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ABB AB

KTH/EH2740 Lecture 3

Introduction to Modern Power System Protection

Digital Protective Relay

- A digital protective relay is an industrial microprocessor system operating in real time
- It measures digitally the currents and/or voltages and/or some other signals associated with a protected element
- It applies in a digital way certain operating criteria to recognize automatically and fast whether or not a protected element suffers an internal fault
- In the case of an internal fault a relay asserts a tripping signal

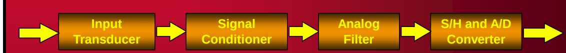
Digital Protective Relay Advantages

- Accurate measurement
- More sophisticated operating principles
- Self-monitoring and improved availability
- Better security and dependability
- Faster operation
- Communication, data storage, easy reprogramming, and other functional improvements

Major Elements of a Digital Relay

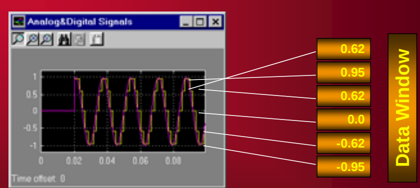
- The major functional components of a digital relay are:
  - Data Acquisition (analog filtering & sampling)
  - Measurement (phasor estimation)
  - Logic (tripping, alarming, carrier send, etc.)

Data Acquisition Block



- The front-end of a digital relay consists of four elements:
  - input transducer
  - signal conditioner
  - Analog anti-aliasing Filter (AF)
  - Analog to Digital (A/D) converter

Sampling



- Sampling - taking samples of the analog input signal (usually at regular time intervals) and representing them in the sampled form

Sampling Frequency

- The sampling theorem: *A signal to be reconstructed from its digital (sampled) form must be sampled at least twice in its period*
- A given relaying principle uses certain frequency components from its input signals. The highest frequency component determines the minimum sampling frequency
- The higher the sampling frequency, the better representation of the analog signal

Analog Filters

- AF is used to eliminate both the aliasing frequencies and the signal spectrum not utilized by the relay
- Usually a low-pass active filter of the order 2 (up to 4) with the cut-off frequency below half of the sampling rate is used
- Standard AF approximations are often used to provide optimal time and frequency responses
- AF introduces certain phase shift (time delay) between its input and output signals. This delay may slow down operation of a relay

Word Length of an A/D Converter

- an A/D converter covers certain range of the input signal ($2X_{max}$) using certain number of bits (N)
- the minimum recognizable change of the signal assumes:

$$\Delta X = 2X_{max} / 2^N$$

- for example, X_{max}=100, N = 12, ΔX=0.0488
- 12 bits are usually sufficient for the voltage channels
- 16 bits are sufficient for the current channels

Data Acquisition Conclusions

- The AF must be used to eliminate the aliasing frequencies; it may also eliminate some noise
- The sampling frequency must meet the needs of the applied relaying principle
- The word length of the A/D converter must meet the expected range of input signals

Phasor Definition

- A pure sine signal of a known frequency may be mathematically represented by two numbers: the magnitude and the phase
- The pair of the magnitude and phase is called *a phasor*
- Mathematically, a phasor is often denoted as a complex number: magnitude $\angle$ phase

Phasor Application

- Most of the contemporary digital relays are based on the classical relaying principles using phasors
- Those principles use phasors of the input signals and the relations between the phasors (such as impedance or power) to make the tripping decision
- Usually the phasors of the fundamental frequency components are used for protection

Phasor Estimation Requirements

- After a step change of a signal (due to a fault), the estimate of a phasor should reflect this change as fast as possible with the dynamic errors as small as possible
- The estimate of a phasor should not be sensitive to signal distortions such as off-nominal frequencies including the d.c. component, high-frequency noise, etc.

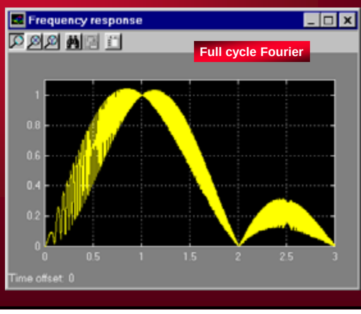
Fourier Algorithm

- Fourier algorithm is often used in today's digital relays
- Mathematically, the Fourier algorithms is a linear transformation of input signal's samples into a phasor
- In the Fourier algorithm the data window covers either a full cycle of the fundamental frequency (full-cycle algorithm) or half a cycle (half-cycle algorithm)

Fourier Algorithm Properties

- Full-cycle algorithm:
  - Response time (data window) of one full cycle
  - Not sensitive to harmonics nor to the d.c. component
- Half-cycle algorithm:
  - Response time (data window) of half of a cycle
  - Not sensitive to odd harmonics
  - Sensitive to the d.c. component and even harmonics

Frequency Response



Phasor measurement Conclusions

- There is a number of different measuring algorithms developed for power system protection
- Short-window algorithms are fast but inaccurate; long-window algorithms are more accurate but slower
- Always certain compromise between the speed and accuracy requirements must be made

Logic

- The logic block of a digital relay performs the following tasks;
  - it applies certain characteristics to the measured signals (such as zones in an impedance relay)
  - it applies certain timing functions (such as delay for the second zone trip in a distance relay)
  - it asserts the relay outputs (such as the tripping signal, alarms, carrier send signal in a distance relay, etc.)

Overcurrent Relay
An example of a digital relay

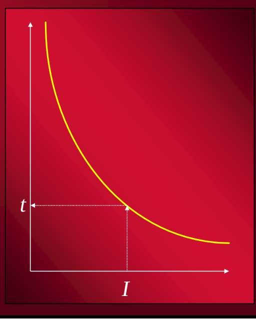
- The three major components of a digital overcurrent relay are:
  - Data Acquisition unit
  - Phasor measuring unit for estimation of the current amplitude
  - Decision making unit for implementation of a given tripping characteristic

Overcurrent Relay Design Issues

- Sampling frequency
  - rate
  - constant vs. variable
- Analog filter
  - cut-off frequency
  - order and approximation
- Vertical resolution
- Measuring algorithm
- Tripping logic

Overcurrent Relay Modes of Operation

- Instantaneous tripping
- Definite time tripping (a constant delay)
- Time dependent tripping



Overcurrent Relay Tripping Logic Issues

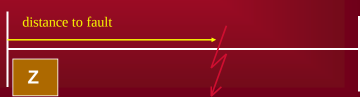
- The way of resetting
  - immediate reset
  - delayed reset
  - reversed timing when re-set
- The operating current
  - present current amplitude used for reading the time-out parameter
  - average amplitude used to time-out

Summary

- A digital relay is an on-off controller which asserts its output signals (trip signal primarily) in the way of on-line computations
- Since an algorithm run on a relay determines the relay properties, there is a large space for research and improvement of digital relays

Digital Distance Relay

- *Operating principle*: impedance seen from the relaying point is a measure of the distance to a fault, thus a base for trip/no-trip decision



Digital Distance Relay

- All the key elements of a digital distance relay, i.e.,
  - starting element (pick-up)
  - phase selection element
  - zone measuring elements
  - power swing blocking element
  - directional element
  - tripping, carrier and alarm logic
- are realized in a digital way

Digital Distance Relay Starting Element

- Changes of certain signals can be measured very fast digitally enabling ultra-high speed activation of a relay
- Advanced principles can be used to start a relay (relative increase of certain signals between two samples or within a cycle, for example)
- Adaptable techniques can be used to auto-tune the starting element to the existing load conditions

Digital Distance Relay Phase Selection

- Fast and accurate digital measurement of phase voltages, currents and impedances enables robust and fast recognition of the type of fault
- Advanced techniques can be used to make the recognition more robust

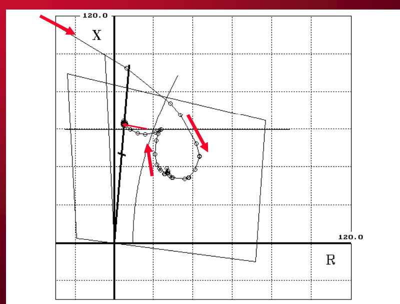
Digital Distance Relay Zone Elements

- A number of diverse measuring algorithms are available for fast and accurate impedance estimation
- Zone characteristics can be shaped freely in a digital relay
- First zone trip can be accelerated by adaptive self-adjustment of the first zone depending on fault location and scale of the transient

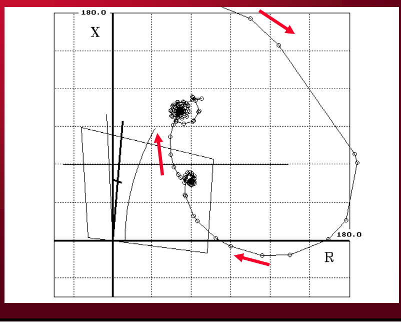
Digital Distance Relay Zone Elements

- Digitally measured impedance moves on the impedance plane as the transient develops marking an impedance trajectory
- Measuring algorithms can be optimized to provide favorable trajectories under various system and fault conditions

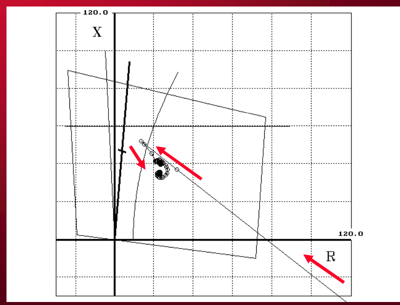
Digital Distance Relay Sample Impedance Trajectory



Digital Distance Relay
Sample Impedance Trajectory



Digital Distance Relay
Sample Impedance Trajectory

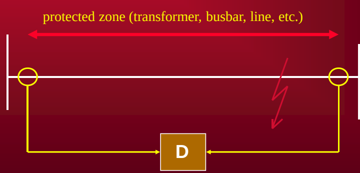


Digital Distance Relay

- Power swing and directional elements can apply sophisticated checkings in order to block the relay when needed, but without decrease of the relay sensitivity

Digital Differential Relay

- *Operating principle*: for internal faults, the differential current is substantially larger than the restraining current



Digital Differential Relay **Advantages**

- Software compensation for the ratio mismatch, transformer vector group and CTs connections
- Adaptive bias for high sensitivity
- Fast measurement and trip of clear cases
- Sophisticated operating principles for inrush or saturation of CTs
- Functional improvement by integrating protection, control (tap changer) and monitoring functions (transformer, breakers, etc.)