The Use of Symmetrical Components in Electrical Protection

by

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Agenda

- Introduction
- Overview of symmetrical components
- Symmetrical components in electrical protection
  - line protection
  - transformer protection
  - protection of electrical machines
  - protection of distribution networks
  - microgrid protection
- Conclusion
**Introduction**

- Overview of symmetrical components
- Symmetrical components in electrical protection
  - line protection
  - transformer protection
  - protection of electrical machines
  - protection of distribution networks
  - microgrid protection

**Conclusion**
Introduction

- The method of symmetrical components was introduced by engineer Charles LeGeyt Fortescue at the 1918 edition of the Annual Convention of the American Institute of Electrical Engineers.

- The method is an important tool in electrical engineering, simplifying the analysis of multi-phase electrical circuits operating under unbalanced conditions.

- The applications of the method of symmetrical components include short-circuit calculations for power system planning and power system protection studies.

- Some protection systems operate on symmetrical components, as these quantities are more sensitive to fault conditions compared to phase voltage/current.
Introduction

- the advancement of numerical relays allows the implementation of more complex protection systems that use the method of symmetrical components

- there is a relatively large number of technical papers discussing protection algorithms and protection schemes based on the method of symmetrical components

- these papers cover many types of applications, from high voltage power systems and high voltage equipment to distribution networks and end-user equipment

- the present paper/presentation presents a short review of the most relevant technical papers regarding the use of symmetrical components in protection relaying
• Introduction

• Overview of symmetrical components

• Symmetrical components in electrical protection
  • line protection
  • transformer protection
  • protection of electrical machines
  • protection of distribution networks
  • microgrid protection

• Conclusion
any unbalanced set of $N$ related phasors can be expressed, when $N$ is a prime number, as a linear combination of $N$ symmetrical sets of $N$ phasors, named the symmetrical components of the initial set of phasors

the symmetrical components of an unbalanced set of three phasors ($N=3$), consist from:

- 3 positive-sequence quantities (PSQ), equal in magnitude, symmetrical displaced by 120° and with the same phase-sequence as the initial set of phasors
- 3 negative-sequence quantities (NSQ), equal in magnitude, symmetrical displaced by 120° and with reversed phase-sequence compared to the initial set of phasors
- 3 zero-sequence quantities (ZSQ), equal in magnitude and without phase displacement
Overview of symmetrical components

abc-012 transformation:

\[
\begin{align*}
\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} &= \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}, \\
\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} &= \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}
\end{align*}
\]

\[ a = 1 \angle 120^\circ = -\frac{1}{2} + j \frac{\sqrt{3}}{2} \]

Sequence impedance:

\[ Z_m = \frac{V_m}{I_m}, \quad m = 0, 1, 2 \]
Overview of symmetrical components

(a) No fault;  (b) Phase-ground fault;  (c) Phase-phase fault;  (d) Open-phase fault;
Introduction

Overview of symmetrical components

Symmetrical components in electrical protection

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- transformer protection
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Conclusion
Symmetrical components in electrical protection

**Line protection**

- directional elements, based on phase angle difference of:
  - voltage NSQ and current NSQ
  - superimposed components of voltage NSQ and current NSQ
  - fault current NSQ and pre-fault current NSQ
  - voltage ZSQ and current ZSQ
  - current ZSQ at relay location and voltage at transformer neutral
  - superimposed components of voltage PSQ and current PSQ
  - fault current PSQ and pre-fault current PSQ
Symmetrical components in electrical protection

**Line protection**

- distance relays
  - polarized by voltage PSQ
  - fault phase selection schemes based on current seq. comp.
    - Example: AG fault: $I_b = I_c = 0$, $\angle (I_0, I_2) = 0^\circ$; BG fault: $I_a = I_c = 0^\circ$, $\angle (I_0, I_2) = 120^\circ$;
    - AB fault: $I_a = -I_b$, $\angle (I_1, I_2) = 60^\circ$; BC fault: $I_b = -I_c$, $\angle (I_1, I_2) = 180^\circ$;
  - zero-sequence current compensation in ground distance elements
  - zero-sequence mutual compensation for double-circuit lines

```
\[
\begin{bmatrix}
I_0 \\
I_1 \\
I_2
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
1 & 1 & 1 \\
1 & a & a^2 \\
1 & a^2 & a
\end{bmatrix} \begin{bmatrix}
I_a \\
I_b \\
I_c
\end{bmatrix}
\]
```
Symmetrical components in electrical protection

**Line protection**

- negative-sequence differential schemes
  - differential principle applied to current NSQ entering and leaving the protected zone

- directional-comparison schemes:
  - comparing the direction of PSQ of reactive power at the two line ends
  - comparing the direction of current NSQ at the two line ends
  - in both cases a fault is indicated by opposite directions of the monitored quantities
Symmetrical components in electrical protection

**Transformer protection**

- negative-sequence differential schemes
  - percentage restrained principle applied to NSQ of zone currents
  - higher sensitivity to inter-turn faults compared to conventional transformer differential protection

- negative-sequence directional comparison schemes
  - internal fault indicated by a phase angle mismatch between the NSQ of currents entering and leaving the protected zone (transformer), once the current NSQ exceed a minimum threshold
  - improved detection of minor inter-turn transformer faults
Symmetrical components in electrical protection

Transformer protection

- internal fault detection based on equivalent negative-sequence impedances of transformer
  - uses voltage NSQ and current NSQ on both sides of transformer
  - secondary side quantities are referred to primary side
  - internal fault indicated by large difference between negative-sequence impedances of the two sides

- transient events detection based on negative-sequence admittance of transformer
  - uses voltage PSQ and current PSQ on both sides of transformer
  - localization on a specific quadrant of the accumulated positive-sequence admittances indicates the event type, e.g. normal operation, internal fault, external fault or inrush conditions
Symmetrical components in electrical protection

**Transformer protection**

- Inrush restraining algorithm for differential protection based on negative-sequence power
  - Negative-sequence power calculated using voltage NSQ of primary and NSQ of differential current
  - Transformer energization does not cause a significant negative-sequence power
  - 2\(^{nd}\) harmonic restraint disabled upon detection of significant negative-sequence power

- Internal/external fault discrimination based on criteria involving symmetrical components
  - Internal fault indicated by the increase above a threshold of \(I_2/I_1\) ratio of differential current
  - Internal fault indicated by the increase above a threshold of \(I_2/I_1\) ratio of primary current
Protection of electrical machines

- open-phase and unbalance protection
  - overcurrent elements operating on current NSQ
  - overvoltage elements operating on voltage NSQ
  - directional power elements operating on negative-sequence power
  - elements tripping on a significant $I_2/I_1$ ratio or significant $V_2/V_1$ ratio

- stator-rotor current differential elements for inter-turn fault protection of synchronous generators
  - based on ampere-turn balance between the fields created by the NSQ of stator current and by the rotor double-frequency current
Protection of electrical machines

- improvement of a generator ground fault protection using current NSQ
  - stator ground faults detected by ground overvoltage element (59G)
  - 59G could trip for ground faults on HV side due to zero-sequence voltage coupling
  - miss-operation avoided by delaying operation of 59G – not optimal for generator faults

- improvement: accelerated 59G operation in the absence of a significant current NSQ at generator terminals
- significant current NSQ generated by faults on HV side, but not for generator internal faults
Symmetrical components in electrical protection

Protection of distribution networks

- ground fault protection
  - overcurrent elements operating on current ZSQ
  - overvoltage elements operating on voltage ZSQ
  - directional elements operating on current ZSQ and voltage ZSQ
  - zero-sequence wattmetric protection

- phase fault protection
  - overcurrent elements operating on current NSQ
  - overvoltage elements operating on voltage NSQ
Symmetrical components in electrical protection

Protection of distribution networks

- ground fault protection based on NSQ in ungrounded systems
  - current NSQ larger than current ZSQ in faulty feeders
  - current NSQ practically non-existent in healthy feeders
  - ground faults detected by zero-sequence overvoltage relays placed on each feeder, with adaptive (accelerated) operation upon detection of current NSQ

- fault section identification (ground fault) in distribution feeders based on comparison of the differential ZSQ current with the capacitive current expected on protected section section
Symmetrical components in electrical protection

*Microgrid protection*

- microgrids (active distribution networks) are more challenging for protection compared to traditional distribution network due to:
  - presence of distributed generators (characterized by intermittent generation)
  - directional power flow (requirement of directional elements)
  - variability of short-circuit currents (grid-connected mode vs. islanded mode)
  - relatively reduced short-circuit power (mal-operation of overcurrent relays)

- some authors proposed utilization of protection methods based on symmetrical components to mitigate the challenges of microgrid protection
Symmetrical components in electrical protection

Microgrid protection

- overcurrent protection based on symmetrical components
  - phase faults indicated by current NSQ
  - ground faults indicated by current ZSQ
- directional protection based on symmetrical components
  - positive-sequence directional elements
  - negative-sequence directional elements
- communication-based directional schemes using logic discrimination for accelerated tripping
Introduction

Overview of symmetrical components

Symmetrical components in electrical protection
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Conclusion
Conclusion

- a literature review of the most interesting technical papers discussing the use of symmetrical components in protection relaying has been realized

- the theoretical background of the method of symmetrical components and the derivation of these quantities from phase-domain counterparts have also been presented

- the literature study indicates a very high relevance of symmetrical components in electrical protection, which will continue, most probably, in the future

- modern protection relays and the method of symmetrical components could allow the development of new and more complex protection algorithms
Thank you!