Short Circuit in Power System
Technical Colloquium Indonesia PLN - ABB
Important notices

1. Please be aware of Safety requirements & Emergency Exit
2. Kindly keep your mobile phones in “SILENT MODE”.
3. More discussions / interactions on the topic.
Power Consulting
Global network of industry recognized subject matter experts…

A team of 125 technical experts with deep know-how, located worldwide to support you on extensive matters related to electrical power systems.

John D. Subsynch. Phenomenon
Dave D. HVDC/FACTS
Rodolfo K. System Stability & Dynamics
Albert K. System Studies
Sal G. Digital Grid / Distr. Planning
Lan T. Gen./Renewables Planning
Jin Z. Power Economics
Sri P. Trans. Planning & Operations
Ron Willoughby T&D Planning Optimization
Fahd H. WAMS
Ramana B. AC/DC Interaction
Alireza M. Harmonics Analysis
Andreas U. Distribution Sys. Modeling
Arefeh S. Insulation Coordination
Julia S. Industrial Power Systems
Manoj K Arc Flash Mitigation
Bandaru K Failure Analysis Power Products
Nihar R. Renewables Integration
Paula F. Protection Coordination
Joaquin M. Microgrids
Khoi V. Energy Storage
Carlos H. Substation Automation
Ricardo G. Power System Analysis
Ines Romero Renewables / Supergrids.
Short Circuit

Agenda

1. What is Short Circuit
2. Some Basics
3. Why does this occur in Power System
4. Effects of Short Circuit
5. Some solutions…
6. Case Studies
Short Circuit
What is it??.

- Accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal or close to zero.
  – IEC 60909-0 (ed1.0) 2001
- Different Definitions….
  - An unwanted low-resistance connection between two points in an electric circuit.
  - An abnormal electric path
  - The condition that occurs when a circuit path is created between the positive and negative poles of a battery, power supply, or circuit.
  - A situation that occurs when hot and neutral wires come in contact with each other.
  - An accidentally established connection between two points in an electric circuit, such as when a tree limb, or an animal bridges the gap between two conductors.

One of the most critical aspect in Power System affecting economics & availability
Short Circuit
Basic – Simple Electric Circuit

- Normal Power flow in the network
- The current flow in the network depends on the network elements R, L and C

\[
i = \frac{E}{R + jX}
\]

\[
i = \frac{E}{R + j\left(\omega L - \frac{1}{\omega C}\right)}
\]

\[
i_{\text{magnitude}} = \left(\frac{E}{\sqrt{R^2 + X^2}}\right)
\]

\[
i_{\text{angle}} = \tan^{-1}\left(\frac{X}{R}\right)
\]
Short Circuit
Basic – Simple Electric Circuit

- A constant AC power source
- A switch
- Impedance Z_sc
  - Z_sc represents all impedances upstream to the switch
- Load impedance Z_L
- Upstream of switch includes various networks with different voltage levels, transmission lines, cables, generators, transformers etc.
Applying Kirchoff’s voltage law (KVL)

\[ E_{\text{max}} \sin(\omega t + \phi) = R.i + L \frac{di}{dt} \]

\[ \phi \in (0, 2\pi) \text{rad} \]

There are two solution parts of this equation

- Natural response
- Particular solution

\[ i(t) = i_n(t) + i_p(t) \]

\[ i_p(t) = C_1 e^{-(R/L)t} + \frac{E_{\text{max}}}{\sqrt{R^2 + \omega^2 L^2}} \sin \left( \omega t + \phi - \tan^{-1} \left( \frac{\omega L}{R} \right) \right) \]
Short Circuit
Basic – Expression for Short Circuit Current

\[ i(t) = e^{-\frac{R}{L}t} \left[ -\frac{E_{\text{max}}}{\sqrt{R^2 + \omega^2 L^2}} \sin \left( \phi - \tan^{-1} \left( \frac{\omega L}{R} \right) \right) \right] + \]

Alternating and sinusoidal component

Aperiodic component

DC component
- Initial value depend upon \( \phi \) i.e. the point on wave when switching is done
- Decay rate is depend upon the ratio of R/X ( R/(wL) )

Sinusoidal component
- Magnitude independent of ratio R/X
Short Circuit
Basic – Short Circuit Current Wave Form

1. Sub transient period: 10 – 20 ms
2. Transient period: 20 ms – 100 ms
3. Steady State: 100 – 300 ms

Key:
1. current
2. top envelope
3. decaying d.c. component, \( i_{d,c} \), of the short-circuit current
4. bottom envelope
5. time
A. initial value of the d.c. component, \( i_{d,c} \), of the short-circuit current
Short Circuit
Basic – Symmetrical Short Circuit Current Wave Form

Machine is Unloaded

$X_l = \text{Leakage Reactance}$

$X_a = \text{Armature Reactance}$

$X_f = \text{Field Reactance}$

$X_D = \text{Damper winding Reactance}$
Peak current is deduced from the RMS value of the symmetrical short circuit current using equation

\[ i_p = \kappa \sqrt{2} I_k'' \]

Where, \( \kappa \) depends on the R/X or X/R ratio

Peak current are calculated to determine
Making capacity of the Circuit breaker
Electro-dynamic force that installation must withstand

\[ \kappa = 1,02 + 0,98e^{-3\frac{R}{X}} \]
## Short Circuit
### Basic – Magnitude of short circuit current

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Cases</th>
<th>Fault Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location of the Fault</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>At the equipment Terminal</td>
<td>↑</td>
</tr>
<tr>
<td>1.2</td>
<td>At a distance from the source</td>
<td>↓</td>
</tr>
<tr>
<td>2</td>
<td>Source in operation</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Maximum number of Generator in service</td>
<td>↑</td>
</tr>
<tr>
<td>2.2</td>
<td>Minimum number of Generator in service</td>
<td>↓</td>
</tr>
<tr>
<td>3</td>
<td>With Power transformer operation in parallel</td>
<td>↑</td>
</tr>
<tr>
<td>4</td>
<td>Type of Short Circuit (LLL, LG, LLG)</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>Depends on Circuit constants</td>
<td>↓</td>
</tr>
<tr>
<td>5</td>
<td>Increase in fault resistance</td>
<td>↓</td>
</tr>
<tr>
<td>6</td>
<td>High Ground Impedance</td>
<td>↓</td>
</tr>
<tr>
<td>7</td>
<td>Growth in AC Load and Generation</td>
<td>↑</td>
</tr>
<tr>
<td>8</td>
<td>Operating Voltage instant of fault. (Varies with instant)</td>
<td>↑</td>
</tr>
<tr>
<td>9</td>
<td>High X/R ratio (High DC Component in system)</td>
<td>↑</td>
</tr>
</tbody>
</table>
Short Circuit
Basic – Effect of X/R ratio on Fault current

High X/R ratio increases the decay, $I_{\text{inst}}$ & the peak current

![Graph showing the effect of X/R ratio on fault current](image)
Short Circuit
Basic – Instant of Fault

What happens at 90 deg ??
Short Circuit
Basic – Instant of Fault

1. With the increase in the value of $\theta$, the DC component comes down for a fixed value of $X/R$
2. It is max at 0 deg and min at 90 deg again the value will increase but in the opposite direction
3. The switching instant is equally important.
4. Incase of normal switching this aspect is controlled by controlled switching.
Short Circuit
Basic – Type of Faults in Power System

Symmetrical
- Line to line to line (L-L-L) fault,
- Also known as three phase fault

Asymmetrical
- Line to ground (L-G) fault
- Line to line (L-L) fault
- Line to line to ground (L-L-G) fault

75 – 80% is LG Fault
7 – 8% is LL Fault
10-12% is LLG Fault
8 – 10% is LLLG Fault
The nature of each type of short circuit creates certain mathematical boundary conditions.

These conditions are useful to model a faulted system with sequence impedance network.

<table>
<thead>
<tr>
<th>Type of fault</th>
<th>Boundary conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single phase</strong></td>
<td>( I_b = I_c = 0 ) and ( V_a = 0 )</td>
</tr>
<tr>
<td><strong>2 Phase to ground</strong></td>
<td>( I_a = 0 ) and ( V_b = V_c = 0 )</td>
</tr>
<tr>
<td><strong>2 Phase</strong></td>
<td>( I_b = -I_c ) and ( V_b = V_c )</td>
</tr>
<tr>
<td><strong>3 Phase</strong></td>
<td>( I_a + I_b + I_c = 0 ) and ( V_a = V_b = V_c )</td>
</tr>
</tbody>
</table>
Short Circuit
Basic – Standards

- The available software packages for fault analysis are
  - NEPLAN
  - ETAP
  - PSS/E
  - and many more....

  141-1993 IEEE Red Book
  399-1997 IEEE Brown Book
  242-2001 IEEE Protection and Coordination of Industrial and Commercial Power System

<table>
<thead>
<tr>
<th>Standard</th>
<th>Pub. Year</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 56</td>
<td>1978</td>
<td>High voltage alternating-current circuit-breakers</td>
</tr>
<tr>
<td>IEC 282-1</td>
<td>1985</td>
<td>Fuses for voltages exceeding 1000 V ac</td>
</tr>
<tr>
<td>IEC 61363</td>
<td>1998</td>
<td>Electrical Installations of Ships and Mobile and Fixed Offshore Units</td>
</tr>
<tr>
<td>IEC 781</td>
<td>1989</td>
<td>Application guide for calculation of short-circuit currents in low voltage radial systems</td>
</tr>
<tr>
<td>IEC 909-1</td>
<td>1991</td>
<td>Short-circuit calculation in three-phase ac systems</td>
</tr>
<tr>
<td>IEC 909-2</td>
<td>1988</td>
<td>Electrical equipment - data for short-circuit current calculations in accordance with IEC 909</td>
</tr>
<tr>
<td>IEC 947-1</td>
<td>1988</td>
<td>Low voltage switchgear and controlgear, Part 1: General rules</td>
</tr>
<tr>
<td>IEC 947-2</td>
<td>1989</td>
<td>Low voltage switchgear and controlgear, Part 2: Circuit-breakers</td>
</tr>
</tbody>
</table>
Short Circuit
Different Cause....

- Lightning strike on the transmission lines
- Travelling wave phenomenon
- High tower footing resistance can also lead to high stress on the insulators
- Can lead to Insulator flashover

Lightning Phenomenon

Switching Phenomenon

- Switching phenomenon is critical at EHV and UHV levels
- Switching of CB’s can produce high stress on insulation within system leading to dielectric failures
- This may cause faults within system.
Short Circuit
Different Cause...

Insulator contamination
- Contamination of insulators, deposition of salts
- Stringent environmental issues near industry & Sea coast / saline areas
- There is also an increase PD activity

Equipment failure
- Undesired voltage and currents within the system can stress insulation and accelerate the equipment aging.
- Inadequate rating, increase in fault levels, incorrect erection, problems in protection are few of the trigger for equipment failure.
Short Circuit
Different Cause...

With increase in load & generation, grid becomes more complex.

With growth in the AC systems there is increase in the fault levels within the Power System.

This increases the short circuit levels within system.

Growing Power System

Nature

Increased snow condition can increase the line loading leading to Transmission line failure.

High storm condition can also lead to transmission line failure leading to short circuit within Power System.
Short Circuit
Different Cause...

Vegetation

Trees near the transmission line are one of the big contributors to faults.

Increased load can also increase sag, thereby reduce clearance

Im proper Maintenance

Improper maintenance and higher loading of equipments can reduce the equipment life

Earthing, erection, testing & maintenance are critical aspects

Any small negligence can lead to failure thus faults
Short Circuit
Effect of Short Circuit Current

Test on Rigid Conductor by FGH Mannheim

Tube (E-AlMgSi 0.5 F22): 120mm/5mm
Distance between conductors: 1.0 m
Distance between supports: 11.5 m
Initial sym. short-circuit current: 38 kA
Peak short-circuit current: 106 kA
Duration of short-circuit current: 300 ms.

High Electrodynamic Forces – Can lead to massive “DAMAGE”
Short Circuit
Effects of Short Circuit Current.

Very High Arc Energy – Safety Issues

Switchgear Adequacy

<table>
<thead>
<tr>
<th>Bus Number</th>
<th>Max Wind Injection in MW $P_{wind0}$</th>
<th>Rank</th>
<th>Bus Wind Injection Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>156</td>
<td>1</td>
<td>Strong</td>
</tr>
<tr>
<td>119</td>
<td>131</td>
<td>2</td>
<td>Strong</td>
</tr>
<tr>
<td>110</td>
<td>109</td>
<td>3</td>
<td>Strong</td>
</tr>
<tr>
<td>115</td>
<td>88</td>
<td>4</td>
<td>Weak</td>
</tr>
<tr>
<td>123</td>
<td>83</td>
<td>5</td>
<td>Weak</td>
</tr>
<tr>
<td>95</td>
<td>45</td>
<td>6</td>
<td>Weak</td>
</tr>
</tbody>
</table>
High thermal energy leads to insulation damage.

It can also lead to fusing or melting of conductors

Fire and Damage to equipments and persons

High Fault currents needs to be AVOIDED & In-depth System Study is REQUIRED
Short Circuit Currents can have multiple effects.

- Voltage dip till the fault is cleared – till few milli seconds (Depends on Protection setting)
- Shutdown of the part of network – Area depends on the protection philosophy design and operation of protective relays
- Dynamic instability and loss of synchronism
- Disturbance in control / monitoring system
- The high induced current may also cause disturbance in the nearby circuits.
Short Circuit
Effect of Short Circuit Current - EDF

Ref: Parametric Analysis of Electrodynamic forces in Power System based on IEC 60865 by Nihar Raj
Short Circuit
Significance of Short Circuit Current

1. Maximum Short Circuit Current
   1. Breaking capacity of circuit breaker
   2. Making capacity of circuit breaker
   3. Electrodynamically withstand capacity of the switchgear and different elements of Power System
   4. Thermal capacity of Switchgear
   5. Insulation degradation

2. Minimum Short Circuit Current (Sensitivity of Protection System)
   3. Sizing of equipments (CT, Transformer, Isolator, Busbars etc..)
   4. Network Stability
   5. Voltage stability and Reactive Power compensation
   6. Decides the strength of network to absorb Renewable Power.

Both values: “Maximum” & “Minimum” is Important
Short Circuit
Significance of Short Circuit Current – Deicing & Arc Furnace

Short circuit current can create heat due to Joule’s effect
This can help in de-icing
Requirement is also to know the right amount of current to be passed without damaging the conductor.
Arc furnace – Aluminum Smelter : High heat is produced by the electric arc

Both values : “Maximum” & “Minimum” is Important
Short Circuit
Significance of Short Circuit Current - Earthing

1. Fundamental input for Earthing Designs
2. With increase in the value of currents safety is a concern
3. Earthing design to be done as per FEM solutions
4. Site measurements are very important to ensure safety of design

Very Critical for Earthing Design impacting SAFETY of Human & Equipment
There are several methods that can be used to reduce fault level in the network.

- Current limiting reactors
- Is-limiter
- Superconducting fault current limiter
- Solid-state fault current limiter
- Network splitting
### Short Circuit
Fault Current Reduction – $I_s$ Limiters

- $T_0$: Response time of the protection relay: 10 - 20 ms
- $T_1$: Operating time of the protection relay: 30 - 40 ms
- $T_2$: Operating time of the circuit-breaker: 40 - 80 ms
- $T_3$: Arc duration: 10 - 20 ms, 90 - 160 ms

Total time of current flow through $I_s$-limiter: $T = 5 - 10$ ms
Short Circuit
Fault Current Reduction – Is Limiters
Short Circuit
Fault Current Reduction – Is Limiters

Current curve at the short-circuit location

\[ i = i_1 + i_2 \]

without \( I_S \)-limiter

with \( I_S \)-limiter

\( I_{k_{\text{perm.}}} = 50 \text{ kA} \)

\( I_k = 50 \text{ kA} \)
Short Circuit
Case Study 01: High Reliability High Short Circuit

33kV Switchgear Short Circuit Withstand capability is 25kA/1sec
To mitigate the adverse effects of increased short circuit levels, analysis done to provide optimal current limiting device.
Comparative analysis between current limiting reactor & Is limiter were made.

<table>
<thead>
<tr>
<th>Current Limiting reactor</th>
<th>Is Limiter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adds voltage drops</td>
<td>No voltage drop</td>
</tr>
<tr>
<td>Reactive power loss</td>
<td>No reactive power loss</td>
</tr>
<tr>
<td>Space required is more</td>
<td>Less Space required</td>
</tr>
</tbody>
</table>

As technically Is limiter provides more benefits to the refinery system, 5 Nos. of Is limiters were proposed to installed in 33kV Ties.
Short Circuit
Case Study 01 : High Reliability High Short Circuit

System studies

Customer Need

High Reliability
Optimize on Generator cost
Transient stability of the system

ABB Response

Detail system study and close coordination with customer.
Introduction of Fault current limiter and Reactive power study to improve power factor

Customer Benefit

Improved Active Power within system
Limitation of short circuit currents with Is limiters
Improved system stability.
Short Circuit
Case Study 02 : High EDF for 400kV Substation

High Electrodynamic Forces

Customer Need
Substation in polluted area
High short circuit level
Requirement of design as per standards

ABB Response
Detail design and calculations
Solution to overcome the effect of high Electrodynamic forces

Customer Benefit
Safe Engineered solution running for more than 12 years.
High reliability. Safe Gantry and Structure design.
Short Circuit
Case Study 03 : Safe Solution for High Short Circuit Current

Safe Earthing Solution

Customer Need
- Identify unsafe areas within Installation
- Check the health of existing earthing system
- Upgrade the earth installation from 40kA to 63KA

ABB Response
- Detail site measurements as per latest standards
- Simulation on FEM software to identify areas to be strengthened.

Customer Benefit
- Safe solution to the customer for increased fault level of 63KA
- Earthing Health assessment for the entire Power Plant
Short Circuit Summary

One of the most vital element in Power System Planning – “Short Circuit Current”

- Short Circuit Studies are MUST on regular basis.
- Maximum and Minimum short circuit currents; both are equally important
- Short circuit currents are formed up on AC and DC components which have different decay.
- Different network parameters decide the value of the short circuit currents in system.
- There are different challenges for high & low value of the short circuit currents in system which affect the safety of person and equipments
- ABB has an rich experience of dealing with different issues and providing different solutions which have added value to customer requirements.

Short Circuit Currents decide the system economy, availability & safety
Nihar S. Raj
Hub Manager - Asia, Power Consulting, ABB India Limited

Nihar S. Raj is the Business Head for Power Consulting – Asia. In his previous role he contributed as Head of Engineering for +/-800kV HVDC North East Agra Project in ABB India. He has designed several air and gas insulated substations ranging from 11kV to 800kV. He was also involved for design of 800kV GIS, hybrid substation solutions and preliminary conceptualization of 1200kV system.

He completed his electrical engineering degree from M.S. University Vadodara and areas of expertise includes Power Systems, Substation Design (AIS, GIS), and Earthing Systems. He is a life member of Society of Power Engineers (Vadodara Chapter), member of CIGRE India, CBIP National Expert group member for Earthing & GIS, National CIGRE SC B3, IEEE PES member (Gujarat Chapter) and has presented several technical papers at various national and international conferences.

**ABB Group profile**
ABB (www.abb.com) is a leading global technology company in power and automation that enables utility, industry, and transport & infrastructure customers to improve their performance while lowering environmental impact. The ABB Group of companies operates in roughly 100 countries and employs about 135,000 people.
Power and productivity for a better world™