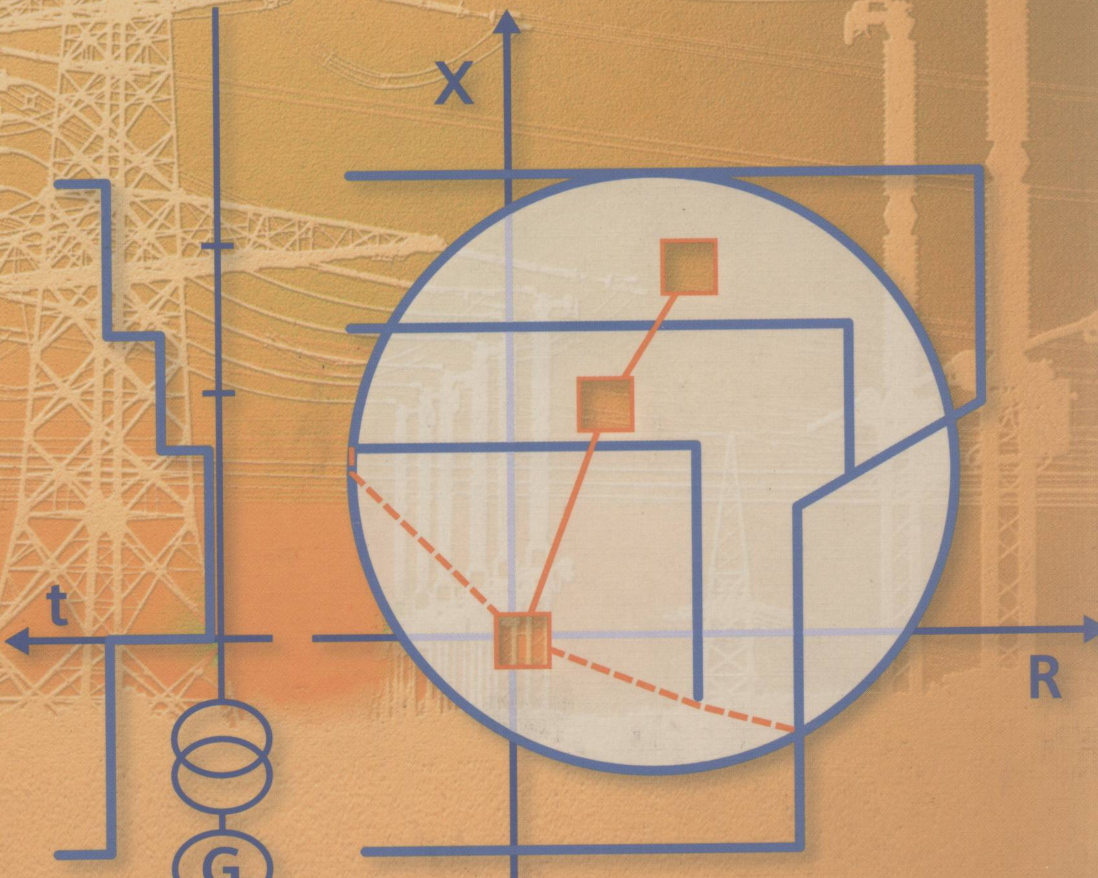
Gerhard Ziegler

Numerical Distance Protection

Principles and Applications

SIEMENS



Third Edition

Ziegler Numerical Distance Protection

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He was active in the areas of product support, application and project planning, marketing and sales, on a world-wide basis. He retired in 2002 but continues to work as consultant. G. Ziegler has published numerous national and international contributions in the area of power system protection. He served in international organisations for many years.

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Preface

to the First Edition

Distance protection provides short-circuit protection for universal application. It provides the basis for network protection in transmission systems and meshed distribution systems. While classic distance protection, based on electro-mechanical or static technology, are still in wide use, the state of the art today are multi-functional micro-processor devices. They communicate with centralised control systems and may be operated with personal computers locally or from remote. The basic operating principles of distance protection also apply to the new technology. Numerical signal processing, and intelligent evaluation algorithms facilitate measuring techniques with increased accuracy and protection functions with improved selectivity. The large degree of functional integration along with continuous self-monitoring results in the space-saving protection concepts, as well as economical maintenance strategies.

The book at hand initially covers the general principles of distance protection, thereby addressing the particular influence of numerical technology. The emphasis is placed on the practical application of numerical distance relays in power systems. The behaviour of the distance protection during varying fault and system conditions is extensively analysed. Procedures and equations for practical application are derived.

As the device design is manufacturer-specific, and subject to relatively rapid change, particular device configurations are only addressed in-so-far as this is necessary for general understanding. The Siemens device range 7SA is used as an illustrative example. The general statements however also apply to other manufacturers. Furthermore, reference is made to the documentation provided by the manufacturers.

Finally, the current practice in relation to distance protection application in utility and industrial systems is described. The choice of topics and examples is based on the authors extensive experience in the area of power system protection. The queries and problems experienced by users have therefore directly or indirectly contributed to this book.

This books is aimed at students and young engineers who wish to familiarise themselves with the subject of distance protection and its application as well as the experienced user, entering the area of numerical distance protection. Furthermore it serves as a reference guide for solving particular application problems.

Nuremberg, July 1999 Gerhard Ziegler

Preface

to the third edition

The second edition of this book was sold out within only two years. This confirms that the book is very well accepted in the relay community as a reference for studies and as application guide.

With this new edition further calculation examples have been included for a better understanding of the partly complex matter. The appendix has been extended by some useful reference material. It includes a section about the fundamentals of calculation with phasors and complex numbers. A further section is dedicated to the basics of symmetrical component analysis. Finally a collection of formulas for determination of line constants has been added.

The author hopes that this book will continue to be used world-wide by beginning and experienced protection engineers as well as students interested in the art and science of protective relaying.

Nuremberg, January 2008 Gerhard Ziegler

Contents

1 Introduction

Distance protection is a universal short- circuit protection.

It's mode of operation is based on the measurement and evaluation of the short- circuit impedance, which in the classic case is proportional to the distance to the fault.

Area of application

Distance protection forms the basis for network protection in transmission, as well as interconnected distribution networks.

Thereby it acts as the main protection for overhead lines and cables and in addition functions as backup protection for adjoining parts of the network, such as busbars, transformers and further feeders.

Distance protection is faster and more selective than overcurrent protection. It is also less susceptible to changes in the relative source impedances and system conditions.

A further advantage of numerical distance protection is the integrated fault location function.

Therefore it is also applied in radial networks.

Its tripping time is approximately one to two cycles (20 to 40 ms at 50 Hz) in the first zone for faults within the first 80 to 90% of the line length. In the second zone, for faults on the last 10 to 20% of the protected feeder, the tripping time is approximately 300 to 400 ms. Further zones acting as remote backup protection accordingly follow with longer set grading times.

With a communication channel between the two line-ends (pilot wire, power line carrier, radio link or optical fibre) the distance protection can be upgraded to a comparison protection scheme with absolute selectivity. It then facilitates fast tripping of short circuits on 100% of the line length similar to a differential protection scheme, whilst in addition providing remote backup protection for adjoining parts of the network.

The distance protection communication only requires a narrow band width channel, as no measured values, but only "GO/NO GO" signals are transmitted. These distance protection schemes with signal transmission appear in various forms, particularly in HV and EHV networks.

Finally the distance protection is also applied as backup protection for large generator and transformer blocks, where high pick-up sensitivity along with short tripping times are required.

Technical advances

In 1920 distance protection was introduced and it has since then undergone continuous development – from induction disk measuring elements to moving coil technology, and further to analogue static relays with operational amplifiers. Hereby the accuracy and selectivity were approved upon substantially. The tripping time was also improved by a factor ten, from the original several hundred to the present few tens of milliseconds. A quantum leap in the development of distance protection was achieved roundabout 1985, when microprocessor technology was introduced: [1.1-1.4]

The numerical devices are intelligent. They can store information and communicate with peripherals. These capabilities introduce fundamentally new concepts for the improvement of protection quality. For the application and management of protection fundamentally new aspects result. At the same time the further developments of distance protection correspond to the higher demands on protection systems, resulting from the growing complexity of the transmission and distribution networks and the increased utilisation of the plant.

Numerical distance protection

The discreet signal processing and the numerical mode of measurement allows a higher accuracy and shorter tripping times with exact filter algorithms and the application of adaptive processes. Intelligent evaluation routines furthermore allow improved selectivity, even during complex fault situations. Over and above this the cost/performance ratio was dramatically improved: [1.5-1.8]

The modern devices are multifunctional and thereby can implement the protection functions as well as additional functions for other tasks such as e.g. operational measurements and disturbance recordings. Only one device for main and one device for backup protection (when applied) is therefore required at each line end. By means of the integrated self monitoring the transition from the expensive preventive maintenance to the more cost effective condition based maintenance and testing is achieved.

The numerical devices also allow for the operation with PC or the integration into network control systems, via serial interfaces. Thereby several new aspects arise for the configuration, installation, commissioning and maintenance.

2 Definitions

In this document the following terminology is used.

Where the definitions correspond to IEC60050-448: "International Electro-technical Vocabulary – Chapter 448: Power System Protection", the relevant reference number is indicated: [2.1]

Distance protection

A non-unit protection whose operation and selectivity depend on local measurement of electrical quantities from which the equivalent to the fault is evaluated by comparing with zone settings. [448-14-01]

Static relay (protection)

Analogue electronic relay generation using transistors, operational amplifiers and logic gates. In the US called solid-sate relay (protection).

Numerical distance protection (relay)

Fully digital distance protection utilising microprocessor technology with analogue to digital conversion of the measured values (current and voltage), computed (numerical) distance determination and digital processing logic. Sometimes the designation computer relay has also been used.

The term "digital distance relay" was originally used to designate a previous generation relay with analogue measurement circuits and digital coincidence time measurement (angle measurement), using microprocessors.

In the US, the term "digital distance protection" has always been used in the meaning of numerical protection.

Nowadays, both terms are used in parallel.

Digital distance protection

See "numerical distance protection".

Distance zones

The reaches of the measuring elements of distance protection, in a power system. [448-14-02].

Under- and/or overreach

Mode of operation of the distance protection where the fastest zone is set with a reach which is shorter (underreach), or longer (overreach) than the protected zone. [448-14-05/07]

Zone limit (cut-off distance, balance point, set point)

Measured impedance corresponding to the zone end.

Transient overreach

Operation of a distance zone for a larger value of impedance than that for which it is adjusted to operate under steady state condition. [15] This tendency occurs with offset of the short circuit current initially after fault inception. Conventional relays used a "line replica" shunt in the current path to minimise this effect. Numerical relays avoid the overreach by digital filtering of the DC component and adaptive control of the zone reach.

Impedance characteristic (relay)

Distance zone characteristic with constant impedance reach (Circle in the impedance plane centred at the origin of the R-X diagram). When used as directional zone, a directional characteristic (e.g. straight line) must be added

When the circle is shifted in the R-X diagram, we get a modified or offset impedance-type characteristic.

Impedance relay

Originally this term designated a relay with impedance circle characteristic.

Impedance however is a generic term including resistance and reactance alone or a combination of the two. In this sense, the term impedance relay is often used as generic term equivalent to distance relay.

MHO (Admittance) characteristic (relay)

Circle characteristic which passes through the origin of the R-X-diagram. It is therefore inherently directional. The name is due to the fact that the MHO circle corresponds to a straight line in the admittance (1/OHM) plain.

Polarisation

Providing a relay with directional sensitivity.

Cross polarisation

Polarisation of a relay for directionality using some portion of the healthy (unfaulted) phase voltage(s). In many cases *quadrature polarisation* is used. In this case the polarising voltage is in quadrature to the faulted phase voltage. Also the positive-sequence voltage is sometimes used for polarisation.

Polarised MHO characteristic

The traditional MHO relay with a circle passing through the origin of the R-X diagram uses the voltage of the short-circuit loop (faulted phase(s) voltage) as polarising quantity. It is more precisely called self polarised MHO relay.

The *cross polarised MHO* version adds a certain percentage of healthy phase(s) voltage to the polarising voltage to ensure unlimited direction sensitivity for close-up zero-voltage faults. In consequence, the circle extends in negative X-direction for forward faults depending on the source impedance and draws together excluding the origin in case of reverse faults. (see paragraph 3.4.2)

Reactance characteristic (relay)

Straight line characteristic parallel to the R-axis with constant X-reach.

The reach in R-direction is unlimited. The reactance characteristic must therefore be combined with a starter characteristic (e.g. MHO type)

Quadrilateral characteristic (relay)

As the name implies, the characteristic is composed of four straight lines.

Angle-impedance (OHM) characteristic

This term designates a straight line characteristic in the R-X plane which is inclined by an angle (often the line angle) against the R-axis. A pair of these straight lines is called blinder characteristic ("blinders") and is used to limit the zone reach, e.g. of a MHO relay, in positive and negative R-direction against load encroachment. (see paragraph 3.1.6)

Load blocking zone (load cut out)

A wedge shaped area which is cut out of distance zones to reduce the reach in R-direction and to allow higher loading of the relay (line). (see 6.2.3 and 6.3.2)

Loadability of distance relays

As the line load increases, the measured load impedance becomes lower and encroaches the distance zones. The load MVA at which the farthest reaching zone (starting or 3rd zone) is on the verge of operation, is called the loadability limit of the relay. (see 6.2.3)

Measuring system (measuring element)

Module for the measurement of the fault distance and direction, including starting characteristics. The inputs are the short- circuit current and voltage. An active signal appears at the output when the fault lies within the corresponding zone, i.e. when the measuring system picks up.

Conventional relays used an electro-mechanical or static measuring system. With numerical relays the measuring system is a software module for the calculation of the loop impedance and for the value comparison with the set zone characteristic.

Full scheme distance protection (non-switched)

Distance protection generally having separate measuring elements for each type of phase-to-phase fault and for each type of phase-to-earth fault and for each zone measurement. [448-14-03]

For numerical protection this implies that all ph-ph and all ph-E loop impedances are simultaneously computed and compared with the zone limits. (e.g. 7SA6 or 7SA522)

Switched distance protection

Distance protection generally having only one measurement element for all power system faults and/or for all zones. [448-14-04]

In case of numerical protection the term “switched” is not applicable as all measured values are continuously sampled and stored in a buffer. There is no HW-switching in the measuring circuits. Relays which use a fault detector controlled loop selection and only evaluate one fault loop for the distance measurement may be called “single system” distance relays. (earlier digital relay versions, e.g. 7SA511)

Switched distance protection (multiple measuring system)

Distance protection with multiple measuring systems need only simplified loop selection. Three measuring systems are normally connected in delta for phase faults and are switched to wye connection in case of single phase to earth faults. (This variant was common in Germany in electromechanical EHV protection, e.g. type R3Z27)

Protection using telecommunication

Protection requiring telecommunication between the ends of the protected section in a power system. [448-15-01] In US called *pilot protection*.

Distance protection with teleprotection channel

Distance protection requiring telecommunication between the ends of the protected section in a power system. [according to 448-15-01]