Presents

Practical Power Systems Protection for Engineers and Technicians

Revision 8.1

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Acknowledgements
IDC Technologies expresses its sincere thanks to all those engineers and technicians on our training workshops who freely made available their expertise in preparing this manual.
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IDC Technologies is a specialist in the field of industrial communications, telecommunications, automation and control and has been providing high quality training for more than six years on an international basis from offices around the world.

IDC consists of an enthusiastic team of professional engineers and support staff who are committed to providing the highest quality in their consulting and training services.

The Benefits to you of Technical Training Today
The technological world today presents tremendous challenges to engineers, scientists and technicians in keeping up to date and taking advantage of the latest developments in the key technology areas.

- The immediate benefits of attending IDC workshops are:
- Gain practical hands-on experience
- Enhance your expertise and credibility
- Save $$$s for your company
- Obtain state of the art knowledge for your company
- Learn new approaches to troubleshooting
- Improve your future career prospects

The IDC Approach to Training
All workshops have been carefully structured to ensure that attendees gain maximum benefits. A combination of carefully designed training software, hardware and well written documentation, together with multimedia techniques ensure that the workshops are presented in an interesting, stimulating and logical fashion.

IDC has structured a number of workshops to cover the major areas of technology. These courses are presented by instructors who are experts in their fields, and have been attended by thousands of engineers, technicians and scientists world-wide (over 11,000 in the past two years), who have given excellent reviews. The IDC team of professional engineers is constantly reviewing the courses and talking to industry leaders in these fields, thus keeping the workshops topical and up to date.
Technical Training Workshops

IDC is continually developing high quality state of the art workshops aimed at assisting engineers, technicians and scientists. Current workshops include:

**Instrumentation & Control**
- Practical Automation and Process Control using PLC’s
- Practical Data Acquisition using Personal Computers and Standalone Systems
- Practical On-line Analytical Instrumentation for Engineers and Technicians
- Practical Flow Measurement for Engineers and Technicians
- Practical Intrinsic Safety for Engineers and Technicians
- Practical Safety Instrumentation and Shut-down Systems for Industry
- Practical Process Control for Engineers and Technicians
- Practical Programming for Industrial Control – using (IEC 1131-3; OPC)
- Practical SCADA Systems for Industry
- Practical Boiler Control and Instrumentation for Engineers and Technicians
- Practical Process Instrumentation for Engineers and Technicians
- Practical Motion Control for Engineers and Technicians
- Practical Communications, SCADA & PLC’s for Managers

**Communications**
- Practical Data Communications for Engineers and Technicians
- Practical Essentials of SNMP Network Management
- Practical Field Bus and Device Networks for Engineers and Technicians
- Practical Industrial Communication Protocols
- Practical Fibre Optics for Engineers and Technicians
- Practical Industrial Networking for Engineers and Technicians
- Practical TCP/IP & Ethernet Networking for Industry
- Practical Telecommunications for Engineers and Technicians
- Practical Radio & Telemetry Systems for Industry
- Practical Local Area Networks for Engineers and Technicians
- Practical Mobile Radio Systems for Industry
Electrical
- Practical Power Systems Protection for Engineers and Technicians
- Practical High Voltage Safety Operating Procedures for Engineers & Technicians
- Practical Solutions to Power Quality Problems for Engineers and Technicians
- Practical Communications and Automation for Electrical Networks
- Practical Power Distribution
- Practical Variable Speed Drives for Instrumentation and Control Systems

Project & Financial Management
- Practical Project Management for Engineers and Technicians
- Practical Financial Management and Project Investment Analysis
- How to Manage Consultants

Mechanical Engineering
- Practical Boiler Plant Operation and Management for Engineers and Technicians
- Practical Centrifugal Pumps – Efficient use for Safety & Reliability

Electronics
- Practical Digital Signal Processing Systems for Engineers and Technicians
- Practical Industrial Electronics Workshop
- Practical Image Processing and Applications
- Practical EMC and EMI Control for Engineers and Technicians

Information Technology
- Personal Computer & Network Security (Protect from Hackers, Crackers & Viruses)
- Practical Guide to MCSE Certification
- Practical Application Development for Web Based SCADA
Comprehensive Training Materials

Workshop Documentation
All IDC workshops are fully documented with complete reference materials including comprehensive manuals and practical reference guides.

Software
Relevant software is supplied with most workshops. The software consists of demonstration programs which illustrate the basic theory as well as the more difficult concepts of the workshop.

Hands-On Approach to Training
The IDC engineers have developed the workshops based on the practical consulting expertise that has been built up over the years in various specialist areas. The objective of training today is to gain knowledge and experience in the latest developments in technology through cost effective methods. The investment in training made by companies and individuals is growing each year as the need to keep topical and up to date in the industry which they are operating is recognized. As a result, the IDC instructors place particular emphasis on the practical hands-on aspect of the workshops presented.

On-Site Workshops
In addition to the quality of workshops which IDC presents on a world-wide basis, all IDC courses are also available for on-site (in-house) presentation at our clients’ premises. On-site training is a cost effective method of training for companies with many delegates to train in a particular area. Organizations can save valuable training $$$’s by holding courses on-site, where costs are significantly less. Other benefits are IDC’s ability to focus on particular systems and equipment so that attendees obtain only the greatest benefits from the training.

All on-site workshops are tailored to meet with clients training requirements and courses can be presented at beginners, intermediate or advanced levels based on the knowledge and experience of delegates in attendance. Specific areas of interest to the client can also be covered in more detail. Our external workshops are planned well in advance and you should contact us as early as possible if you require on-site/customized training. While we will always endeavor to meet your timetable preferences, two to three month’s notice is preferable in order to successfully fulfil your requirements. Please don’t hesitate to contact us if you would like to discuss your training needs.
Customized Training
In addition to standard on-site training, IDC specializes in customized courses to meet client training specifications. IDC has the necessary engineering and training expertise and resources to work closely with clients in preparing and presenting specialized courses.

These courses may comprise a combination of all IDC courses along with additional topics and subjects that are required. The benefits to companies in using training are reflected in the increased efficiency of their operations and equipment.

Training Contracts
IDC also specializes in establishing training contracts with companies who require ongoing training for their employees. These contracts can be established over a given period of time and special fees are negotiated with clients based on their requirements. Where possible, IDC will also adapt courses to satisfy your training budget.

References from various international companies to whom IDC is contracted to provide on-going technical training are available on request.

Some of the thousands of Companies worldwide that have supported and benefited from IDC workshops are:
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Preface

This book has been designed to give plant operators, electricians, field technicians and engineers a better appreciation of the role played by power system protection systems. An understanding of power systems, along with correct management, will increase your plant efficiency and performance as well as increasing safety for all concerned. The book is designed to provide an excellent understanding on both a theoretical and practical level.

The book starts at a basic level, to ensure that you have a solid understanding of the fundamental concepts and also to refresh the more experienced readers in the essentials. The book then moves onto more detailed applications. It is most definitely not an advanced treatment of the topic and it is hoped the expert will forgive the simplifications that have been made to the material in order to get the concepts across in a practical useful manner.

The book features an introduction covering the need for protection, fault types and their effects, simple calculations of short circuit currents and system grounding. The book also refers to some practical work, such as simple fault calculations, relay settings and the checking of a current transformer magnetisation curve which are performed in the associated training workshop. You should be able to do these exercises and tasks yourself without too much difficulty based on the material covered in the book.

This is an intermediate level book – at the end of the book you will have an excellent knowledge of the principles of protection. You will also have a better understanding of the possible problems likely to arise and know where to look for answers.

In addition you are introduced to the most interesting and “fun” part of electrical engineering to make your job more rewarding. Even those who claim to be protection experts have admitted to improving their knowledge after studying this book; but this book will perhaps be an easy refresher on the topic enabling you to pass on knowledge to your less experienced colleagues.

We would hope that you will gain the following from this book:
• The fundamentals of electrical power protection and applications
• Knowledge of the different fault types
• The ability to perform simple fault and design calculations
• Practical knowledge of protection system components
• Knowledge of how to perform simple relay settings
• Increased job satisfaction through informed decision making
• Know how to improve the safety of your site
Typical people who will find this book useful include:

- Electrical Engineers
- Project Engineers
- Design Engineers
- Instrumentation and Engineers
- Electrical Technicians
- Field Technicians
- Electricians
- Plant Operators
- Plant Operators

You should have a modicum of electrical knowledge and some exposure to electrical protection systems to derive maximum benefit from this book.

This book was put together by a few authors although initiated by the late Les Hewitson, who must be one of the finest instructors on the subject who presented this course in his own right in South Africa and throughout Europe/North America and Australia for IDC Technologies. It is to him that this book is dedicated.

**Hambani Kahle (Zulu Farewell)**

*Sources: Canciones de Nuestra Cabana (1980), Tent and Trail Songs (American Camping Association), Songs to Sing & Sing Again by Shelley Gordon*

Go well and safely.
Go well and safely.
Go well and safely.
The Lord be ever with you.

Stay well and safely.
Stay well and safely.
Stay well and safely.
The Lord be ever with you.

Hambani kahle.
Hambani kahle.
Hambani kahle.
The Lord be ever with you.

Steve Mackay
Series Editor FIE (Aust), CPEng, BSc(ElecEng), BSc(Hons), MBA
1

Need for protection

Important notes

1. This book was originally written for UK and other European users and contains many references to the products and standards in those countries. We have made an effort to include IEEE/ANSI/NEMA references wherever possible. The general protection approach and theoretical principles are however universally applicable.

2. The terms ‘earth’ as well as ‘ground’ have both been in general use to describe the common power/signal reference point interchangeably around the world in the Electro-technical terminology. While the USA and other North American countries favor the use of the term ‘ground’, European countries including UK and many other Eastern countries prefer the term ‘earth’. In this book, we will adopt the term ‘ground’ to denote the common electrical reference point. Our sincere apologies to those readers who would have preferred the use of ‘earth’ to the term ‘ground’.

1.1 Need for protective apparatus

A power system must be not only capable of meeting the present load but also requires the flexibility to meet the future demand. A power system is designed to generate electric power in sufficient quantity, to meet the present and estimated future demands of the users in a particular area, to transmit it to the areas where it will be used and then distribute it within that area, on a continuous basis.

To ensure the maximum return on the significant investment in the equipment, which goes to make up the power system, and to keep the users satisfied with reliable service, the whole system must be kept in operation continuously without major breakdowns.

This can be achieved in two ways:

- The first option is to implement a system using components, which should not fail and which require minimal maintenance to maintain the continuity of service. However, implementing such a system is neither economical nor feasible, except for small systems.
• The second option is to anticipate any possible effects or failures that may cause a long-term shutdown of a system, which in turn may take a longer time to bring the system back to its normal operation. The main idea is to restrict the disturbances during such failures to a limited area and maintain power distribution to the remaining areas. Special equipment is normally installed to detect such kind of failures (also called ‘faults’) that can possibly happen in various sections of a system, and to isolate faulty sections so that the interruption is limited to a localized area. The special equipment adopted to detect such possible faults is referred to as ‘Protective equipment or a protective relay’ and the system that uses such equipment is termed a ‘Protection system’.

A protective relay is the device, which gives instruction to disconnect a faulty part of the system. This action ensures that the remaining system is still fed with power, and protects the system from further damage due to the fault.

Hence, use of protective apparatus is very necessary in the electrical systems, which are expected to generate, transmit and distribute power with least interruptions and restoration time.

1.2 Basic requirements of protection

A protection system has three main functions/duties:

• Safeguard the entire system to maintain continuity of supply.
• Minimize damage and repair costs where it senses a fault.
• Ensure safety of personnel.

These requirements are necessary, firstly for early detection and localization of faults and secondly, prompt removal of faulty equipment from service.

In order to carry out the above duties, protection must have the following qualities:

a) Selectivity: To detect and isolate the faulty item only.
b) Stability: To leave all healthy circuits intact to ensure continuity of supply.
c) Sensitivity: To detect even the smallest fault, current or system abnormalities and operate correctly at its setting before the fault causes irreparable damage.
d) Speed: To operate speedily when it is called upon to do so, thereby minimizing damage to the surroundings and ensuring safety to personnel.

To meet all of the above requirements, protection must be reliable which means it must be:

• Dependable - it must trip when called upon to do so.
• Secure - it must not trip when it is not supposed to.

1.3 Basic components of protection

The protection of any distribution system is a function of many elements and this section gives a brief outline of the various components that go into protecting a system. The following are the main components of a protection system.
Need for protection

• A fuse self destructs and carries the currents in a power circuit continuously and sacrifices itself by blowing under abnormal conditions. These are normally independent OR stand-alone protective components in an electrical system unlike a circuit breaker, which necessarily requires the support of external components.

• Accurate protection cannot be achieved without properly measuring the normal and abnormal conditions of a system. In electrical systems, voltage and current measurements give feedback on whether a system is healthy or not. Voltage transformers and current transformers measure these basic parameters and are capable of providing accurate measurement during fault conditions without failure.

• The measured values are converted into analog and/or digital signals and are made to operate the relays, which in turn isolate the circuits by opening the faulty circuits. In most of the cases, the relays provide two functions viz., alarm and trip; once the abnormality is noticed. The relays in earlier times had very limited functions and were quite bulky. However, with the advancement in digital technology and use of microprocessors, relays monitor various parameters, which give a complete history of a system during both pre-fault and post-fault conditions.

• The opening of faulty circuits requires some time, typically milliseconds. However, the circuit breakers, which are used to isolate the faulty circuits, are capable of carrying these fault currents until the fault currents are totally cleared. The circuit breakers are the main isolating devices in a distribution system, which can be said to directly protect the system.

• The operation of relays and breakers require power sources, which shall not be affected by faults in the main distribution. Hence, the other component, which is vital in protective system, are batteries that are used to ensure uninterrupted power to relays and breaker coils.

The above items are extensively used in any protective system and their design requires careful study and selection for proper operation.

1.4 Summary

<table>
<thead>
<tr>
<th>Power system protection-main functions</th>
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<tbody>
<tr>
<td>1. To safeguard the entire system to maintain continuity of supply.</td>
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<tr>
<td>2. To minimize damage and repair costs.</td>
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<tr>
<td>3. To ensure safety of personnel.</td>
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<table>
<thead>
<tr>
<th>Power system protection-basic requirements</th>
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</thead>
<tbody>
<tr>
<td>1. Selectivity: To detect and isolate the faulty item only.</td>
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<tr>
<td>2. Stability: To leave all healthy circuits intact to ensure continuity of supply.</td>
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<tr>
<td>3. Speed: To operate as fast as possible when called upon, to minimize damage, production downtime and ensure safety to personnel.</td>
</tr>
<tr>
<td>4. Sensitivity: To detect even the smallest fault, current or system abnormalities and operate correctly at its setting.</td>
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</tbody>
</table>
Power system protection-speed is vital!!

The protective system should act fast to isolate faulty sections to prevent:

- Increased damage at fault location. Fault energy = $I^2 \times R_f \times t$, where $t$ is time in seconds.
- Danger to the operating personnel (flashes due to high fault energy sustaining for a long time).
- Danger of igniting combustible gas in hazardous areas, such as methane in coal mines which could cause horrendous disaster.
- Increased probability of ground faults spreading to healthy phases.
- Higher mechanical and thermal stressing of all items of plant carrying the fault current, particularly transformers whose windings suffer progressive and cumulative deterioration because of the enormous electro-mechanical forces caused by multiphase faults proportional to the square of the fault current.
- Sustained voltage dips resulting in motor (and generator), instability leading to extensive shutdown at the plant concerned and possibly other nearby plants connected to the system.

Power system protection-qualities

<table>
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<tr>
<th>Reliability</th>
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<tr>
<td>Dependability</td>
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<tr>
<td>Security</td>
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</table>

1) **Dependability**: It MUST trip when called upon.
2) **Security**: It must NOT trip when not supposed to.

Power system protection-basic components

1. Voltage transformers and current transformers—To monitor and give accurate feedback about the healthiness of a system.
2. Relays—To convert the signals from the monitoring devices, and give instructions to open a circuit under faulty conditions or to give alarms when the equipment being protected, is approaching towards possible destruction.
3. Fuses—Self-destructing to save the downstream equipment being protected.
4. Circuit breakers—These are used to make circuits carrying enormous currents, and also to break the circuit carrying the fault currents for a few cycles based on feedback from the relays.
5. DC batteries—These give uninterrupted power source to the relays and breakers that is independent of the main power source being protected.