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Numerical Differential Protection

Principles and Applications

SIEMENS

Second Edition

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Foreword
to the First Edition

Differential protection provides absolute selectivity and fast operation, and is applied in numerous variations for the protection of electrical machines, transformers, busbars and feeders at all voltage levels.

Substantial progress has been made with numerical technology which has made this measuring principle even more attractive for the user, such as for example the integrated CT ratio adaptation and the large degree of CT saturation tolerance. The application of digital data exchange over interference free fiber optic cables has simplified the protection of cables and overhead lines in urban and industrial networks substantially, while also improving the security. Digital communication networks are finding increasing application for the transfer of protection data in overhead line networks. Thereby, the differential protection may also be applied on longer lines well exceeding 100 km as well as complex system configurations with multiple line terminals.

The book at hand initially conveys the basic principles of differential protection with analogy and digital technology. Special note will be taken of current transformers, data transfer and digital communication. Subsequently the various types of differential protection and the practical applications will be covered, using the Siemens SIPROTEC product range. In principle, the explanations however also apply to the devices of other manufacturers. Practical examples are calculated for illustration purposes.

This book is aimed at students and young engineers, who require an introduction to the topic of differential protection. However, users with practical experience, seeking an entry to digital technology of differential protection may also find this book to be a useful addition to their library. Furthermore, it may also be used as a reference for special application problems.

Nuremberg, March 2005 Gerhard Ziegler

Foreword
to the Second Edition

Differential protection is a fast and selective method of protection against short-circuits. It is applied in many variants for electrical machines, transformers, busbars, and electric lines.

Initially this book covers the theory and fundamentals of analog and digital differential protection. Current transformers are treated in detail including transient behaviour, impact on protection performance, and practical dimensioning. An extended chapter is dedicated to signal transmission for line protection in particular to modern digital communication and GPS timing.

The emphasis is then placed on the different variants of differential protection and their practical application illustrated by concrete examples. This is completed by recommendations for commissioning, testing and maintenance.

Finally the design and management of modern differential protection is explained by means of the latest Siemens SIPROTEC relay series.

A textbook and standard work in one, this book covers all topics which have to be paid attention to for planning, designing, configuring and applying differential protection systems. The book is aimed at students and engineers who wish to familiarise themselves with the subject of differential power protection, as well as the experienced user, entering the area of digital differential protection. Furthermore it serves as a reference guide for solving application problems.

For this second edition all contents have been revised, extended and updated to the latest state of protective relaying.

Nuremberg, August 2011 Gerhard Ziegler

Contents

1 Introduction

Differential protection was already applied towards the end of the 19th century, and was one of the first protection systems ever used.

Faults are detected by comparison of the currents flowing into and out of the protected plant item. As a result of the fast tripping with absolute selectivity it is suited as main protection of all important items of plant, i.e. generators, transformers, busbars as well as cables and overhead lines.

The protected zone is clearly defined by the positioning of the current transformers. The back-up protection function for external faults must therefore always be implemented with an additional time graded protection (over-current or distance protection).[1]

1.1 Protection principle

Differential protection calculates the sum of all currents flowing into and out of the protected object. Apart from magnetising currents and capacitive charging currents, this current sum must always be equal to zero (Kirchhoff's current law) if the protected object is un-faulted. Internal faults are therefore detected by the appearance of a differential current. For security against mal-operation due to CT transformation errors, the pick-up threshold of the protection is increased in proportion to the total current flow (stabilising or restraint current). Thereby, the protection sensitivity is automatically matched to the prevailing short circuit conditions.

Implementation of differential protection is simpler in the case of protected objects that are not geographically spread out (generators, transformers, busbars), where the current transformers are situated close together. In this case, the current transformers may be connected to the protection device directly via control cables.

In the case of HV cables and overhead lines, the measured currents must be transmitted over large distances to the corresponding opposite line end, for the comparison to take place. Utilising pilot wire connections (special protection cables), distances of approximately 25 km may be spanned. With modern relays, using digital communication via fiber optic cables, differential protection may also be implemented on long overhead lines of over 100 km.

[1] In most cases simple back-up protection is integrated in numerical devices, so that a separate device is not necessary for applications in distribution networks. A back-up protection for faults on the protected object must always be provided by a separate device in order to achieve hardware redundancy. This is particularly true for the transmission network.

High impedance differential protection is a particular variant of differential protection. It is adapted to the non-linear transformation characteristic of current transformers and achieves stability during CT saturation by means of a high series resistance at the differential relay.

Due to its simplicity, high impedance differential protection is relatively common in Anglo-Saxon influenced countries. It is suitable for protection of galvanically connected units such as busbars, generators, motors, compensating reactors and auto- transformers, but not for normal transformers with separate windings. A disadvantage lies in the fact that all current transformers must be identical.

1.2 Numerical differential protection

Towards the end of the 1980's, the numerical technology was introduced to protection applications. [1-1]

A number of general advantages are:

- Modern relays are multi-functional and, apart from the protection functions, capable of executing additional tasks such as operational measurement and disturbance recording.
- Due to integrated self-monitoring, event driven maintenance, instead of costly preventive routine maintenance may be applied.
- Devices may be operated locally and from remote with a PC via serial interface.
- All important measured values are indicated with the integrated measuring function. External measuring instruments during commissioning and testing are therefore not normally required.

Particular advantages are also obtained specifically for differential protection:

- Digital measuring techniques have substantially improved filters for the in-rush stabilisation and intelligent measuring algorithms provide additional stabilisation during CT saturation.
- With conventional devices, additional matching transformers were required to adapt different CT ratios and transformer vector groups. Numerical relays implement this adaptation internally by computation.
- Phase segregated measurement can be implemented with moderate effort and therefore achieves the same pick-up sensitivity for all fault types as well as reliable pick-up in the event of multiple faults.
- Communication links are also covered by the continuous self-monitoring.
- Decentralised construction of the busbar protection with communication via fiber optic cables and PC-based configuration achieved a significant reduction in complexity.

2 Definitions

The following terms are used in this document.

If they correspond to the definitions of the International Electrotechnical Vocabulary Chapter 448: Power System Protection (IEC 60050-448), then the corresponding reference number is given:

Protection (in USA: Relaying)
The provisions for detecting faults or other abnormal conditions in a power system, for enabling fault clearance, for terminating abnormal conditions, and for initiating signals or indications. [448-11-01]

Protection relay (in USA: protective relay)
Measuring relay that, either solely, or in combination with other relays, is a constituent of a protection equipment. [448-11-02]

Protection equipment (in USA relay system)
An equipment incorporating one or more protection relays and, if necessary, logic elements intended to perform one or more specified protection functions. [448-11-03]

Protection system
An arrangement of one or more protection equipments, and other devices intended to perform one or more specified protection functions. [448-11-04]

NOTE 1: A protection system includes one or more protection equipments, instrument transformer(s), wiring, tripping circuit(s) and, where provided, communication system(s). Depending on the principle(s) of the protection system, it may include one end or all ends of the protected section and, possibly, automatic reclosing equipment.

NOTE 2: The circuit breaker(s) are excluded.

Protected section
That part of the system network, or circuit within a network, to which specified protection has been applied. [448-11-05]

Digital (Numerical) protection (relay)
Fully digital relays utilising microprocessor technology with analog to digital conversion of the measured values (current and voltage) and subsequent numerical processing by computer programs. Earlier the designation “computer relay” has been used.

In Europe, it has sometimes been distinguished between “digital” and “numerical” relays. The term “digital” has been used with the earlier relay generation using micro-processors instead of discrete static measuring and logic circuits. The term “numerical” has been reserved for the modern computer type relays. [A-15]

In the US, the term “digital” has always been used in this meaning of “numerical” protection.

Nowadays, both terms are used in parallel.

Unit protection
A protection whose operation and section selectivity are dependent on the comparison of electrical quantities at each end of the protected section.

NOTE: In the USA, the term “unit protection” designates the protection provided for an electrical generator.

Longitudinal differential protection (generally designated as differential protection)
Protection, the operation and selectivity of which depends on the comparison of the magnitude or the phase and magnitude of the currents at the ends of the protected section. [448-14-16]

Transverse differential protection
Protection applied to parallel connected circuits and in which operation depends on unbalanced distribution of currents between them. [448-14-17]

Biased (stabilised) differential protection (in USA: percentage differential relay)
Differential protection, with a pick-up threshold that increases proportional to the increasing through current (sum of the absolute values of the currents from all the line ends).

Operating (tripping) current (of a differential relay)
Current difference that tends to initiate operation (in general tripping).

Restraint (stabilising) current (of a differential relay)
Current proportional to through current that tends to inhibit differential relay operation.

Variable slope characteristic
Operating characteristic of a differential relay with an increasing slope (percentage) dependent on increasing restraint current.

High impedance differential protection
Current differential protection using a current differential relay whose impedance is high compared with the impedance of the secondary circuit of a saturated CT. [448-14-22]

Low impedance differential protection (generally designated differential protection)

Current differential protection using a current differential relay whose impedance is not high compared with the impedance of the secondary of a saturated CT. [448-14-23]

Phase comparison protection

Protection whose operation and selectivity depends on the comparison of the phase of the currents at each end of the protected section. [448-14-18]

Discriminative zone

The selective part of a multi-zone busbar protection, generally supervising current flow into and out of a single section of busbar. [448-14-24]

Check zone

The non-selective part of a multi-zone busbar protection, generally supervising current flow at the complete station. [448-14-25]

NOTE: Tripping of the busbar protection is conditional on the operation of both the check and a discriminating zone.

Restricted earth fault protection (in USA: ground differential protection)

Protection, in which the residual current from a set of three-phase current transformers is balanced against the residual output from a similar set of current transformers located on the earthing connection, if any, of a neutral point. [448-14-29]

NOTE: This term is also used when the neutral of the protected plant is unearthed i.e. neither a second set of three-phase current transformers nor a CT in the neutral connection is needed to restrict the protected section.

Partial Differential Protection

Protection circuit which is often used in regions with Anglo-Saxon history. It is applied to busbars with bus section coupler and parallel in-feed. Current relays are connected to measure the differential current between the in-feed and the section coupler. One time grading step can be saved in the grading of the overcurrent relays. (see section 3.5)

Pilot wire protection

Protection associated with telecommunication using metallic wires. [448-15-04]

Short circuit loop (fault loop)

The circuit path in the energy system to and from the fault location as seen from the source.

Short circuit (fault) impedance

The impedance at the point of fault between the faulted phase conductor and earth (ground) or between the faulted phase conductors themselves. [448-14-11]