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1. Scope

This Practice provides guidelines for electrical system analysis used to develop and validate electrical power systems performance, including safety, reliability, and efficiency.

This Practice does not provide guidance on the type of analysis to be performed for specific applications. The following items are examples of additional studies which are beyond the scope of this Practice:

a. Ground grid study
b. High voltage substation design analysis
c. Insulation coordination studies
d. Switching transients
e. Flicker
f. Telephone Interference Factor (TIF)
g. Load shedding
h. Motor re-acceleration
i. System efficiency
j. Power factor correction

2. References

Applicable parts of the following industry codes and standards shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 Industry Codes and Standards

- Institute of Electrical and Electronic Engineers (IEEE)
  - IEEE C37.06 - AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis – Preferred Ratings and Related Required Capabilities for Voltages Above 1000 V
  - IEEE C37.010 - Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
  - IEEE C37.012 - Application Guide for Capacitance Current Switching for AC High Voltage Circuit Breakers
  - IEEE C37.5 - Guide for Calculation of Fault Currents for Application of AC High-Voltage Circuit Breakers on a Total Current Basis (withdrawn)
  - IEEE C37.13 - Low Voltage AC Power Circuit Breakers Used in Enclosures
  - IEEE 141 (IEEE Red Book) - Recommended Practices for Electric Power Distribution in Industrial Plants
  - IEEE 242 (IEEE Buff Book) - Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
3. Definitions

_Arc Flash Hazard Calculations:_ An analysis of the electrical system performed to determine the flash protection boundaries and arc energies near energized electrical equipment. Results are used to determine the minimum personal protective equipment (PPE) required. Short circuit calculations and coordination studies are used to determine the flash protection boundaries.

_Average Service Availability Index (ASAI):_ Per IEEE 1366, ASAI is the fraction of time (often in percentage) that a customer has received electrical power during a defined reporting period.

_Bus:_ A junction into which one or more feeders enter or exit. In a software model, a bus is also a system node, and can represent a junction between equipment (such as between a transformer and a cable).

_Coordination Study:_ Calculations used to determine optimal electrical protective device selection and settings to assure prompt isolation of faults with minimal effects on the surrounding system, and fast restoration of power once the fault has been cleared. Short Circuit calculations are used in determination of optimal settings. Arc flash calculations are used to determine the effects of device fault clearing times on incident energy.

_Feeder:_ A cable or bus-bar arrangement used to transmit electric power

_Flash Protection Boundary:_ An approach limit at a distance from exposed energized parts within which a person could receive a second degree burn if an electrical arc flash were to occur.

_Harmonic Analysis:_ Calculations used to predict the distortion caused by harmonic frequencies produced by non-linear loads.

_Load Flow Analysis:_ Calculations which determine the flow of power and current into and out of a bus and the bus voltage and power factor.
**Mean Time Between Failures (MTBF):** Average exposure time between consecutive failures of a component

**Point of Common Coupling:** Defined in IEEE 519 as the point in a utility power system at which another customer can be served

**Reliability Study:** Calculations used to predict equipment failure rates in terms of expected time between failures, expected effect of those failures upon the operation of the plant served, and expected recovery times from failures

**SCADA:** Supervisory Control And Data Acquisition

**Short Circuit Calculations:** Calculations used to determine the maximum and minimum short circuit currents that can be present during an electrical short circuit at a given bus

**Stability Study:** Calculations used to predict the behavior of synchronous machines in an AC system when changes in the system occur (e.g., addition of loads, loss of loads, faults)

**System Average Interruption Duration Index (SAIDI):** Per IEEE 1366, the total duration of electrical power interruption during a defined period of time

**System Average Interruption Frequency Index (SAIFI):** Per IEEE 1366, how often a sustained electrical power interruption occurs over a defined period of time

**Time-Current Curve:** A log-log graph in which current is the x-axis and time is the y axis, used to plot the protection device characteristics against available fault and load currents for the purpose of coordinating between protective devices

4. **General**

4.1 This Practice is intended for use by persons knowledgeable of the applicable codes and standards, and responsible for electrical system design, operations and maintenance of electrical facilities and power systems.

4.2 The studies described in this Practice can be used in the design of new installations or the review or modification of existing installations.

4.3 This Practice does not cover each type of study in detail, but provides general guidance for the application of the studies. The IEEE documents referred to in this Practice provide a step by step procedure for each study. NETA ATS provides additional guidance.

4.4 The system studies to be conducted are typically performed using software of the owner’s choice.

4.5 Input values for all studies should be based on actual manufacturer nameplate data or certified test reports obtained from project design documents or from a field survey of the facility equipment. Typical data is also available from IEEE standards or guidelines.

4.6 The owner should identify the responsibility for the collection of raw data for studies. Typically, for a grass roots facility, an engineering firm is responsible for data gathering. In the case of existing facilities, the data gathering may be performed by the owner, the engineering firm or jointly. Typically, the owner is responsible for obtaining the utility data.
4.7 The owner should identify different scenarios to address all critical aspects of normal operation, abnormal operation, outages, turnarounds, and commissioning. These scenarios should be defined by the owner and discussed with the consultant during the preliminary design stage using separate one-line configurations (e.g., startup, fault, seasonal loading, and separate sources in-service).

4.8 The owner should determine the level of detail of the power study (e.g., loads less than 480 V may be modeled at the discretion of the customer or entity performing the study, lumping loads other than largest motor, or lumping loads 50 HP and smaller and modeling loads greater than 50 HP).

4.9 The owner should be responsible for defining which electrical equipment (e.g., standby generators, UPS systems, panelboards, DC systems) is included in the scope of the study.

4.10 Methods, background information, and discussion for all studies in this Practice and others can be found in IEEE 399.

5. **Types of Studies**

5.1 **Stages of Design**

5.1.1 **Preliminary Studies**

Preliminary studies use preliminary data from typical data sources for the following:

a. Determine preliminary ratings for major equipment

b. Develop preliminary performance of the system. Perform load flow and voltage drop. Identify areas of concern such as “large” loads, harmonic loads, etc.

c. Determine acceptable parameters for preliminary studies (e.g., 1 kVA=1 HP, typical load data, load data based on process and mechanical calculations)

d. Define equipment data tolerances (e.g., IEEE’s standard transformer impedance tolerance of ± 7 ½ %)

e. Determine the limits of the system. Cases are analyzed for variations in load, available short circuit, available sources, and known issues with topology (long cable runs).

f. Develop the source requirements used for local generation development. (e.g., utility voltage, number of lines, available short circuit capacity)

g. Determine reliability requirements for the operating equipment (includes sources MTBF)

h. Develop system topology to account for normal/spare, 2 out of 3 loads, etc.

i. Address key items, summarize findings, and provide recommendations, basis, methodology, and assumptions

j. Establish load shedding requirements, if any
5.1.2 Final Studies

5.1.2.1 Final studies use actual test data for installed equipment and the following:

a. Source data from utility
b. Transformer name plate data. If name plate data is unavailable, use IEEE’s standard transformer impedance tolerance of ± 7 ½ %.
c. Load data from manufacturers
d. Cable lengths from cable schedule
e. Topology in one line diagrams
f. Special conditions or considerations (e.g., spares, future growth, large motors)
g. Feeder topology, duct banks, open wire
h. Harmonic loads

5.1.2.2 Final studies perform the following functions:

a. Address key items, summarize findings, and give recommendations
b. State the basis, methodology, and assumptions
c. Establish load shedding requirements, if any
d. Validate power study with real-time power system field measurements

5.1.3 Future sources (e.g., generation, utility lines) and future loads should be included in the studies as operating cases.

5.2 Load Flow Studies

5.2.1 Load flow studies are essential for planning and design of power systems. Load flow studies analyze and predict static system performance under specified operating conditions. Conditions may include normal and alternate (e.g., emergency, stand-by) modes, present and future arrangements, etc. Load flow studies provide the real and reactive power flows of the system, voltages at system buses, power factor, evaluation of equipment/feeder ratings, and transformer tap selection.

5.2.2 The load flow study is typically performed before other studies and is used to establish an operating point for other studies.

5.2.3 The effect of system performance under changing system configurations can also be predicted. Real-time information from SCADA systems may be used in what-if load flow analysis to assist in control of local generation and load shedding schemes.

5.2.4 Real power, reactive power, current, power factor, node voltages and other results are used to verify equipment ratings and operating conditions. Study results can be used to confirm the following:
a. Bus operating voltages are within specified values (standard system voltages and acceptable voltage ranges should be in accordance with IEEE 141 “Red Book”).

b. Equipment is loaded within specified values (equipment ratings are provided by equipment manufacturers; although some typical ratings are available in software libraries or standards, e.g., cable ampacity tables).

c. Power factor, voltage levels and reactive power consumption are within utility contract limits or the limits of the power source.

5.2.5 The load flow study can identify spare capacity to allow for growth.

5.2.6 Utility per unit voltage range is typically supplied by the electric utility.

5.2.7 The load flow cases that are to be analyzed (i.e., base case and alternate configurations) should be identified as follows:

a. Maximum load base case to help set transformer taps and ampacity requirements.

b. Minimum load base case to help set transformer taps. Under low-load conditions bus voltages can become too high.

c. Alternate load cases to verify operation under expected conditions such as the following:
   (1) Startup loads and their sequence
   (2) Seasonal loads
   (3) Loads dependent on process conditions
   (4) Expansion or design allowances
   (5) Normal/spare (e.g., 2 out of 3) loads. This requires careful consideration of the connection points of the loads. A diversity factor may be used to account for the simultaneous demand of the loads.

   Comment: The use of diversity factors should be considered on a case by case basis.

d. Alternate source/distribution configurations such as the following should be considered where applicable:
   (1) Double ended buses with single source feed (closed tie breaker)
   (2) Double ended buses with dual source feed (open tie breaker)
   (3) Loss of utility. May be complete loss or partial loss (e.g., loss of one of multiple feeders).
   (4) Loss of generation
   (5) Loss of transformer

5.2.8 Combinations of loads and alternate conditions may be required depending on the requirements of design.

5.2.9 Transformer taps should be set to maintain voltage within tolerance for all expected load variations.
5.3 Short Circuit Studies

5.3.1 The short circuit study is essential for specifying withstand and interrupting capacities for electrical equipment, for determining optimal protective device settings, and for grounding system design. The results of these studies are also used in arc-flash studies to predict incident energy.

5.3.2 Short circuit current is calculated at system buses and other nodes depending on the desired study. Software programs permit selection of the nodes to analyze. Typically, short circuit current is calculated at all electrical equipment (e.g., switchgear, motor control centers, panels).

5.3.3 Calculations are performed in accordance with the methods discussed in IEEE C37.06, C37.010, C37.5 and C37.13.

5.3.4 Sources of Short Circuit Current

5.3.4.1 For each case study individual sources of short circuit current should be considered.

5.3.4.2 Generators and many loads are sources of short circuit currents. Typically, generators are included in the short circuit calculations, but loads may not be included depending on the load type.

5.3.4.3 For many facilities the electric utility is the only generation source available. Utility fault contribution values should be obtained from the utility. If utility contribution is unknown, an infinite bus (i.e., MVA > 999) with a reactance to resistance ratio (X/R) of 17 may be assumed for preliminary calculations. This contribution is conservative and yields higher short circuit values than reality in most cases. Assuming an infinite bus may result in lower incident energy for arc flash, depending on the relay operating settings.

5.3.4.4 Non-motor loads do not contribute to short circuit (for AC short circuit calculations) and therefore are ignored in calculations.

5.3.4.5 Motors contribution to a short circuit at the motor terminals is approximately the locked rotor current (LRC) of the motor. Software programs use the motor sub-transient reactance, (X$d$”), for calculations. This reactance can be approximated as 1/LRC of the motor.

5.3.4.6 Motors driven by variable speed drives (VSD) do not contribute to short circuit on the line side of the VSD.

5.3.4.7 If capacitor banks are used, special considerations should be given to their impact on circuit breaker close and latch ratings and capacitor switching ratings. For additional information see IEEE C37.012.

5.3.4.8 See IEEE 141 for guidance on consideration of loads in short circuit calculations.
5.3.5 Parameters

5.3.5.1 Driving Voltage

1. A driving voltage is required at each source of short circuit. Typically, 1.02 per unit voltage is used, especially in initial calculations. However, the final study should use the actual values provided by the utility.

2. Utility per unit voltage range is typically supplied by the electric utility together with their short circuit information (typically MVA, impedance and X/R ratio).

3. Generator driving voltage is set as part of the generator operating parameters.

4. Some software programs can take the utility voltage and propagate the voltage through the system based on transformer tap settings. This method can give a more realistic short circuit calculation.

5.3.5.2 Impedance

1. Elements of the electrical system are generally defined by their impedance values for the purposes of short circuit calculations.

2. The short circuit capability of generators is obtained from the manufacturer’s data. This capability is typically in the form of base MVA and per unit reactance. For initial calculations typical data is available in IEEE C37.010. (The same information is available in IEEE 141.)

3. Generator short circuit contribution decays in time. ANSI standards use generator saturated direct-axis subtransient reactance (Xd") for ½ cycle (i.e., momentary) short circuit calculations, generator saturated direct-axis transient reactance (Xd’) for 5 cycle (i.e., interrupting) calculations, and generator direct-axis reactance (Xd) for 30 cycle calculations.

4. Passive elements (e.g., cables, reactors and transformers), which carry short circuit current, are defined by their impedance.

5. Transformer impedance is available from the manufacturer’s name plate and is typically shown on one-line diagrams. Typical values are also available in IEEE 141. Some software programs include typical values in their libraries.

6. Cable impedance is available from manufacturer data sheets and software libraries. It should be noted that feeder impedance is a function of the physical configuration of the circuit. A typical triplex cable has lower impedance than a flat configuration of single conductors.

7. All elements mentioned above have an X/R ratio used in calculations to determine the asymmetry of short circuit current. If using typical data, the X/R ratios can be obtained from IEEE 141.
5.3.6 The scenarios that are to be analyzed (i.e., base case and alternate configurations) should be identified as follows:

a. Minimum short-circuit case (e.g., no loads included or only in-plant generation)

b. Maximum short-circuit case (e.g., all generation including stand-by)

c. Alternate load cases including the following:
   (1) Loads with alternate feeds, especially large motors
   (2) Seasonal loads
   (3) Expansion or design allowances

d. Alternate source/distribution configurations such as the following should be considered where applicable:
   (1) Double ended buses with single source feed (closed tie breaker)
   (2) Double ended buses with dual source feed (open tie breaker)
   (3) No utility (i.e., in-plant generation only)

5.3.7 Combinations of loads and alternate conditions may be required depending on the requirements of design.

5.3.8 For primary and secondary selective systems, if both sources are paralleled only momentarily during automatic or manual transfer operations, short circuit studies may be performed with only one of the sources present. If both sources are paralleled for an extended length of time, the study should be performed with both sources present. Having both sources paralleled results in higher fault currents.

5.3.9 Several sets of calculations should be performed to evaluate electrical equipment, and for use in other relay coordination and arc flash analysis. These calculations should include the following cases:

a. Three-Phase Fault, 1/2 cycle, for comparison to low voltage (i.e., below 1kV) breaker ratings in accordance with IEEE C37.13. This case can also be used for fuse ratings of all voltages.

b. Three-Phase Momentary Duty for comparison to ratings in accordance with ANSI C37.5 for equipment certified to the 1964 standard, and Momentary Close and Latch for comparison with ratings in accordance with IEEE C37.010 for equipment certified since 1964 standard. If name plate data is unavailable, manufacturer can supply actual data.

c. Three-Phase Interrupting Duty for comparison with ratings of high voltage (i.e., 1 kV and above) circuit breakers in accordance with ANSI C37.5 for total current rated breakers certified to the 1964 standard, and IEEE C37.010 for symmetrical current rated breakers certified since 1964 standard. For an X/R ratio greater than 17, the asymmetrical current should be evaluated to properly size the interrupting rating of the circuit breaker. If name plate data is unavailable, manufacturer can supply actual data.

   Comment: If the node is more than two transformations away from a generator, the X/R ratio is typically less than 17.
d. Three-Phase, 30 cycle, for relay coordination and arc flash calculations

e. Momentary and interrupting calculations for relay coordination and arc flash calculations

5.3.10 Typically, the three-phase fault report is the worst case scenario. However, in some solidly-grounded systems, line to ground faults near the source can be higher than the three-phase fault. A line to ground fault case should be run on solidly grounded systems for ground protective device coordination.

5.3.11 For resistance grounded systems, popular in industrial facilities, line to ground fault currents are typically limited by the ground impedance and can be determined by inspection. If multiple zero-sequence sources (i.e., ground fault contributions) are available, they are additive. For multiple zero-sequence sources cases, multiple ground fault coordination scenarios may be needed.

5.3.12 Line to line faults are not used for equipment ratings and are typically not required for relay coordination. However, it should be noted that a line to line fault on the Y side of a Delta-Y transformer results in Delta side currents 15% greater than the turns ratio equivalent.

5.4 Protection and Coordination Studies

5.4.1 The protection and coordination study is essential for determining protective device selectivity, optimal protective device settings, and system fault isolation. Arc-flash studies cannot be performed using only short circuit study data. The protection and coordination study is required to determine the fault interruption time at minimum and maximum fault levels.

5.4.2 A protection and coordination study should be based on principles and methods discussed in IEEE 242 (Buff Book), and requirements of NFPA 70.

5.4.3 A short circuit study model of the power system in its normal operating state should be used for the protection and coordination study. Typically, a separate coordination case for each system configuration should be used, such as the following:

a. Alternate sources
b. Main-tie-main configurations
c. Utility vs. local generation, or a combination of the two
d. Start-up and commissioning cases
e. Abnormal operating conditions

5.4.4 Coordination should be reviewed whenever a substantial change is made to the electrical system or as required by the authority having jurisdiction.

5.4.5 If using automatic transfer schemes to restore power quickly, care should be taken, through the use of zone based protection or current based blocking schemes, not to force the automatic transfer system to reclose into a fault.

5.4.6 Zone-based protection (e.g., differential or zone-based interlocking) is frequently used at medium and high voltage as primary protection for devices like transformers, busses, and long feeder cables, with overcurrent protection as backup. Zone based protective devices should be shown on the Time Current
Curve (TCC). The coordination modules of software packages do not typically cover zone-based protection because settings are hardware-specific. However, a user defined curve or other notation may be used to illustrate the zone protection performance and coordination with time-current devices. The manufacturer’s instruction bulletin should be consulted for settings, instructions, and clearing times.

5.4.7 Modern digital relays are multi-function in nature and perform both zone-based and coordinated protection functions, and numerous other functions (e.g., data storage and communication to a SCADA system). Typically, these devices are sufficiently reliable and one relay can perform primary and backup functions. However, in very critical reliability operations, installing two or more multi-function relays in redundant configurations should be considered.

5.4.8 Low voltage essential distribution systems (e.g., UPS, standby generation, DC supplies) should also be coordinated.

5.5 Arc-Flash Hazard Studies

5.5.1 Arc-flash hazard calculations are performed to determine the worst case incident energy and arc flash boundaries of electrical installations.

5.5.2 Once the short circuit study determines the bolted fault magnitudes, an arc flash hazard calculation should be performed in accordance with NFPA 70E and/or IEEE 1584.

5.5.3 Protective device coordination studies performed in conjunction with the arc-flash hazard analysis should be used to minimize fault clearing times to reduce the incident energy. Coordination can be modified through an iterative process to achieve a lower PPE level.

5.5.4 The use of instantaneous protective devices (e.g., maintenance switches, optical devices, zone-interlocking and differential schemes) can be used to help keep the expected incident energy as low as possible.

5.5.5 IEEE-1584 may be used for three-phase enclosed systems with voltages 208 V–15,000 V and bolted three-phase fault current 700 A–106,000 A.

5.5.6 NFPA 70E may be used for single and three-phase enclosed systems with voltages greater than 50 V.

5.5.7 IEEE C2-2012 may be used for open air substations, open air transmission and distribution three-phase systems.

5.6 Motor Starting Studies

5.6.1 Static motor starting calculations predict the bus and device voltages during a motor start. These predictions are important to ensure that the voltage sag produced by a starting motor does not adversely affect the facility (e.g., High Intensity Discharge (HID) lighting can extinguish and must re-strike, power supplies can sag, contactors can drop out).

5.6.2 As a minimum, dynamic motor starting analysis should be performed for the largest low voltage (LV) motor on a bus and for all medium voltage (MV) motors. The dynamic model produces a graph output of voltage, torque, and
5.6.3 Motor starting studies should be considered on the largest motor on a bus if the motor is ≥30\% of the nominal kVA rating of the transformer supplying the bus, or ≥15\% of the kVA rating of the motor’s supply generator.

5.6.4 Minimum acceptable voltage levels are provided in *IEEE 399-1997* (Brown Book), Table 9-1.

5.6.5 Motor starting studies should be performed at nominal short-circuit conditions and repeated at minimum short-circuit values. Minimum short-circuit values are site specific and are a function of substation conditions (e.g., a secondary selective substation on one transformer, transmission lines out of service, and/or reduced generation on islanded schemes).

5.6.6 The manufacturer name plate data should be used for the motor and driven equipment speed-torque curves when dynamic starting evaluations are completed.

5.7 Stability Studies

5.7.1 Steady-state stability studies determine the ability of the power system containing two or more synchronous machines and/or interconnected generation systems to maintain synchronism between machines within the system following slow or normal (i.e., not transient changes such as faults and switching operations) load changes.

5.7.2 Transient stability studies predict the reactions of synchronous machines supplying power to a system under abnormal conditions. These studies are performed for the following reasons:

a. To ensure generation stays on line and can accept the step load change upon partial loss of generation or of the power system

b. To iteratively determine critical maximum fault clearing times for line to ground and line to line faults to prevent instability and loss of generation

c. To iteratively determine critical maximum fault clearing times for line to ground and line to line faults to prevent instability of large synchronous motors

d. If the power system is subjected to un-synchronized break before make transfers

5.7.3 Facilities with synchronous condensers or multiple large synchronous motors should also be addressed when performing stability studies.

5.7.4 Proper consideration should be taken when deciding to perform stability studies due to high cost and complexity. For example, a system with purely inductive loads might not require a stability study.

5.7.5 *IEEE-399* provides recommended practices and procedures for performing stability studies.

5.7.6 Engine, governor, generator, motor and exciter model data should be obtained from machine tested or nameplate data. Estimated or typical data should not be
used unless certified as type-test data by the machine manufacturer. Available software provides typical default values; however the user should not expect an accurate study based on these defaults unless the actual values are known to be close to them.

5.8 Harmonic Studies

5.8.1 Harmonic studies are used to predict the steady-state harmonic content of the power system waveform.

5.8.2 Modern power systems feed a variety of non-linear devices (e.g., adjustable speed drives, soft-starters, solid-state rectifiers, lighting ballasts, dimmers and many other devices). These devices, by virtue of their non-linearity, introduce power signals at higher harmonic frequencies. The power signals cause system disturbances and additional heat, reactive and capacitive losses. In addition, capacitors and reactors added to power systems to mitigate power factor or short circuit current concerns, interact with the higher harmonic power flows, such that harmonic content needs to be considered when specifying power factor correction equipment.

5.8.3 Typically system harmonic studies are performed if non-linear loads are greater than 30% of the total system loads, although limited studies may be performed in the vicinity of large non-linear loads.

5.8.4 For some newer drive technologies, the topology of the drive may minimize the need for harmonic studies.

5.8.5 Limits and specifications for Total Harmonic Distortion (THD) and Total Demand Distortion (TDD) values should be in accordance with IEEE 519.

5.8.6 Values of THD and TDD provided in IEEE 519 apply at the Point of Common Coupling (PCC) and are meant to be a net value for an entire system. However, if the system has a defined point where all the non-linear loads are coupled to only linear loads, a measurement of THD at that point is a valid measurement of the THD to which the linear loads are subjected.

5.8.7 Studies performed in accordance with IEEE 519 are not capable of predicting local harmonics induced by adjacent drives, soft starters, or other non-linear loads. Measures need to be taken to prevent these currents from affecting linear loads. Harmonic studies should not be expected to pinpoint the following local problems:

a. Nuisance alarms on high resistance ground detection circuits

b. Nuisance alarms or trips on sensitive ground fault protection on transformers

c. Negative sequence current flow in motors

d. System resonances and damage to capacitor banks

5.8.8 Harmonic studies are most effective at predicting distortion values if the plant to be evaluated has all linear and non-linear loads running, and the values of THD and TDD are nearly the same. Measurements of THD performed at part loads penalize the plant for the low load condition. Therefore, the TDD value should be applied for low load conditions. THD values are always higher except if the plant is fully loaded.
5.8.9 Harmonic studies should be considered to address IEEE 519 requirements for new and for plant expansions with significant capacitance and non-linear loads to determine the presence or absence of system resonances.

5.8.10 Harmonic studies should also be considered for a new facility if the load-flow and power factor compensation are needed to determine how to meet the reactive power demands and harmonic performance limits of the system.

5.8.11 IEEE-399 (Brown Book) provides recommended practices and procedures for performing harmonic studies.

5.8.12 Typically, if harmonic studies are required, the results should be followed-up with field measurement to validate the results and investigate for harmonic impact on equipment life cycle.

5.9 Reliability Studies

5.9.1 Reliability refers to the ability of a component or system to perform required functions safely under stated conditions for a stated period of time.

5.9.2 System reliability studies use probability theory to quantify the relative reliability of potential configurations of an existing or new system. Results from the studies include reliability indices such as frequency of load point failures (lambda), average outage duration and annual unavailability, and other indices (e.g., SAIFI, SAIDI, ASAI) to assess the decrease in availability of the system because of system and equipment failures.

5.9.3 Reliability studies are used to address electrical system issues to make the following determinations:

a. To identify single point of failures that would adversely affect system reliability

b. See that faults are properly isolated and that critical loads are not vulnerable to interruption or delayed repair

c. Analyze the critical areas and evaluate the need for special restoration equipment and spare parts

d. Based on probability and economic analysis, recommend capital or preventive maintenance investments as indicated by the studies

e. Make carefully documented contingency plans

f. Check the quality of the power supply from the utility and throughout the plant to determine if the equipment is vulnerable to premature failure

g. Develop preventive maintenance and checking to ensure continuous optimum reliability performance of the plant

5.9.4 Reliability studies are used to determine if a proposed power system meets the reliability requirement of its loads. Reliability studies can be used to quantify cost versus reliability to evaluate the optimal level of redundancy required in a system. System performance and cost are optimized based on the ability of the loads to operate with an acceptable amount of downtime.

5.9.5 Reliability studies are most effective if historical data from the same site, conditions, and equipment is used. IEEE 493 contains generic historical
reliability data which may be used if actual historical data from the site in question is not available. Generic data should only be used if site data is unavailable.

5.9.6 Reliability study calculations are based on typical or historical failure rates and time to repair. The failure rates are affected by additional factors such as maintenance and operating practices. Maintenance which is deferred, and the availability of up-to-date engineering drawings or written documents, can have an effect on reliability by increasing time-to-repair intervals. These factors cannot be predicted by a study, so their effect should be additionally considered in predicting the reliability of a site.

5.9.7 Reliability study calculations and methods are provided in IEEE 493 (Gold Book) and IEEE 1366.

5.9.8 The IEEE PCIC website has additional data at no extra cost from John Probst’s paper PCIC 2007-1 “An update to the Spreadsheet Electrical Reliability Model”.

6. Deliverables

6.1 A reproducible final report that includes the following information should be provided to the owner:

a. List of specific studies included
b. Description, purpose and scope, and basis of study including any assumptions
c. Software generated One Line Diagrams of the system study on an individual scenario basis
d. If provided, marked up One Line Diagrams of the system
e. Listing of system data
f. Short Circuit current of system fault types and system configurations in a summary table
g. An evaluation of equipment ratings subject to available short circuit currents
h. Tabulation of arc hazard assessment findings and incident energy equipment labels
i. For each study, a list of deficiencies, problems and limitations within the system accompanied with recommendations for resolving the problems
j. System modeling and component libraries
k. Low voltage Motor Control Center (MCC) protection tables
l. One Time Current Curve (TCC) per type of motor (MV), or as an alternate One TCC per motor (MV), and associated relay setting tables
m. One TCC for largest motor only for LV bus
n. Separate TCC for each generator
o. Separate TCC for process substation incomers
p. Relay data bases (company specific formats)
q. Relay configuration (setting) files (e.g., Multilin, Siemens, SEL). Exclude communications mapping.

r. Main-tie-main control configurations (i.e., protective relay set-ups)

s. See the *NETA ATS*, Section 6 for additional guidance

t. Direct Current (DC) and Uninterruptible Power System (UPS) auxiliary power system analysis

u. Raw equipment input data used

v. Existing system model for the facility if available

w. Firmware versions, serial numbers of relays, and complete order number

x. Decisions on level of study Levels of details and written analysis needed