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APPENDIX VII

SHORT CIRCUIT ANALYSIS PROCEDURES

APPENDIX VII – Specific Short Circuit Analysis Procedures

VII. SPECIFIC SHORT CIRCUIT ANALYSIS PROCEDURES

- A. Short Circuit Analysis
- B. System Impedance and Data Reduction
- C. Short Circuit Study Procedures
 - 1. Introduction General Discussion
 - 2. Short Circuit Calculations
 - 3. Switchgear Ratings
 - 4. Standards for Short Circuit Duty Calculations
 - 5. Type of Short Current Calculations
- D. Short circuit Calculation Output Explanation
 - 1. One-Half Cycle (Momentary) Duty
 - 2. Interrupting Duty
- E. General
 - 1. Input Data
 - 2. Output Data
 - a) Interrupting Duty Low-Voltage Short Circuit Currents
 - b) Interrupting Duty High-Voltage Short Circuit Currents
 - c) Momentary Low Voltage Currents Using Momentary Impedance Circuit
 - d) Momentary High Voltage Currents Using Momentary Impedance Circuit
 - e) Equipment Duty Violation and Warning Summary Report
 - f) 30 Cycle Relay Short Circuit Currents

VII. SPECIFIC SHORT CIRCUIT ANALYSIS PROCEDURES

A. Short Circuit Analysis

A power system Short Circuit Study is used to calculate system fault current duties which can be compared with the short circuit current ratings of circuit-interrupting devices, such as circuit breakers and fuses, and guide the selection and rating or setting of short circuit protective devices such as direct-acting, trips, fuses, and relays.

B. System Impedance and Data Reduction

The single-line diagrams included in this report represent the electrical power distribution system under study. The impedance values used are listed in the study data and include conversion to a per-unit base (apparent power and voltages) basis.

A utility system is represented by a per-unit impedance or MVA and X/R Ratio, which is equivalent to the maximum short circuit duty that is available from the utility company at the incoming service.

Technical data for each device was obtained from field verification, nameplate data, manufacturing data, past studies, or IEEE reference books.

The transformer impedances, usually given on the nameplate in percent on the self-cooled kVA rating of the transformer, are converted to a per-unit base.

The system cable and busway impedances are typical impedance values for such equipment shown in standard reference, such as the IEEE "Red Book", converted to a per-unit base.

For transformers with motor control centers, the motor control centers are grouped (lumped) to an equivalent motor kVA to match the base kVA of the supplying transformer. The modeled short circuit connected percent of 80 was used to simulate connected load on the transformer. ANSI Code 5 was used for impedances and interrupting duty multipliers for these induction motor groups.

Direct current motors are lumped where possible and given an ANSI Code 5 multiplier with a zero connected value. The horsepower of the DC motors match the base kVA of the supplying transformer. DC motors are considered to contribute negligible fault current.

All devices, such as fuses, low-voltage breakers, etc., where technical data was not available, a conservative rated device were used. This approach then allows the short circuit analysis to determine if any device is overdutied.

C. Short Circuit Study Procedures

1. Introduction General Discussion

The Short Circuit Study begins with the representation of the electric power distribution system in matrix form. Each of the power system components (utility sources, generators, motors, transformers, cables, etc.) is represented by an impedance value (resistance and reactance or reactance alone). The model places an assumed three-phase fault at each bus location in the system, and a set of short circuit currents is calculated which could be compared with the published short circuit ratings of the power system equipment including interrupting devices.

Interrupting devices must be able to withstand and interrupt the most severe short circuit currents realizable in the actual system. Three-phase bolted faults at maximum load, maximum utility short circuit MVA available, and maximum local generation are usually considered most severe. Under some conditions tie breakers in the distribution system are assumed to be closed to produce the highest possible short circuit currents.

The calculation techniques used are in accordance with the American National Standards C37.13-1990 for low-voltage circuit breakers, C37.010 1999 and C37.50-1989 (R2000) for medium-voltage and high-voltage circuit breakers.

ANSI Code provides an efficient way to enter ANSI Standard impedances and interrupting duty multipliers for motors. Code numbers are chosen according to the motor types, sizes and modeling method. Regardless of the code chosen, ANSI Standard interrupting value multipliers are used.

Using the ANSI Code field is the recommended method to enter motor impedances to assure that the proper interrupting duty impedance multiplier is used for ANSI Standard calculations.

TABLE 1: IMPEDANCE MULTIPLIERS FOR ANSI STANDARD SHORT CIRCUIT CALCULATIONS			
CODE	MOTOR	MOMENTARY DUTY FIRST- CYCLE	INTERRUPTING DUTY 1.5-4 CYCLES
1.	Synchronous	$1.0 X''_{dv}$	$1.5 X''_{dv}$
2.	Induction Motor > 1000 HP or > 250 HP @ 3600 RPM	$1.0 X''_{dv}$	$1.0 X''_{dv}$
3.	Induction Motor Group > 50 HP	$1.2 X''_{dv}$	$3.0 X''_{dv}$
4.	Induction Motor Group < 50 HP	$1.67 X''_{dv}$	Infinite X''_{dv}
5.	Lumped Induction Motor Group	$1.0 X''_{dv}$ (X=25%)	$3.0 X''_{dv}$
Note: X'' for induction motor groups three (3) and four (4) are typically assumed equal to 16.7%. This corresponds to an equivalent motor contribution of 3.6 to 4.8 times the full load current.			

All system connected motors and generators are assumed to be operating unless noted otherwise. This assumption produces the highest calculated short circuit currents since the rotating machine contributions are maximized.

2. Short Circuit Calculations

Four (4) types of faults apply to a three-phase system:

1. Three-phase fault: The three-phase conductors are shorted together.
2. Phase-to-phase fault: Any two-phase conductors are shorted together.
3. Phase-to-phase-to-ground fault: Any two-phase conductors are shorted together and simultaneously to ground.
4. Phase-to-ground fault: One-phase conductor is shorted to ground.

For a particular location in a power system, the initial magnitude of fault current is generally the greatest for three phase faults and least for phase to ground faults. However, phase to ground fault current magnitude can exceed the three phase fault current magnitude under certain conditions. This can occur near:

1. a solidly grounded synchronous machine or near the solidly grounded wye connection.
2. a delta wye transformer of the three-phase core (three (3) leg) design.
3. a grounded wye-delta "tertiary" autotransformer.
4. a grounded wye-grounded wye-delta tertiary three-winding transformer.

Additional complexity is introduced in the calculation of phase to ground fault currents; therefore, normally only three phase fault currents are calculated. Phase to ground fault currents are calculated only when the

nature of the particular system, the operating conditions, or study requirements dictates. It is not necessary to calculate the phase to ground fault currents in a resistance grounded system since the neutral grounding resistance limits the fault current to not more than a maximum value.

The Short Circuit Study does not include pre fault steady state load currents. The effect of system load currents is usually negligible in short circuit studies for industrial and commercial power distribution systems.

The model automatically simulates a fault on each bus and calculates three phase short circuit current duties. Depending on the type of calculation selected, results available for each bus are:

1. The first cycle symmetrical and asymmetrical (total) short circuit current duty to be compared with the closing and latching capability (or momentary rating) of medium voltage or high voltage circuit breakers or the interrupting rating of fuses or low voltage circuit breakers.
2. The interrupting short circuit current duties (five [5] cycle), to be compared with the interrupting capabilities of medium or high voltage circuit breakers of two (2) types (symmetrical and total rated), and two or four interrupting time ratings, showing also the system X/R ratio at the fault point and associated multiplying factor.
3. The calculated symmetrical short circuit current at a later time (thirty [30] cycles), for protective device coordination purposes.

For all types of calculations selected, results include the short circuit contribution from all buses connected to the faulted bus.

Some model output data sheets, along with a listing of the input data, are included in this report. Contributions from major sources of short circuit current such as utility system and local generators are indicated on the model printout.

3. Switchgear Ratings

The short circuit current ratings assigned to medium voltage or high voltage power circuit breaker by a manufacturer are significant in two (2) ways.

First, the ratings represent a conservative statement of the actual capability of the circuit breaker design to close against, to withstand, and to interrupt short circuit currents. Thus, the assigned ratings represent the maximum condition under which the circuit breaker design may be safely applied.

Secondly, the ratings represent the maximum conditions of application for which the manufacturer guarantees that the circuit breaker will

perform satisfactorily. It is essential then, that a circuit breaker be applied within its assigned rating if the installation is to be safe, and is to be covered to the full extent of the manufacturer's warranty.

From a series of laboratory tests, the manufacturer determines the actual capability of the circuit breaker design. In the United States, the procedures for testing circuit breaker design, the rating structure and the list of preferred ratings are industry standard dictated by the Standards Committee on Power Switchgear (C37) of the American National Standards Institute.

The short circuit current rating of a circuit breaker is its capability at the maximum voltage at which the breaker may be applied. There may be a difference between the short circuit current rating of the circuit breaker and its capability in a specific application.

Prior to 1964, medium voltage and high voltage circuit breakers were assigned a short circuit interrupting rating in (asymmetrical) MVA and a range of voltages over which the interrupting MVA remains constant. An equivalent interrupting capacity in amperes could then be calculated at each application voltage within its operating range. This is called a total current basis of rating breakers. A circuit breaker shall not be applied at a voltage above the stated upper limit of the operating voltage range.

Below the stated lower limit of operating voltage, the interrupting capability in amperes is constant at the value calculated from the interrupting MVA at the lower limit voltage. Momentary (or First Cycle) current capability is defined as the maximum fully offset RMS current the breaker can withstand for one (1) second and is assigned by the manufacturer.

Since 1964, circuit breakers have been assigned a symmetrical RMS current interrupting rating applicable at the rated maximum operating voltage, and the capability at lower voltages increases inversely in proportion to voltage up to a specified maximum interrupting current. This is the symmetrical current basis of rating. Under this rating structure, an MVA rating may still be assigned to breakers for class distinction, but most cases it is not the interrupting capability of the device.

The symmetrical current basis of rating medium voltage and high voltage circuit breakers specifies a factor k that defines the permissible range of operating voltage and short circuit interrupting capability. The circuit breaker application falls into one (1) of three (3) categories:

1. Operating voltage greater than rated maximum voltage: The breaker may not be applied.
2. Operating voltage between rated maximum voltage and $1/k$ times rated maximum voltage, the interrupting current capability is:

(interrupting current rating) (rated maximum voltage)/(actual operating voltage).

3. Operating voltage less than I/k times rated voltage: The interrupting current capability is k times the interrupting current rating.

The momentary current capability, defined as the available fully offset RMS short circuit against which the breaker must be able to close and latch its contacts, is $1.6k$ times the symmetrical RMS current interrupting rating of the circuit breaker and is not a function of the actual voltage of application.

Low voltage power circuit breakers are tested and applied in accordance with ANSI C37.13-1990. Low voltage circuit breakers of recent manufacture have symmetrical current interrupting ratings. For low voltage breakers, calculated first cycle symmetrical short circuit currents are compared with the manufacturer's symmetrical ratings, since these breakers may operate rapidly enough to part their contacts during the first cycle of short circuit current. (Low voltage breakers manufactured prior to 1975 had average asymmetrical short circuit interrupting current ratings which were compared with 1.25 times calculated first cycle symmetrical short circuit currents.)

Fuses are fast acting protective devices, which operate in the first cycle of major faults. Some are rated on a first cycle symmetrical and others on a first cycle asymmetrical (total) short circuit current basis.

4. Standards for Short Circuit Duty Calculations

Electrical power system operating conditions change constantly with system loading and operating procedures. Thus, the available short circuit currents change with system operating conditions. For any operating condition, the short circuit current decreases from a maximum value at the inception of a fault until the fault is removed. The rate of this short circuit decay depends on many factors.

The American National Standards Institute (ANSI) has developed standards to be used by the electrical industry for calculating short circuit currents to be compared with short circuit ratings or capabilities of electrical equipment. Industrial and commercial power system studies are made by calculating short circuit current values in accordance with these standards.

5. Type of Short Current Calculations

The following gives a brief description of the type of calculations that can be made:

- a) First-Cycle Duty per ANSI C37.010-1999 and C37.50-1989 (R2000)

First cycle (momentary) duty calculated in accordance with ANSI C37.010 1999 and C37.50-1989 (R2000) is compared with the closing and latching capability of medium voltage and high voltage circuit breakers. Total impedances (or reactance only) of lines, transformers, motors, generators and utility sources are used for the momentary current calculations. The reactance used for utility sources and generators are sub-transient reactance. The reactance of synchronous and induction motors are modified if necessary using Table I. The circuit E/X (or E/Z) current at the fault point is the symmetrical first cycle (momentary) duty for the circuit breakers. The asymmetrical (total) closing and latching (momentary) duty is found by multiplying the symmetrical duty by 1.6.

The first cycle duty calculating procedure given in C37.13-1990 (next paragraph) for low voltage circuit breakers is sometimes used to determine medium voltage and high voltage circuit breaker first cycle duties, along with those of fuses and low voltage circuit breakers. This calculated duty is usually slightly higher (perhaps 2 to 5 percent) for medium voltage and high voltage circuit breakers than that using ANSI C37.010 1999 and C37.50-1989 (R2000) because small induction motors are included.

b) First-Cycle Duty per ANSI C37.13-1990

First-Cycle (momentary) duty calculated in accordance with ANSI C37.13-1990 is compared with the interrupting ratings of fuses and low voltage circuit breakers, since their circuit opening time for high fault currents is within the first cycle. Sub transient impedances are used for the utility sources, generators and synchronous motors...

Locked rotor impedances, some modified, are used for induction motors. For a simplified and more conservative answer, sometimes only reactance are substituted for impedances.

Present day low voltage circuit breaker ratings are compared to the symmetrical current obtained by an E/Z calculation at the fault point. When the X/R ratio at the circuit breaker bus is greater than 6.6, the calculated duty is multiplied by a number greater than 1.00 as listed in Table 3 of ANSI C37.13-1990. If the X/R ratio is not known, the multiplier used is 1.15. Fuse ratings are generally compared to an asymmetrical current equal to 1.55 times the symmetrical current. For symmetrically rated low voltage current limiting fuses the multiplier is 1.0.

c) Interrupting Duty per ANSI C37.010-1999 and C37.50-1989 (R2000).

The interrupting duty calculated in accordance with ANSI C37.010 1999 for symmetrical current rated circuit breakers and ANSI C37.5 1999 for total current rated circuit breakers are compared with corresponding medium voltage and high voltage circuit breaker interrupting ratings.

The calculated interrupting current is lower than calculated momentary current because the short circuit current decays with respect to time while the power circuit breaker is opening. The interrupting duty is calculated using the reactance given in Table I.

The interrupting duty is found by calculating the short circuit current (E/X or E/Z), the equivalent reactance at the fault point and the equivalent resistance at the fault point, using a resistance only network reduction. The circuit breaker contact parting time (related to the rated interrupting time), the electrical distance away from generators (measured by the number of intervening transformers or by the reduction of the generator contribution) and the X/R ratio at the fault are used to determine a multiplying factor to be applied to the symmetrical current to take into account the appropriate direct current and generator alternating current decrements. The multiplying factors are taken from curves given in ANSI Standard C37.010 1999 for symmetrically rated breakers and in C37.5 1999 for total current rated breakers. They cover circuit breaker rated interrupting times of two (2) to eight (8) cycles. Frequently, interrupting current calculations are made using IEEE Transactions Paper 69TP146 IGA Sept/Oct 1969, Interpretation of New American National Standards for Power Circuit Breaker Application (GER 2660) as a guide. The principal interpretative extension of the ANSI standards described in this paper is the use of interpolation between local and remote multiplying factors to cover cases when a short circuit current has important contributions from both types of sources.

d) Short Circuit Relay Currents.

Short circuit studies are also made to calculate the branch currents required to determine settings for relays and protective devices in coordination studies. The impedances of motors and generators depend on the time of interest subsequent to the fault. At one half second and more after the fault, the utility impedance and time modified impedances of the generators may represent the only short circuit sources in the network.

D. Short circuit Calculation Output Explanation

A computer model calculates three phase, short circuit duties using matrices of positive sequence R and jX impedances expressed in a per unit base on the study apparent power and voltage. The following two (2) types of short circuit duties are normally calculated:

1. One-Half Cycle (Momentary) Duty

Calculated one half cycle (momentary) short circuit currents are used to evaluate equipment mechanical strength requirements to determine closing and latching requirements for medium voltage and high voltage circuit breakers, and interrupting duty for fast operating interrupters such as fuses and low voltage circuit breakers, and to calculate relay currents used in protective device coordination studies. One half cycle duty currents are calculated using sub transient or modified sub transient reactance (X''_d) for all sources of short circuit current as specified in the appropriate ANSI calculating procedures. (See Appendix XI - References).

2. Interrupting Duty

Calculated one (1), three (3) and five (5) cycle (interrupting) short circuit currents are used to determine interrupting duties for medium voltage and high voltage circuit breakers, and to calculate relay currents used in protective device coordination studies. Interrupting duty currents are calculated using modified sub transient reactances for all sources of short circuit current, as specified in the appropriate ANSI calculating procedures (See References).

The Short Circuit Study does not include pre fault steady state load currents, since the effects of system load currents on the total current through a device during a fault is usually negligible in typical industrial and commercial electrical distribution systems.