Introduction to Short Circuit Current Analysis

An Online Continuing Education Course for Engineers

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Introduction to Short Circuit Current Analysis

Velimir Lackovic, Electrical Engineer

Introduction and Scope

Electrical power systems are systems composed of a wide range of power equipment used for generating, transmitting, and distributing electrical power to consumers. Complexity of these systems indicates that breakdowns and faults are unavoidable, no matter how carefully these systems have been designed. Electrical systems can be designed with zero failure rates, however that is economically unjustifiable. From the perspective of short-circuit analysis, system faults manifest themselves as insulation breakdowns. These breakdowns lead to one or more phenomena:

- Undesirable power flow
- Currents of excessive magnitudes that usually cause equipment damage
- Excessive over-voltages
- Voltage depressions
- Cause conditions that could harm personnel

Short circuits cannot always be prevented so system designers can only try to mitigate their potentially damaging effects. Electrical systems should be designed so that the occurrence of the short circuit becomes minimal. In the case if a short circuit occurs, mitigating its effects consists of:

- managing the magnitude of the undesirable fault currents,
- Isolating the smallest possible portion of the system around the faulted area in order to retain service to the rest of the system.

One of the major parts of system protection is orientated towards short-circuit detection. Interrupting equipment at all voltage levels that is capable of withstanding the fault currents and isolating the faulted area requires considerable investments. Therefore, main reasons for performing short-circuit studies are as follows:

- Verification of the adequacy of existing interrupting equipment
- Defining system protective device settings and that is done by quantities that describe the system under fault conditions
- Defining effects of the fault currents on various system components such as cables, overhead lines, buses, transformers, capacitor banks and reactors during the time the fault

persists. Mechanical stresses from the resulting fault currents are compared with the corresponding short-term withstand capabilities of the system equipment

- Assessment of the effect that different kinds of short circuits of varying severity may have on the overall system voltage profile. These calculations identify areas in the system for which faults can result in unacceptable voltage depressions
- Design and sizing of system layout, neutral grounding, and substation grounding
- Compliance with codes and regulations governing system design and operation

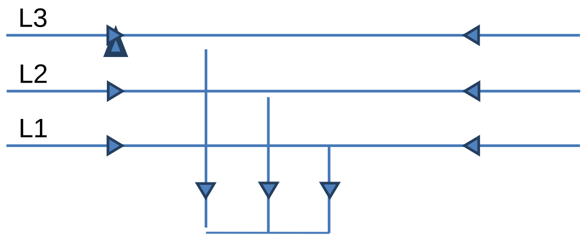
Extent and Requirements of Short-Circuit Studies

Short circuit studies are necessary for any power system as other fundamental system studies including power flow studies, transient stability studies, harmonic analysis studies, etc. Short-circuit studies can be performed at the planning stage in order to help finalize the single line diagrams, determine and set voltage levels, and network equipment such as cables, transformers, and conductors. For existing systems, fault studies are necessary in the cases of added generation, installation of extra rotating loads, network topology modifications, rearrangement of protection equipment, verification of the adequacy of existing breakers, relocation of already acquired switchgear, etc. Short-circuit studies can also be performed in order to duplicate the reasons and system conditions that led to the system's failure.

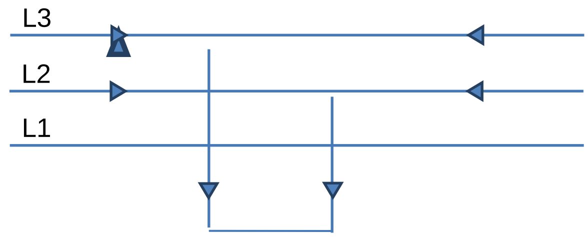
The requirements of a short-circuit study will depend on the set objectives. These objectives will dictate what type of short-circuit analysis is required. The amount of data required will also depend on the extent and the nature of the study. The majority of short-circuit studies in industrial and commercial power systems address one or more of the following four kinds of short circuits:

- Three-phase fault. May or may not involve ground. All three phases shorted together.
- Line-to-line fault. Any two phases shorted together.
- Double line-to-ground fault. Any two phases connected together and then to ground.
- Single line-to-ground fault. Any one, but only one, phase shorted to ground.

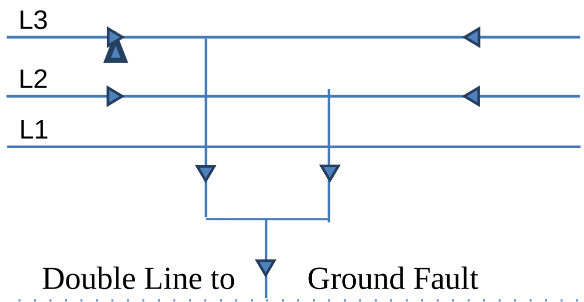
Fault types are graphically presented in figures below.



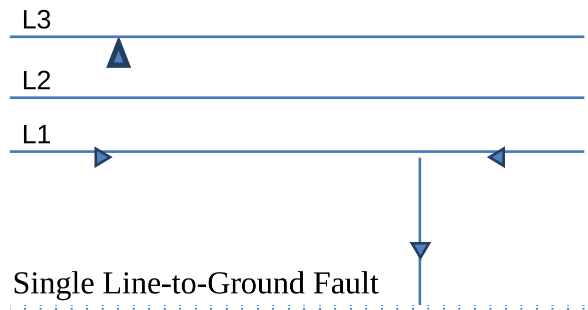
Three Phase Fault



Line to Line Fault



Double Line to Ground Fault



Single Line-to-Ground Fault

These types of short circuits are also referred to as “shunt faults;” all four are associated with fault currents and MVA flows diverted to paths different from the pre fault “series” ones. Three-phase short circuits often turn out to be the most severe of all. It is thus customary to perform only three phase-fault simulations when searching for the maximum possible magnitudes of fault currents. However, exceptions exist. For instance, single line-to-ground short-circuit currents can exceed three-phase short-circuit current levels when they occur in the electrical vicinity of:

- A solidly grounded synchronous machine
- The solidly grounded wye side of a delta-wye transformer of the three-phase core (three-leg) design
- The grounded wye side of a delta-wye autotransformer
- The grounded wye, grounded wye, delta-tertiary, three-winding transformer

For electrical systems where any or more of the above conditions exist, it is advisable to perform a single line-to-ground fault simulation. Line-to-line or double line-to-ground fault studies may also be required for protective device coordination requirements. Also, since only one phase of the line-to-ground fault can experience higher interrupting requirements, the three-phase fault will still contain more energy because all three phases will need the same interrupting requirements. Other types of fault conditions that may be of interest include the “series faults” and they refer to one of the following types of system unbalances:

- One line open. Any one of the three phases may be open.
- Two lines open. Any two of the three phases may be open.
- Unequal impedances. Unbalanced line impedance discontinuity.

Series fault types are graphically presented in figures below.

One line open

Two lines open

The term “series faults” is used because these faults are associated with a redistribution of the pre-fault load current. Series faults are of interest when assessing the effects of snapped overhead phase wires, failures of cable joints, blown fuses, failure of breakers to open all poles, inadvertent breaker energization across one or two poles and other situations that result in the flow of unbalanced currents.

System Modeling and Computational Techniques

AC and DC Decrement

Physical phenomena that determine the magnitude and duration of the short-circuit currents are:

- The operation of the rotating machinery in the electrical system
- The electrical proximity of the rotating machinery to the short-circuit location
- The fact that the pre-fault system currents cannot change instantaneously, due to the significant system inductance

The first two can be conceptually linked to the AC decrement, while the third, to the DC decrement.

AC Decrement and Rotating Machinery

AC decrement is determined by the fact that the magnetic flux inside the windings of the rotating machinery cannot change momentarily. From that reason synchronous machines, under fault conditions, show different flux variation patterns as compared to induction machines. The flux dynamics dictate that short-circuit current decays with time until a steady-state value is reached. Machine software models present rotating machines as constant voltages behind time-varying impedances.

For modeling purposes, these impedances increase in magnitude from the minimum post fault subtransient value $X_d^{"}$, to the relatively higher transient value $X_d^{'}$, and finally reach the even higher steady-state value X_d, assuming that the fault is not cleared before. The rate of increase of machine reactance is different for synchronous generators/motors and induction motors. Rate of increase for induction motors is higher than for synchronous generators. This modeling approach is fundamental in properly determining the symmetrical RMS values of the short-circuit currents furnished by the rotating equipment for a short circuit anywhere in the system.

Fault Current DC Decrement and System Impedances

Fault current DC decrement is also impacted by the fact that because the current existing in the system before the fault cannot change instantaneously, a considerable unidirectional component may exist in the fault current which actually depends on the exact occurrence of the short circuit. This unidirectional component of the fault current is often referred to as "DC current offset" as it reduces with time exponentially. The rate of decay is related to the system total reactance and resistance. Although this decay is quick, the DC current component could last enough time to be detected by the protective relay equipment, particularly when fast fault clearing is very needed to maintain system stability or prevent the damaging effects of the fault currents.

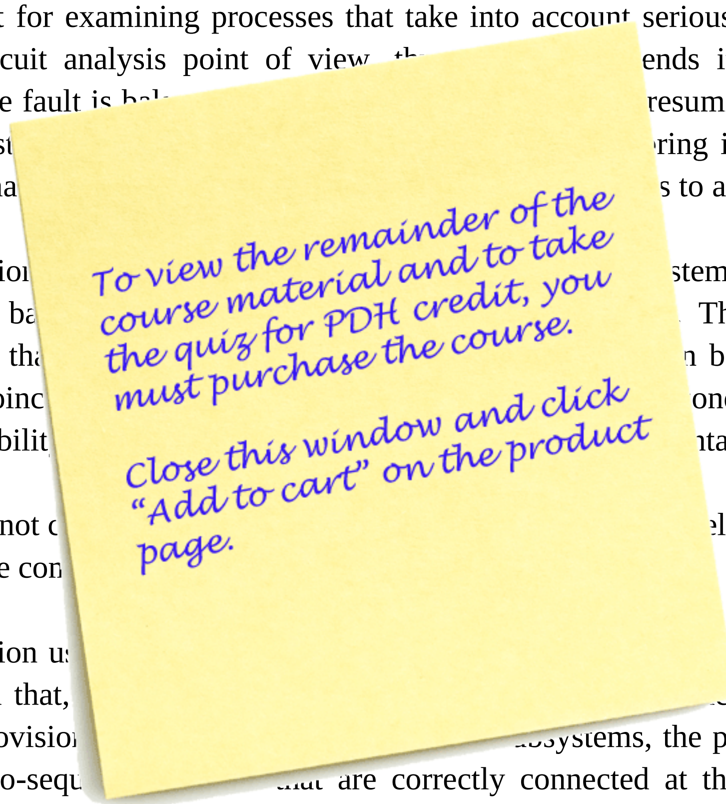
Short circuit currents cleared by circuit breakers must consider this unidirectional component, especially for shorter interrupting periods. Same DC component is important when verifying the capability of a circuit breaker to reclose against or withstand fault currents. Fault currents containing high current DC offsets usually present no zero crossings in the first several cycles right after fault introduction. They are especially burdensome to the circuit breakers of large generators.

Modeling Requirements of the Power System

Modern power systems are usually systems compromised of more generators, with many motors and usually more than one generator. They are interlinked using other equipment like transformers, overhead lines and cables. Also there are usually one or more locations at which local, smaller power systems are connected to a larger electrical grid. These locations are referred to as “point of common coupling”. The main goal of the short-circuit study is to calculate the short-circuit currents and voltages at various location throughout the system. Fault currents have a dynamic aspect that is necessary to associate calculated short circuit currents to a specific moment in time from the onset of the short circuit. AC current decrement assessment is used to properly determine the symmetrical RMS values of the short circuit currents, while DC decrement calculations provide the necessary DC current component of the fault current, hence affording a correct approximation of the total short circuit current. The total fault current must be used for breaker and switchgear sizing, and in some specific scenarios for protective relay device coordination. Electrical system topology conditions are evenly significant. The system arrangement and electrical closeness of the rotating machinery to the fault location will influence the total order of magnitude of the fault current. Therefore, it is essential to come up with an electrical system model as a whole and examine it as such in an accurate and computationally convenient manner.

Representation of the Three-Phase vs. Symmetrical Components

It is a custom practice for conventional three-phase electrical systems to be interpreted on a single-phase basis. Mentioned simplification, successfully applied for power flow and transient stability studies, leans on the assumption that the electrical system is equally balanced or can be accepted to be so for practical purposes. However, electrical system modeling, on a single-phase basis is insufficient for examining processes that take into account serious system imbalances. From the short-circuit analysis point of view, th... ends itself to single-phase analysis because the fault is bal... resuming a balanced three-phase electrical syst... ring imbalances that need analysis for the rema... s to address the problem:



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