# SECTION 260573 - POWER SYSTEM STUDIES

## PART 1 - GENERAL

### 1.1 SUMMARY

A. The Work of this Section Includes:

1. Arc-flash hazard study.

B. Related Requirements:

1. Section 260010 "Supplemental Requirements for Electrical" specifies additional requirements applicable to coordinating, scheduling, and sequencing of the Work specified in this Section.

### 1.2 DEFINITIONS

A. Digital Twin: The digital representation of a real-world entity, concept, or notion, either physical or perceived.

### 1.3 ACTION SUBMITTALS

A. Product Data: For power system analysis software to be used for studies.

1. Product Certificates: For power system study software applications, include certificate stating compliance with specified requirements, signed by software manufacturer.

B. Power System Study Reports:

1. Submit reports after approval of system protective devices submittals. Submittals must be in digital form.

2. Submit arc-flash study input data, including completed computer-program input data sheets.
3. Submit study report for action prior to receiving final approval of distribution equipment submittals. If formal completion of studies will cause delay in equipment manufacturing, obtain approval from Architect for preliminary submittal of sufficient study data to ensure that selection of devices and associated characteristics is satisfactory.
4. Submit revised one-line diagram, reflecting field investigation results and results of short-circuit study.

C. Data files for studies in format compatible with Owner's power system analysis software.



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D. Digital-twin models.

1.4 QUALITY ASSURANCE

A. Studies must be performed using commercially developed and distributed software designed specifically for power system analysis.

B. Software algorithms must comply with requirements of standards and guides specified in this Section.

C. Manual calculations are unacceptable.

PART 2 - PRODUCTS

2.1 POWER SYSTEM ANALYSIS SOFTWARE

A. Manufacturers: Subject to compliance with requirements, provide products by the following:

1. EasyPower; brand of Bentley Systems, Inc.

B. Standard Features:

1. Power System Analysis:

a. Power-systems-analysis software applications must have analytical capability to calculate "mandatory," "very desirable," and "desirable" features as listed in IEEE 3002 series standards.
b. Computer software application must be capable of plotting and diagramming time-current-characteristic curves as part of its output. Computer software program must report device settings and ratings of overcurrent protective devices and must demonstrate selective coordination by computer-generated, time-current coordination plots.
c. Computer software application must be designed to perform arc-flash analysis or have function, component, or add-on module designed to perform arc-flash analysis.

2. Analysis Standards:

a. Short-Circuit Current Analysis: In accordance with IEEE 3002.3.
b. Device Coordination Analysis: In accordance with IEEE 3004.3 and IEEE 3004.5.
c. Load-Flow Analysis: In accordance with IEEE 3002.2.
d. Motor-Starting Analysis: In accordance with IEEE 3002.7.
e. Harmonic Analysis: In accordance with IEEE 3002.8.
f. Transient Stability Analysis: In accordance with IEEE P3002.9.
g. Arc-Flash Hazard Analysis: In accordance with IEEE 1584.



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3. Capable of printing arc-flash hazard warnings for equipment on vinyl, weather- and UV-resistant, pressure-sensitive adhesive labels complying with NFPA 70E.

    a. Label must have orange header with wording, "WARNING, ARC-FLASH HAZARD," and must include the following information taken directly from arc-flash hazard study:

        1) Equipment designation.
        2) Nominal voltage.
        3) Protection boundaries.

            a) Arc-flash boundary.
            b) Restricted approach boundary.
            c) Limited approach boundary.

        4) Arc-flash PPE category.
        5) Required minimum arc rating of PPE in Cal/cm squared.
        6) Available incident energy.
        7) Working distance.
        8) Engineering report number, revision number, and issue date.

C. Other Available Features Required by the Project:

1. Simultaneous faults.
2. Explicit negative sequence.
3. Mutual coupling in zero sequence.

## PART 3 - EXECUTION

### 3.1 EXAMINATION

A. Collect and analyze data for power system studies.

1. Verify completeness of data supplied in one-line diagram on Drawings. Call discrepancies to Architect's attention.
2. For equipment included as Work on the Project, use characteristics submitted under provisions of action submittals and information submittals for the Project.
3. For relocated equipment and equipment that is existing to remain, obtain required electrical distribution system data by field investigation and surveys, conducted by qualified technicians and engineers in accordance with NFPA 70E.
4. Gather and tabulate required input data to support power system studies. Comply with requirements in Section 017839 "Project Record Documents" for recording circuit protective device characteristics. Record data on Record Document copy of one-line diagram. Comply with recommendations in IEEE 3002 series standards as to amount of detail that is required to be acquired in field. Field data gathering must be by, or under supervision of, qualified electrical professional engineer. Data include, but are not limited to, the following:



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a. Product data for the Project's overcurrent protective devices involved in overcurrent protective device coordination studies. Use equipment designation tags that are consistent with electrical distribution system diagrams, overcurrent protective device submittals, input and output data, and recommended device settings.
b. Electrical power utility impedance at service.
c. Power sources and ties.
d. Short-circuit current at each system bus (three phase and line to ground).
e. Full-load current of loads.
f. Voltage level at each bus.
g. For transformers, include kVA, primary and secondary voltages, connection type, impedance, X/R ratio, taps measured in percent, and phase shift.
h. For reactors, provide manufacturer and model designation, voltage rating, and impedance.
i. For circuit breakers and fuses, provide manufacturer and model designation. List type of breaker, type of trip and available range of settings, SCCR, current rating, and breaker settings.
j. Generator short-circuit current contribution data, including short-circuit reactance, rated kVA, rated voltage, and X/R ratio.
k. For relays, provide manufacturer and model designation, current transformer ratios, potential transformer ratios, and relay settings.
l. Maximum demands from service meters.
m. Busway manufacturer and model designation, current rating, impedance, lengths, and conductor material.
n. Motor horsepower and NEMA MG 1 code letter designation.
o. Low-voltage cable sizes, lengths, number, conductor material, and conduit material (magnetic or nonmagnetic).
p. Medium-voltage cable sizes, lengths, conductor material, cable construction, metallic shield performance parameters, and conduit material (magnetic or nonmagnetic).
q. Derating factors.

## 3.2 PREPARATION

A. Preparation of Data for Short-Circuit Study:

1. Verify completeness of data supplied on one-line diagram. Call discrepancies to Architect's attention.
2. For equipment included as Work on the Project, use characteristics submitted under provisions of action submittals and information submittals for the Project.
3. Prepare one-line diagram of modeled power system, showing the following:

a. Protective device designations and ampere ratings.
b. Conductor types, sizes, and lengths.
c. Transformer kVA and voltage ratings.
d. Motor and generator designations and kVA ratings.
e. Switchgear, switchboard, motor-control center, and panelboard designations and ratings.
f. Derating factors and environmental conditions.



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g. Revisions to electrical equipment required by study.

B. Preparation of Data for Overcurrent Protective Device Coordination Study:

1. Prepare data sheets to supplement electrical distribution system one-line diagram, cross-referenced with tag numbers on diagram, indicating the following:

a. Special load considerations, including starting inrush currents and frequent starting and stopping.
b. Transformer characteristics, including primary protective device, magnetic inrush current, and overload capability.
c. Motor full-load current, locked rotor current, service factor, starting time, type of start, and thermal-damage curve.
d. Generator thermal-damage curve.
e. Ratings, types, and settings of utility company's overcurrent protective devices.
f. Special overcurrent protective device settings or types stipulated by utility company.
g. Time-current-characteristic curves of devices indicated to be coordinated.
h. Manufacturer, frame size, interrupting rating in amperes root mean square (rms) symmetrical, ampere or current sensor rating, long-time adjustment range, short-time adjustment range, and instantaneous adjustment range for circuit breakers.
i. Manufacturer and type, ampere-tap adjustment range, time-delay adjustment range, instantaneous attachment adjustment range, and current transformer ratio for overcurrent relays.
j. Switchgear, switchboards, motor-control centers, and panelboards ampacity, and SCCR in amperes rms symmetrical.
k. Identify series-rated interrupting devices for condition where available fault current is greater than interrupting rating of downstream equipment. Obtain device data details to allow verification that series application of these devices complies with NFPA 70 and UL 489 requirements.

2. Examine the Project's overcurrent protective device submittals for compliance with electrical distribution system coordination requirements and other conditions affecting performance of the Work. Devices to be coordinated are indicated on Drawings.
3. Proceed with coordination study only after relevant equipment submittals have been assembled. Overcurrent protective devices that have not been submitted and approved prior to coordination study may not be used in study.

C. Preparation of Data for Arc-Flash Hazard Study:

1. Assemble data from short-circuit study and overcurrent protective device coordination study.
2. Proceed with arc-flash study only after relevant equipment submittals have been assembled. Overcurrent protective devices that have not been submitted and approved prior to arc-flash study may not be used in study.



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3.3 SHORT-CIRCUIT STUDY

A. Base study on device characteristics supplied by device manufacturer.

B. Extent of electrical power system to be studied is indicated on Drawings.

C. Begin short-circuit current analysis at service, extending down to system overcurrent protective devices as follows:

1. To normal system low-voltage load buses where fault current is 5 kA or less.

D. Study electrical distribution system from normal and alternate power sources throughout electrical distribution system for the Project. Study cases of system-switching configurations and alternate operations that could result in maximum fault conditions.

E. Include AC fault-current decay from induction motors, synchronous motors, and asynchronous generators and apply to low- and medium-voltage, three-phase AC systems. Also account for fault-current DC decrement to address asymmetrical requirements of interrupting equipment.

F. Calculate short-circuit momentary and interrupting duties for three-phase bolted fault and single line-to-ground fault at equipment indicated on one-line diagram.

1. For grounded systems, provide bolted line-to-ground fault-current study for areas as defined for three-phase bolted fault short-circuit study.

G. Include in report identification of protective device applied outside its capacity.

3.4 OVERCURRENT PROTECTIVE DEVICE COORDINATION STUDY

A. Base study on device characteristics supplied by device manufacturer. When analysis of full range of device is impractical, limiting scope of analysis from 10 to 100 percent of device range is acceptable.

B. Extent of electrical power system to be studied is indicated on Drawings.

C. Begin analysis at service, extending down to system overcurrent protective devices as follows:

1. To normal system low-voltage load buses where fault current is 5 kA or less.

D. Study electrical distribution system from normal and alternate power sources throughout electrical distribution system for the Project. Study cases of system-switching configurations and alternate operations that could result in maximum fault conditions.

E. Transformer Primary Overcurrent Protective Devices:



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1. Device must not operate in response to the following:

    a. Inrush current when first energized.
    b. Self-cooled, full-load current or forced-air-cooled, full-load current, whichever is specified for that transformer.
    c. Permissible transformer overloads in accordance with IEEE C57.96 if required by unusual loading or emergency conditions.

2. Device settings must protect transformers in accordance with IEEE C57.12.00, for fault currents.

F. Motor Protection:

1. Select protection for low-voltage motors in accordance with IEEE 3004.8 and NFPA 70.
2. Select protection for motors served at voltages more than 600 V in accordance with IEEE 620.

G. Conductor Protection: Protect cables against damage from fault currents in accordance with ICEA P-32-382, ICEA P-45-482, and protection recommendations in IEEE 3004.7. Demonstrate that equipment withstands maximum short-circuit current for time equivalent to tripping time of primary relay protection or total clearing time of fuse. To determine temperatures that damage insulation, use curves from cable manufacturers or from listed standards indicating conductor size and short-circuit current.

H. Generator Protection: Select protection in accordance with manufacturer's published instructions and IEEE C37.102.

I. Include AC fault-current decay from induction motors, synchronous motors, and asynchronous generators and apply to low- and medium-voltage, three-phase AC systems. Also account for fault-current DC decrement, to address asymmetrical requirements of interrupting equipment.

J. Include coordination of ground-fault protection devices.

K. Calculate short-circuit momentary and interrupting duties for three-phase bolted fault and single line-to-ground fault at equipment indicated on one-line diagram.

1. For grounded systems, provide bolted line-to-ground fault-current study for areas as defined for three-phase bolted fault short-circuit study.

L. Protective Device Evaluation:

1. Evaluate equipment and protective devices and compare to short-circuit ratings.
2. Adequacy of switchgear, motor-control centers, and panelboard bus bars to withstand short-circuit stresses.
3. Application of series-rated devices must be recertified, complying with requirements in NFPA 70.
4. Include in report identification of protective device applied outside its capacity.



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## 3.5 ARC-FLASH HAZARD STUDY

A. Comply with NFPA 70E, including Annex D, for arc-flash hazard study.

B. Preparatory Studies: Obtain short-circuit study and overcurrent protective device coordination study results prior to starting arc-flash hazard study.

C. Calculate maximum and minimum contributions of fault-current size.

1. Maximum calculation must assume maximum contribution from utility and must assume motors to be operating under full-load conditions.

2. Calculate arc-flash energy at 38 percent of maximum short-circuit current in accordance with NFPA 70E recommendations.

D. Calculate arc-flash protection boundary and incident energy at locations in electrical distribution system where personnel could perform work on energized parts.

E. Include medium- and low-voltage equipment locations.

F. Calculate limited, restricted, and prohibited approach boundaries for each location.

G. Incident energy calculations must consider accumulation of energy over time when performing arc-flash calculations on buses with multiple sources. Iterative calculations must account for changing current contributions, as sources are interrupted or decremented with time. Fault contribution from motors and generators must be decremented as follows:

1. Fault contribution from induction motors must not be considered beyond three to five cycles.
2. Fault contribution from synchronous motors and generators must be decayed to match actual decrement of each as closely as possible (for example, contributions from permanent magnet generators will typically decay from 10 p.u. to 3 p.u. after 10 cycles).

H. Arc-flash energy must generally be reported for maximum of line or load side of circuit breaker. However, arc-flash computation must be performed and reported for both line and load side of circuit breaker as follows:

1. When circuit breaker is in separate enclosure.
2. When line terminals of circuit breaker are separate from work location.

I. Base arc-flash calculations on actual overcurrent protective device clearing time. Cap maximum clearing time at two seconds based on IEEE 1584, Section B.1.2.

## 3.6 POWER SYSTEM STUDY REPORTS

A. Preparation of Power System Study Reports: Prepare and submit the following:



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1. Short-Circuit Study Report Contents:

    a. Executive summary of study findings.
    b. Study descriptions, purpose, basis, and scope. Include case descriptions, definition of terms, and guide for interpretation of results.
    c. One-line diagram of modeled power system, showing the following:

        1) Protective device designations and ampere ratings.
        2) Conductor types, sizes, and lengths.
        3) Transformer kVA and voltage ratings.
        4) Motor and generator designations and kVA ratings.
        5) Switchgear, switchboard, motor-control center, and panelboard designations and ratings.
        6) Derating factors and environmental conditions.
        7) Revisions to electrical equipment required by study.

    d. Comments and recommendations for system improvements or revisions in written document, separate from one-line diagram.
    e. Short-Circuit Study Input Data:

        1) One-line diagram of system being studied.
        2) Power sources available.
        3) Manufacturer, model, and interrupting rating of protective devices.
        4) Conductors.
        5) Transformer data.

    f. Protective Device Evaluation:

        1) Evaluate equipment and protective devices and compare to available short-circuit currents. Verify that equipment withstand ratings exceed available short-circuit current at equipment installation locations.
        2) Tabulations of circuit breaker, fuse, and other protective device ratings versus calculated short-circuit duties.
        3) For 600 V overcurrent protective devices, ensure that interrupting ratings are equal to or higher than calculated 1/2-cycle symmetrical fault current.
        4) For devices and equipment rated for asymmetrical fault current, apply multiplication factors listed in standards to 1/2-cycle symmetrical fault current.
        5) Verify adequacy of phase conductors at maximum three-phase bolted fault currents; verify adequacy of equipment grounding conductors and grounding electrode conductors at maximum ground-fault currents. Ensure that short-circuit withstand ratings are equal to or higher than calculated 1/2-cycle symmetrical fault current.

    g. Short-Circuit Study Output Reports:

        1) Low-Voltage Fault Report: Three-phase and unbalanced fault calculations, showing the following for each overcurrent device location:



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a) Voltage.
b) Calculated fault-current magnitude and angle.
c) Fault-point X/R ratio.
d) Equivalent impedance.

2) Momentary Duty Report: Three-phase and unbalanced fault calculations, showing the following for each overcurrent device location:

a) Voltage.
b) Calculated symmetrical fault-current magnitude and angle.
c) Fault-point X/R ratio.
d) Calculated asymmetrical fault currents based on fault-point X/R ratio; based on calculated symmetrical value multiplied by 1.6; and based on calculated symmetrical value multiplied by 2.7.

3) Interrupting Duty Report: Three-phase and unbalanced fault calculations, showing the following for each overcurrent device location:

a) Voltage.
b) Calculated symmetrical fault-current magnitude and angle.
c) Fault-point X/R ratio.
d) No AC Decrement (NACD) ratio.
e) Equivalent impedance.
f) Multiplying factors for 2-, 3-, 5-, and 8-cycle circuit breakers rated on symmetrical basis.
g) Multiplying factors for 2-, 3-, 5-, and 8-cycle circuit breakers rated on total basis.

2. Overcurrent Protection Device Coordination Study Report Contents:

a. Executive summary of study findings.
b. Study descriptions, purpose, basis, and scope. Include case descriptions, definition of terms, and guide for interpretation of results.
c. One-line diagram of modeled power system, showing the following:

1) Protective device designations and ampere ratings.
2) Conductor types, sizes, and lengths.
3) Transformer kVA and voltage ratings.
4) Motor and generator designations and kVA ratings.
5) Switchgear, switchboard, motor-control center, and panelboard designations.
6) Revisions to electrical equipment required by study.

d. Report recommended settings of protective devices, ready to be applied in field. Use manufacturer's data sheets for recording recommended setting of overcurrent protective devices when available.

1) Phase and Ground Relays:



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a) Device tag.
b) Relay current transformer ratio and tap, time dial, and instantaneous pickup value.
c) Recommendations on improved relaying systems, if applicable.

2) Circuit Breakers:

a) Adjustable pickups and time delays (long time, short time, and ground).
b) Adjustable time-current characteristic.
c) Adjustable instantaneous pickup.
d) Recommendations on improved trip systems, if applicable.

3) Fuses: Show current rating, voltage, and class.

e. Time-Current Coordination Curves: Determine settings of overcurrent protective devices to achieve selective coordination. Graphically illustrate that adequate time separation exists between devices installed in series, including power utility company's upstream devices. Prepare separate sets of curves for switching schemes and for emergency periods where power source is local generation. Show the following information:

1) Device tag and title, one-line diagram with legend identifying portion of system covered.
2) Terminate device characteristic curves at point reflecting maximum symmetrical or asymmetrical fault current to which device is exposed.
3) Identify device associated with each curve by manufacturer type, function, and, if applicable, tap, time delay, and instantaneous settings recommended.
4) Plot the following listed characteristic curves, as applicable:

a) Power utility's overcurrent protective device.
b) Medium-voltage equipment overcurrent relays.
c) Medium- and low-voltage fuses including manufacturer's minimum melt, total clearing, tolerance, and damage bands.
d) Low-voltage equipment circuit-breaker trip devices, including manufacturer's tolerance bands.
e) Transformer full-load current, magnetizing inrush current, and ANSI through-fault protection curves.
f) Cables and conductors damage curves.
g) Ground-fault protective devices.
h) Motor-starting characteristics and motor damage points.
i) Generator short-circuit decrement curve and generator damage point.
j) Largest feeder circuit breaker in each motor-control center and panelboard.

5) Maintain selectivity for tripping currents caused by overloads.
6) Maintain maximum achievable selectivity for tripping currents caused by overloads on series-rated devices.



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7) Provide adequate time margins between device characteristics such that selective operation is achieved.
8) Comments and recommendations for system improvements.

3. Arc-Flash Hazard Study Report Contents:

a. Executive summary of study findings.
b. Study descriptions, purpose, basis, and scope. Include case descriptions, definition of terms, and guide for interpretation of results.
c. One-line diagram, showing the following:

1) Protective device designations and ampere ratings.
2) Conductor types, sizes, and lengths.
3) Transformer kVA and voltage ratings, including derating factors and environmental conditions.
4) Motor and generator designations and kVA ratings.
5) Switchgear, switchboard, motor-control center, panelboard designations, and ratings.

d. Short-circuit study output data.
e. Overcurrent protective device coordination study report contents.
f. Arc-Flash Study Output Reports:

1) Interrupting Duty Report: Three-phase and unbalanced fault calculations, showing the following for each equipment location included in report:

a) Voltage.
b) Calculated symmetrical fault-current magnitude and angle.
c) Fault-point X/R ratio.
d) No AC Decrement (NACD) ratio.
e) Equivalent impedance.
f) Multiplying factors for 2-, 3-, 5-, and 8-cycle circuit breakers rated on symmetrical basis.
g) Multiplying factors for 2-, 3-, 5-, and 8-cycle circuit breakers rated on total basis.

g. Incident Energy and Flash Protection Boundary Calculations:

1) Arcing fault magnitude.
2) Protective device clearing time.
3) Duration of arc.
4) Arc-flash boundary.
5) Restricted approach boundary.
6) Limited approach boundary.
7) Working distance.
8) Incident energy.
9) Hazard risk category.
10) Recommendations for arc-flash energy reduction.



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h. Fault study input data, case descriptions, and fault-current calculations including definition of terms and guide for interpretation of computer printout.

## 3.7 FIELD ADJUSTMENT FOR DEVICE COORDINATION

A. Adjust relay and protective device settings in accordance with recommended settings provided by coordination study. Field adjustments must be completed by engineering service division of equipment manufacturer under "Startup and Acceptance Testing" contract portion.

B. Make minor modifications to equipment as required to accomplish compliance with short-circuit and protective device coordination studies.

C. Testing and adjusting must be by qualified medium-voltage and low-voltage electrical testing and inspecting agency.

1. Perform each visual and mechanical inspection and electrical test stated in NETA ATS. Certify compliance with test parameters. Perform NETA tests and inspections for adjustable overcurrent protective devices.

## 3.8 WARNING LABELING OF ARC-FLASH HAZARDS

A. Apply one arc-flash label on front cover of each section of equipment for each equipment included in study, including each piece of equipment listed below:

1. Medium-voltage switchgear.
2. Medium-voltage switches.
3. Medium voltage transformers.
4. Low-voltage switchgear.
5. Switchboards.
6. Panelboards.
7. Motor-control centers.
8. Low voltage transformers.
9. Safety switches.
10. Control panels.

B. Base arc-flash label data on highest values calculated at each location.

C. Machine print warning labels with no handwritten or field-applied markings.

D. Install arc-flash warning labels under direct supervision and control of qualified electrical professional engineer.

E. Indicate on record Drawings location of equipment where personnel could be exposed to arc-flash hazard during their work.

1. Indicate arc-flash energy.



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2. Indicate protection level required.

END OF SECTION 260573



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