SECTION 16052 - COORDINATION STUDY AND ARC FLASH HAZARD ANALYSIS

PART 1 - GENERAL

1.01 SUBMITTALS

A. Coordination Study detailing electrical system evaluation and protection, protective equipment selectivity and arc flash hazard analysis studies.

The report shall include the following sections:

a. One-line diagram showing protective device ampere ratings and associated designations, cable size & lengths, transformer kVA & voltage ratings, motor & generator kVA ratings, and switchgear/switchboard/panelboard designations
b. Descriptions, purpose, basis and scope of the study
c. Short circuit and protective device evaluations (Pass/Fail)
d. Tabulations of the worst-case calculated short circuit duties as a percentage of the applied device rating (automatic transfer switches, circuit breakers, fuses, etc.); the short circuit duties shall be upward-adjusted for X/R ratios that are above the device design ratings
e. Protective device time versus current coordination curves with associated one-line diagram identifying the plotted devices (make, model and tagname), tabulations of ANSI protective relay functions and adjustable circuit breaker trip unit settings
f. Fault study input data, case descriptions, and current calculations including a definition of terms and guide for interpretation of the computer printout
g. Incident energy and flash protection boundary calculations
h. Comments and recommendations for system improvements, where needed
i. Executive Summary for each section, including source of information and assumptions made.

1.02 DEFINITIONS

A. X/R – ratio of system impedance to system resistance at a point in the distribution system. The ratio is used to calculate the peak asymmetrical fault.
B. Three phase bolted fault – a fault where all three phases are shorted together with no fault resistance between phases.
C. Line to ground bolted fault – a fault where one phase is shorted to ground with no fault resistance between the phase and ground.

1.03 QUALITY ASSURANCE

A. Codes and Standards:
   1. NFPA Compliance: Comply with applicable requirements of NFPA 70E Electrical Safety.
   2. IEEE 1584 Guide for Performing Arc-Flash Hazard Calculations.
   3. National Electrical Code
   4. IEEE Standards 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

1.04 COORDINATION STUDY

A. Include as part of Contract a complete Coordination and Short Circuit Study from incoming power lines through the high voltage switchgear, unit substations, and the motor control centers branch

circuits. Obtain available short circuit current, inrush current, and upstream protective device time current curves from the power company. Include power company current data and protective device curve as part of study. Study shall include all coordinating curves with each fuse size, trip settings, and thermal overloads given for connected loads. Curves shall include feeder wire melting curves and transformer ANSI rating points. The study shall also include variable frequency drives for motors larger than 40 Hp, harmonic filters, power factor correction equipment, transformers and protective devices associated with variable frequency drives, emergency and standby generators associated paralleling equipment and distribution switchgear. Fuse sizes on motor control centers shall be those shown in Drawings throughout the short circuit and coordination study. Changes in loads from those shown on Drawings shall be incorporated in Study.

B. Contractor shall furnish all field data as required for the power system studies and arc flash hazard analysis studies. Include fault contribution of existing motors in the study, with motors < 50 hp grouped together. The Contractor shall obtain required existing equipment data, if necessary, to satisfy the study requirements.

C. Studies shall be performed by a licensed Electrical Professional Engineer employed by the CONTRACTOR, a major electrical supplier (i.e., S&C, G.E., Westinghouse), or equal. Study results shall be submitted to ENGINEER for approval. The Registered/Licensed Professional Electrical Engineer shall have a minimum of five (5) years of experience in performing power system studies.

D. After approval, all recommended equipment settings, thermal overloads, and fuses shall be made to conform to approved results by the CONTRACTOR. CONTRACTOR shall test all trip settings, time delays, and indicating devices on all switchgear, unit substations, and motor control centers. Tests shall be witnessed by ENGINEER.

E. Data sheets for test are to be furnished by CONTRACTOR and shall be filled out showing the desired settings from Coordination Study and results obtained from witnessed test. Data sheets shall be signed by those performing test and witness. Test data sheets and motor list showing fuses, thermal overload sizes, etc. shall be submitted to ENGINEER as part of Contract.

1.05 ARC FLASH HAZARD ANALYSIS

A. Include as part of Contract a complete Arc Flash Hazard analysis from incoming power lines through the switchgear, unit substations, and the motor control centers branch circuits. Obtain available short circuit current, inrush current, and upstream protective device time current curves from the power company. Include power company current data and protective device curve as part of study. Analysis shall include all fuse sizes, trip settings, and thermal overloads given for connected loads, and shall include feeder wire distances and transformer ANSI rating points. The study shall also include variable frequency drives for motors larger than 40 Hp, harmonic filters, power factor correction equipment, transformers and protective devices associated with variable frequency drives and distribution switchgear. Fuse sizes and circuit breakers on motor control centers shall be those shown in Drawings throughout the Analysis. Changes in loads from those shown on Drawings shall be incorporated in Analysis.

B. The CONTRACTOR shall furnish all field data as required for the power system studies and arc flash hazard analysis studies. Include fault contribution of existing motors in the study, with motors < 50 hp grouped together. The CONTRACTOR shall obtain required existing equipment data, if necessary, to satisfy the study requirements.

C. Studies shall be performed by a licensed Electrical Professional Engineer employed by the CONTRACTOR, a major electrical supplier (i.e., S&C, G.E., Westinghouse), or equal. Study results shall be submitted to ENGINEER for approval

PART 2 - PRODUCTS

2.01 SHORT-CIRCUIT AND PROTECTIVE DEVICE EVALUATION STUDY

A. Use actual conductor impedances if known. If unknown, use typical conductor impedances based on IEEE Standards 141, latest edition. Transformer design impedances and standard X/R ratios shall be used when test values are not available.

B. Provide the following information in the study report:
1. Calculation methods and assumptions.
2. Base per unit quantities.
3. One-line diagram of the system being evaluated with available fault at each bus, and interrupting rating of devices noted.
4. Source impedance data, including electric utility system and motor fault contribution characteristics.
5. Typical calculations and tabulations of calculated quantities.
6. Results, conclusions, and recommendations.

C. Calculate short-circuit momentary and interrupting duties for a three-phase bolted fault at each:
1. Electric utility's supply termination point.
2. Incoming switchgear.
3. Unit substation primary and secondary terminals.
4. Low voltage switchgear.
5. Motor control centers.
6. Standby generators and automatic transfer switches.
7. Branch circuit panelboards.
8. Other significant locations throughout the system.

D. On grounded systems, provide a bolted line-to-ground fault current study for areas as defined for the three-phase bolted fault short-circuit study.

E. 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 bracing to withstand short-circuit stresses.
3. Adequacy of transformer windings to withstand short-circuit stresses.
4. Cable and busway sizes for ability to withstand short-circuit heating.
5. Notify Owner in writing, of existing circuit protective devices improperly rated for the calculated available fault current.

2.02 PROTECTIVE DEVICE COORDINATION STUDY

A. Provide an executive summary and table of contents. Executive summary shall include all pertinent values and settings information.

B. Proposed protective device coordination time-current curves shall be displayed on log-log scale graphs.

C. Include on each curve sheet a complete title and one-line diagram with legend identifying the specific portion of the system covered.

D. Terminate device characteristic curves at a point reflecting maximum symmetrical or asymmetrical fault current to which device is exposed.

E. Identify device associated with each curve by device ID, manufacturer, model, type, function, and tap, time delay, and instantaneous settings recommended.

F. Plot the following characteristics on the curve sheets, where applicable:
1. Electric utility's protective device
2. Medium voltage equipment relays
3. Medium and low voltage fuses including manufacturer's minimum melt, total clearing, tolerance, and damage bands
4. Low voltage equipment circuit breaker trip devices, including manufacturer's tolerance bands
5. Transformer full-load current, magnetizing inrush current, and ANSI transformer withstand parameters
6. Conductor damage curves
7. Ground fault protective devices, as applicable
8. Pertinent motor starting characteristics and motor damage points
9. Pertinent generator short-circuits decrement curve and generator damage point
10. Other system load protective devices for the largest branch circuit and the largest feeder circuit breaker in each motor control center

G. Provide adequate time margins between device characteristics such that selective operation is provided, while providing proper protection.

2.03 ARC FLASH HAZARD ANALYSIS

A. The arc flash hazard analysis shall be performed according to the IEEE 1584 equations that are presented in the latest version of NFPA70E.

B. When appropriate, the short circuit calculations and the clearing times of the phase overcurrent devices will be retrieved from the short-circuit and coordination study model. Alternative methods shall be presented in the proposal.

C. The flash protection boundary and the incident energy shall be calculated at all significant locations in the electrical distribution system (switchboards, switchgear, motor control centers, panelboards, busway and splitters) where work could be performed on energized parts.

D. The Arc-Flash Hazard Analysis shall include all medium voltage and 480 volt locations and significant locations in 240 volt and 208 volt systems.

E. Safe working distances shall be specified for calculated fault locations based upon the calculated arc flash boundary considering an incident energy of 1.2 cal/cm^2.

F. The Arc Flash Hazard analysis shall include calculations for maximum and minimum contributions of fault current magnitude. The minimum calculation shall assume that the utility contribution is at a

minimum and shall assume a minimum motor load. Conversely, the maximum calculation shall assume a maximum contribution from the utility and shall assume motors to be operating under full-load conditions.

G. Arc flash computation shall include both line and load side of main breaker calculations, where necessary.

H. Arc Flash calculations shall be based on actual overcurrent protective device clearing time. Maximum clearing time will be capped at 2 seconds based on IEEE 1584, section B.1.2.

2.04 REPORT SECTIONS

A. Executive Summary:

1. Provide summary tables that show the following information for each distribution system protective device. See end of section for example tables.
    a. Device ID
    b. Location
    c. Manufacturer and part number
    d. Short circuit withstand rating
    e. Protective Relaying settings, if applicable
    f. Circuit Breaker trip settings
    g. Arc Flash rating
    h. Required Personal Protective Equipment (PPE)

B. Input Data:
1. Utility three-phase and line-to-ground available contribution with associated X/R ratios
2. Short-circuit reactance of rotating machines with associated X/R ratios
3. Cable type, construction, size, # per phase, length, impedance and conduit type
4. Bus duct type, size, length, and impedance
5. Transformer primary & secondary voltages, winding configurations, kVA rating, impedance, and X/R ratio
6. Reactor inductance and continuous ampere rating
7. Aerial line type, construction, conductor spacing, size, # per phase, and length

C. Short-Circuit Data:
1. Source fault impedance and generator contributions
2. X to R ratios
3. Asymmetry factors
4. Motor contributions
5. Short circuit kVA
6. Symmetrical and asymmetrical fault currents

D. Recommended Protective Device Settings:
1. Phase and Ground Relays:
    a. Current transformer ratio.
    b. Current setting.
    c. Time setting.
    d. Instantaneous setting.
    e. Specialty non-overcurrent device settings.

f. Recommendations on improved relaying systems, if applicable.

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

E. Incident energy and flash protection boundary calculations.
1. Arcing fault magnitude
2. Device clearing time
3. Duration of arc
4. Arc flash boundary
5. Working distance
6. Incident energy
7. Hazard Risk Category
8. Recommendations for arc flash energy reduction

PART 3 - EXECUTION

3.01 ARC FLASH WARNING LABELS

A. The CONTRACTOR shall provide a 3.5 in. x 5 in. thermal transfer type label of high adhesion polyester for each work location analyzed. Label shall meet the requirments for NFPA 70E at a minimum.

B. The label shall have an orange header with the wording, “WARNING, ARC FLASH HAZARD”, and shall include the following information:
1. Location designation
2. Nominal voltage
3. Flash protection boundary
4. Hazard risk category
5. Incident energy
6. Working distance
7. PPE requirements
8. Engineering report number, revision number and issue date

C. Arc flash labels shall be provided in the following manner and all labels shall be based on recommended overcurrent device settings.
1. For each 600, 480 and applicable 208-volt panelboards and disconnects, one arc flash label shall be provided.
2. For each motor control center, two arc flash labels shall be provided, one at each end of the motor control center.
3. For each low voltage switchboard, one arc flash label shall be provided
4. For each switchgear or unit substations, two arc flash labels shall be provided, one at each end of the equipment or near each main breaker.
5. For each medium voltage switch, one arc flash label shall be provided.

D. Labels shall be field installed by the CONTRACTOR after system acceptance testing has been completed.

3.02 ARC FLASH TRAINING

A. The CONTRACTOR, or approved sub-contracted trainer, shall train personnel of the potential arc flash hazards associated with working on energized equipment (minimum of 4 hours). Maintenance procedures in accordance with the requirements of NFPA 70E, Standard for Electrical Safety Requirements For Employee Workplaces, shall be provided in the equipment manuals. The training shall be certified for continuing education units (CEUs) by the International Association for Continuing Education Training (IACET).

B. Two training sessions of four (4) hours minimum shall be provided. Each session shall allot for a maximum of 12 members. The sessions shall be scheduled with the Owner, and CONTRACTOR shall assume the sessions will be two weeks apart.

3.03 EXAMPLE TABLES

Summary - Arc Flash Hazard Calculations

Faulted Bus				Fault Current			Trip Device							
ID	Nom. kV	Equip. Type	Gap (mm)	Bolted Fault (kA) Bus	Bolted Fault (kA) PD	PD Arc Fault (kA)	Source Trip Device ID	Trip (cycle)	Open (cycle)	FCT (cycle)	Flash Boundary (ft)	Incident Energy (cal/cm²)	Working Distance (inches)	Hazard/Risk Level
BLMCC1_BUS	0.480	MCC	25	12.820	12.819	8.107	CB2_MCC2	1.51	0.00	1.51	1.0	0.7	18	0
BLOWERS45	4.160	Switchgear	102	10.825	8.789	8.519	CB_J	26.09	5.00	31.09	16.1	6.2	36	2
BLOWERS123	4.160	Switchgear	102	12.163	9.031	8.736	CB_D	25.04	5.00	30.04	17.7	6.7	36	2
BLOWERSUB1	0.480	Switchgear	32	14.914	13.786	8.120	CB_MAIN-WEST BLOWER	19.80	0.00	19.80	6.0	6.0	24	2
BLOWERSUB2	0.480	Switchgear	32	13.600	13.595	8.132	CB_MAIN-EAST BLOWER	19.80	0.00	19.80	5.7	5.6	24	2
COLLINWOOD1	4.160	Switchgear	1	9.785	9.785	9.500	COLMAIN1_FU	0.60	0.00	0.60	0.2	0.1	36	0
COLLINWOOD2	4.160	Switchgear	1	8.925	8.925	8.679	COLMAIN2_FU	0.65	0.00	0.65	0.2	0.1	36	0
EFF-1	4.160	Switchgear	1	9.265	8.896	8.645	EFF-1_CB	8.00	5.00	13.00	4.3	1.7	36	1
EFF-2	4.160	Switchgear	1	8.110	7.730	7.529	EFF-2_CB	10.73	5.00	15.73	4.5	1.8	36	1
EFF-3	0.480	MCC	1	10.497	10.496	7.881	EFF_CB1	10.20	0.00	10.20	3.2	4.1	18	1
EFF-4	0.480	MCC	1	12.124	11.057	8.215	EFF_CB5	10.20	0.00	10.20	3.5	4.7	18	1
GRBUS1	0.480	MCC	1	13.265	12.509	9.233	GREASEREACMCC_CB	2.48	0.00	2.48	1.5	1.3	18	1
GRFLOC_BUS	0.480	MCC	1	10.397	10.395	7.811	GRFLOC_CB	4.20	0.00	4.20	1.8	1.7	18	1
GRSTORMCC1_BUS	0.480	MCC	1	9.022	9.022	6.849	GRSTORMCC1_CB	1.63	0.00	1.63	0.9	0.6	18	0
MAIN1	4.160	Switchgear	102	12.182	8.452	8.176	CB_E	60.05	5.00	65.05	39.2	14.6	36	3
MAIN2	4.160	Switchgear	102	10.865	8.452	8.192	CB_I	59.94	5.00	64.94	34.5	12.9	36	3
MCC1_BUS	0.480	MCC	1	3.845	3.844	3.105	MCC1-CB	1.41	0.00	1.41	0.5	0.2	18	0
MCC1FEED	0.480	Other	1	11.118							0.0	0.0	18	
MCC2_BUS	0.480	MCC	1	3.894	3.893	3.142	MCC2-CB	1.41	0.00	1.41	0.5	0.2	18	0

EXAMPLE ARC FLASH STUDY TABLE

Device ID	Equipment Designation	Max Voltage (kV)	Manufacturer	Frame (A)	Long-Time			Short-Time				Instantaneous	Ground			
				Sensor (A)	Pickup Setting	Delay Curve	Band	Pickup Setting	Delay Curve	Band	I^2T	Pickup Setting	Pickup Setting	Delay Curve	Band	I^2T
			Model	Rating Plug (A)	Trip (A)			Trip (A)				Trip (A)	Trip (A)			
001-01A CB ATS (N)	Bus5	0.48	Square-D NW12H MICROLOGIC 6.0	1200 1200	0.9 1080	12		6 6480		0.2	OUT	8 9600	J 1200		0.4	OUT
001-01B CB ATS (E)	ATS (E)	0.48	Square-D NW12H MICROLOGIC 6.0	1200 1200	0.9 1080	12		6 6480		0.2	OUT	6 7200	J 1200		0.4	OUT
002-01 MB MCC-A	002 MCC-A LINESIDE	0.48	Square-D PLL MICROLOGIC 6.0	1200 1200	0.9 1080	12		6 6480		0.2	OUT	8 9600	J 1200		0.4	OUT
002-02 FB IPC-1	002 MCC-A LOADSIDE	0.48	Square-D LJ (OR) Micrologic 3.3 (PP)	400 400	400 A 400	16						10 x In 4000				
002-03 FB IPC-2	002 MCC-A LOADSIDE	0.48	Square-D LJ (OR) Micrologic 3.3 (PP)	400 400	400 A 400	16						10 x In 4000				
002-04 FB P-101 VFD	002 MCC-A LOADSIDE	0.48	Square-D LJ (OR) Micrologic 3.3 (PP)	400 400	400 A 400	8						8 x In 3200				

EXAMPLE PROTECTIVE DEVICE SETTING TABLE

END OF SECTION