deals with arc flash. The impact of atmospheric discharge on site safety is discussed in Chapter 11. Chapter 12 is dedicated to the illusive stray voltage problem. Chapter 13 discusses the electric field profile in the right-of-way and vertical clearance of towers. Finally, Chapter 14 discusses the induced voltage in metal pipes, rail tracks, and communication cables.

Besides the engineering analysis in all the aforementioned areas, the book includes several real-life case studies. In addition, it has a number of examples to show that variations in implementing electric safety procedures can create sites with various safety levels. Each chapter has a set of exercises that reinforces the knowledge assimilated. A solution manual for the exercises is also available to instructors on request through the publisher.

Author

Mohamed A. El-Sharkawi is a fellow of IEEE. He received his PhD in electrical engineering from the University of British Columbia in 1980 and joined the University of Washington as a faculty member the same year. He is presently a professor of electrical engineering in the energy area and has previously served as the associate chair and the chairman of graduate studies and research.

Professor El-Sharkawi has also served as vice president, subcommittee chair, conference chair, and task force and working group chair of several IEEE technical societies. He is a member of the IEEE Standards Committee, a member of the editorial boards of various publications, and is the associate editor of several engineering journals. He has published over 250 papers and book chapters in his research areas and has authored two textbooks: *Fundamentals of Electric Drives* and *Electric Energy: An Introduction*. He has also authored and coauthored five research books in the area of power systems and applications.

Professor El-Sharkawi has organized and taught several international tutorials on electric safety, power systems, renewable energy, induction voltage, and intelligent systems. He holds five licensed patents in the area of renewable energy, VAR management, and minimum arc sequential circuit breaker switching. He is an expert witness and trainer in the area of electric safety.

For more information, please visit El-Sharkawi's website at http://cialab.ee.washington.edu or http://cialab.org.

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List of Acronyms

AAAC	All aluminum alloy conductors
AAC	All aluminum conductors
AACSR	Aluminum alloy conductor steel reinforced
AC or ac	Alternating current
ACAR	Aluminum conductor alloy reinforced
ACGIH	American Conference of Governmental Industrial Hygienists
ACSR	Aluminum conductors steel reinforced
AS	Automatic sectionalizer
AV	Artificial ventilation
CB	Circuit breaker
CFR	Code of Federal Regulations
CGS	Centimeter–gram–second
CPR	Cardiopulmonary resuscitation
CT	Current transformer
CVT	Capacitor voltage transformer
DC or dc	Direct current
DoD	Department of Defence
DS	Disconnecting switch
EC	Electrical component
EF	Electric field
EFSP	Electric field strength profile
EGC	Equipment grounding conductor
EMF	Electromagnetic field
EPA	Environmental Protection Agency
EPS	Equipotential surface
FR	Flame resistant
GFCI	Ground fault circuit interrupter
GMR	Geometric mean radius
GPR	Ground potential rise
HV	High voltage
IAD	Insulating aerial device
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
IPE	Isolating protective equipment
INT	Isolated neutral transformer
LAB	Limited approach boundary
LIM	Line isolation monitor
LRT	Light rail traction
MAD	Minimum approach distance
MCC	Motor Control Center

MF	Magnetic field
MNC	Maximum nonfibrillation current
MOV	Metal oxide varistor
MVC	Minimum vertical clearance
NASA	National Aeronautics and Space Administration
NEC	National Electrical Code
NERC	North American Electric Reliability Council
NESC	National Electrical Safety Code
NEV	Neutral to earth voltage
NFPA	National Fire Protection Association
NFRS	Negative floating return system
NOx	Nitrogen oxide
OCPL	Overhead contact power line
OHGW	Overhead ground wire
OSHA	Occupational Safety and Health
PAB	Prohibited approach boundary
PCR	Pipelines, railroads, and communication
PE	Potential energy
PG	Protective ground or temporary ground
PPE	Personal protective equipment
PSC	Public Service Commission
PT	Potential transformer
R	Recloser
RAB	Restricted approach boundary
RH	Reference height
RMS or rms	Root mean squares
ROW	Right of Way
SF6	Sulfur hexafluoride
STATCOM	Static compensator
TASER	Thomas A Swifts Electronic Rifle
TCR	Thyristor-controlled reactor
TES	Traction electrification system
TL	Transmission line
TPS	Traction power substation
TSC	Thyristor-switched capacitor
TW	Trapezoidal wire
USDA	US Department of Agriculture
VD	Voltage divider
VF	Ventricular fibrillation
WHO	World Health Organization
xfm	Transformer

Disclaimer

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