Critical Path Method (CPM) Scheduling, Basic Engineering, and Project Approach for Typical Substation Engineering-Procurement-Construction (EPC) Project

By

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Spring Semester, 2006

An EMGT Field Project report submitted to the Engineering Management Program and the Faculty of the Graduate School of The University of Kansas in partial fulfillment of the requirements for the degree of Master’s of Science

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Date accepted: 4-6-06
ACKNOWLEDGEMENTS

I like to say “Thank You” from the bottom of my heart to the following individuals for my accomplishment of the Master’s degree in Engineering Management.

God - who gave me the knowledge to study and courage to complete this Field Project.

Simi – my lovely wife who always helped and pushed me to achieve this degree.

Fatima - my mother who encouraged me to pursue for higher education.

Burns & McDonnell – the company I work for and paid all the tuition fees.

Herbert Tuttle – The Committee Chairperson for this Field Project and my advisor who advised, encouraged and helped me by providing feedback throughout my journey for accomplishing this degree.

Tom Bowlin – The Committee Member for this Field Project who provided valuable feedback; encouraged and helped me throughout this Field Project.

Chick Keller – The Committee Member for this Field Project who provided valuable feedback including personal experience, encouraged and helped me throughout this Field Project.
John Olander – The EPC manager for the Transmission and Distribution Division of Burns & McDonnell who provided valuable feedback including personal experience for this Field Project.

Jeff Camden – The Division manager for the Transmission and Distribution Division of Burns & McDonnell who provided valuable feedback including personal experience for this Field Project.

Adam Thelen – The scheduler for the Construction Design/Build Division of Burns & McDonnell who helped me develop the sample CPM schedule for this Field Project.

Thanks to all other EMGT instructors and staffs for their knowledge and support.
EXECUTIVE SUMMARY

This Field Project provides an overview of the typical substation Engineering-Procurement-Construction (EPC) project delivery method, the work breakdown structure, activities and sequences in the Critical Path Method (CPM) schedule, basic substation design criteria, substation project approach and defines the Client’s, subcontractor’s and Burns & McDonnell’s responsibilities.

Burns & McDonnell Engineering specializes and acts as Prime Contractor in the EPC of electrical substations. The Transmission and Distribution Division designs the EPC substations and the Construction Design/Build Division purchases the required equipment and materials, monitors substation construction activities and manages all of the field issues.

EPC refers to a method of project delivery where Burns & McDonnell contracts with the Client to perform all design, procurement and construction services in order to complete a substation. A Substation EPC project life cycle includes Pre-Qualification, submitting the Proposal to the Client, Negotiation with the vendors, subcontractors and Client, Design and Procurement of major equipment, Construction, Testing, Commissioning, and Operation.

CPM Schedule is a network scheduling technique where large elements of a project are subdivided based on a work breakdown structure into activities and sequenced based on interrelationships such that time usage can be calculated to determine the earliest
date work can be accomplished and the latest date work needs to be completed.

The critical path is the longest activity path from the start to finish of the project. An activity, which is not on the critical path, will have float. Float is the amount of time an activity can be delayed without it becoming a critical path activity. Any activity on the critical path that experiences a delay will consequently delay the project milestone or completion date or require corrective action.

Some of the activities of a substation EPC project may not be started before other tasks or portion of tasks or activities have been completed. For example, foundations for the steel structures must be in well along before erecting the steel structures can start. Site grading and excavation must proceed before installing the steel structure foundations.

The Client’s responsibilities include identify project goals, decide a project delivery system, determine whether Client needs assistance of a consultant, select a representative and determine any limitations on the representative’s authority, decide upon a procurement process for EPC, determine the appropriate payment methodology for EPC contract, allocate project risk, obtain project financing, furnish site information, identify Client-furnished deliverables, review and approve design submissions of EPC, inspect construction for compliance with contract, develop efficient change order process, and obtain appropriate project insurance.

The substation EPC project design team’s responsibilities include deliverables
according to the contract between Client and Burns & McDonnell. The Electrical engineering group develops the electrical drawings and the Civil engineering group develops the civil drawings for Client’s review. The electrical and civil drawings will be issued for construction after Client’s approval. Substation EPC project design team also reviews and approves vendor drawings. Project coordinator keeps track of the electrical and civil deliverables and construction activities.

Design criteria is very important for a substation EPC project because substation equipment, materials, and construction cost will be established using the defined design criteria. Design criteria should remain the same during the EPC project. If design criteria changes in the middle of the EPC project; engineering and construction reworking cost can be expensive for both the Client and Burns & McDonnell.

Experienced project management, engineering, environmental, procurement, construction management, and construction team will be assembled to perform all of the services required for a substation EPC project. The Project manager leads a select team of experienced professionals through the numerous tasks required to provide the client with fully functional, cost effective substation facility. Burns & McDonnell’s Quality Assurance and Quality Control Program involve throughout the length of the project helping insure that project objectives are met.

Design manual, detailed civil and electrical engineering design for the substation EPC project will be provided to Client by Burns & McDonnell. Substation will be designed in
accordance with applicable Client’s standards, industry standards and codes, and federal, state or local requirements. Burns & McDonnell utilizes the latest version of MicroStation or AutoCAD for detailing and drafting applications. The project design manual addresses the specific parameters of the design including applicable standards, codes, and interpretations of codes and standards that may affect the design. The project design manual also addresses the scope of the project and any specialized or unique design techniques used in the development of the design documents.

Client’s specifications for substation equipment procurement will be utilized and will provide a comprehensive approach to the procurement process, and pre-qualify suppliers that Burns & McDonnell trusts to provide timely and technically sound products. Previous experiences will be considered at time of award and packages will be awarded on a best-value basis and Client’s preferred vendors will be utilized. Substation equipment and materials bid documents include bid forms, general requirements, design condition, major equipments, steel structures, equipment and materials, control building, and relay panels.

Client’s specifications for substation construction will be utilized and Burns & McDonnell will select the substation construction subcontractor. Substation construction includes construction management, site work including grading and erosion control, installation of fence, major equipments, foundations, grounding, conduit, raceway, control building, relay panels, and steel structures erection and equipment testing.
Burns & McDonnell is committed to constructing a safe project. The avoidance of any occupational related deaths or injuries is Burns & McDonnell’s highest priority. As a result of the focus on safety, Burns & McDonnell is dedicated to assuring the safety of all Burns & McDonnell personnel as well as managing safe work sites. One of the most critical aspects of producing a successful project safety and health program is to set the goal from the beginning. A “No Tolerance” standard for unsafe workplace conditions and acts will be established. The subcontractors will be made aware from the onset that safety will play a significant role in the success of the project.

Burns & McDonnell’s quality control organization performs inspections of all items of work to ensure conformance to applicable specifications and drawings with respect to identification. Testing and inspection operations will be reviewed for compliance with contract specifications. Work will be inspected daily to assure continuing compliance with plans and specifications until the completion. Substation engineering team will be responsible for reviewing and certifying shop drawings, catalog data, samples, material certifications and test data that will be performed in coordination with the approved design. No material or equipment will be authorized to release for fabrication or delivery to the job site until the submittals have been approved.
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CHAPTER ONE
INTRODUCTION

“Critical Path Method Scheduling, Basic Engineering, and Project Approach for Typical Substation Engineering-Procurement-Construction Project” provides a comprehensive overview of the typical substation EPC project delivery method, work break down structure, activities and sequences in the CPM schedule, basic substation design criteria, substation project approach, Client’s responsibility, subcontractor’s responsibility, and Burns & McDonnell’s responsibility.

Burns & McDonnell Engineering Inc. (BMcD) is a firm based in Kansas City that specializes and acts as Prime Contractor in the EPC of electrical substations throughout the United States. The Transmission and Distribution (T&D) Division of BMcD designs the EPC substations and the Construction Design/Build Division (CDB) purchases the required equipment and materials, monitors construction activities and manages all of the field issues.

An EPC project for a substation has many varied components: site identification, land acquisition, engineering design, contract drawings, documentation, material procurement, construction contracts administration, construction, equipment testing, and commissioning. Since the EPC process includes many different functions there is a great need for a comprehensive approach to scheduling, basic design criteria and the project approach.
The T&D Division is also involved in a greater number of substation EPC projects than in the past, involving staff design engineers who are relatively new to the process. Therefore it is critical to the function of the section to increase the efficiency of the EPC process. Applying the CPM scheduling to achieve this goal will enhance the overall EPC process and clarify responsibilities and boundaries, thereby providing a document of reference for future EPC projects.

This field project provides an overview of the typical substation EPC project delivery method, the work breakdown structure, activities and sequences in the CPM schedule, basic substation design criteria, substation project approach and defines the Client’s, subcontractor’s and BMcD’s responsibilities.

1.1 Purpose of this Field Project

The purpose of this field project is to identify and describe basic CPM schedule activities, basic substation design requirements and the project approach. In addition it will define the parties involved and their roles in a CPM schedule and substation EPC design project. The information in this field project not only will benefit the author, but also will benefit the present and future engineers of the T&D Division working on any substation EPC project. This field project will accomplish its purpose if substation design engineers learn about the overall substation EPC project process and apply their knowledge to the ongoing and future projects of the T&D Division.
1.2 Substation EPC Project

1.2.1 Definition of a Substation EPC Project

EPC refers to a method of project delivery where BMcD contracts with the Client to perform all design, procurement and construction services in order to complete a substation. These services may be performed solely by BMcD or subcontracted to other companies. The Client, in turn, typically has a number of responsibilities as well on an EPC project to provide direction regarding their desired project. These may include providing final substation circuit diagrams, procurement specifications, design criteria, site selection, the site plans and obtaining regulatory permits.

1.2.2 Substation EPC Project Life Cycle

A Substation EPC project life cycle includes: a) Pre-Qualification, b) submitting the Proposal to the Client, c) Negotiation with the vendors, subcontractors and Client, d) Design and Procurement of major equipment, e) Construction, f) Testing and Commissioning, and g) Operation.¹

a) The Pre-Qualification considers the T&D Division’s past EPC project experience, team organization, BMcD’s financial data, and key employees’ resumes.

b) The next step in the life cycle of the project, submitting the Proposal to the Client includes preparing the scope of work, the project schedule and qualifications. Project terms and conditions, project planning, fee structure and key employees’ resumes are also part of the proposal package to the Client. The fee structure addresses the cost for the entire engineering, procurement, and construction of the project.
BMcD requests the project equipment proposals and pricing from the equipment vendors. These prices are incorporated into the fee structure. BMcD also incorporates construction proposals acquired from construction firms in order to reach a final project fee amount. This part of the project life cycle also includes project bonds and insurance (if required by the Client) and the project delivery method.

c) The Negotiation Phase of the project life cycle consists of negotiations between the Client and BMcD regarding final pricing, contractual terms and conditions, project scope, planning and delivery methods, and construction schedules and phases.

d) The Design Phase of the project life cycle includes detailed project planning, detailed scheduling, procurement of long-lead equipment, final contract negotiations between BMcD and subcontractors or vendors design, and reviewing vendor drawings. Further design development is required before issuing the final design drawings to the field for construction.

e) The Construction Phase of the project life cycle includes project control systems; procurement of goods and services; site start-up and mobilization; site grading; foundations; erecting the steel structures; installing equipment, grounding, raceway, control building and control cables; as well as quality assurance, time and cost management.

f) The Testing and Commissioning Phase of the project life cycle includes testing and
commissioning of equipment. This phase also includes training the Client’s employees about the equipment.

g) The Operation Phase of the project life cycle involves bringing the substation to full operation and transferring the substation and warranty of equipment to the Client.

The major substation EPC project phases and estimated time for each phase are illustrated in Figure 1.

![Figure 1: Major Substation EPC Project Phases](image)
1.2.3 Substation EPC Project Team

Successful substation EPC project delivery is dependent on assembling the right project team. Substation EPC project teams are formed before pursuing an EPC project and tailored to satisfy the Client’s needs and specifications.

Large Substation EPC project design teams may consist of: a project manager and a project coordinator; an engineering manager, a lead electrical engineer and one to three electrical engineers; a lead civil engineer and one to three civil engineers; a drafting manager, one to three drafters; permitting and land acquisition; a purchaser; a construction manager, a contractor, and one to five subcontractors. Figure 2 demonstrates the structure of a typical EPC project team in the T&D Division.

![Figure 2: Substation EPC Project Team Structure](image_url)
1.2.4 Understanding EPC Project Scope

It is very important to understand the EPC project scope before submitting the proposal to the Client. BMcD may suffer financially if the project’s scope is not well defined in the initial planning stages. In order to facilitate the process of understanding the project’s scope, prior to the start of the Design Phase, BMcD arranges a partnering session attended by the in-house Design-Build team as well as the Client’s team.

The purpose of the partnering session is to develop a common understanding of roles, responsibilities, goals and objectives. This session helps build an honest and open relationship with the Client in order to minimize the future possibility of antagonistic conditions that might risk the quality and financial success of the project. The partnering session provides an overview of the design-build schedule, BMcD’s in house quality control plan, permit requirements and coordination of the work between all entities. This process enables the creation of positive goal oriented relationships that last through the life of the project.

Successful management is accomplished by providing proper support to the construction team and allowing them to make and implement decisions necessary to achieve success. The construction site team is empowered to provide comprehensive on-site management of the construction, scheduling, loss control (safety), subcontract administration, quality assurance control and start up. Designated home office staff has the responsibility to support construction personnel in these areas. Although the design
may be complete, the engineers maintain continuous contact with the on-site staff.

BMCD offers a true “single source” responsibility for the Client’s projects.

1.3 Substation EPC Project Planning and Scheduling

1.3.1 Planning the EPC Project

Project planning consists of breaking the project tasks down into sub-tasks and establishing the sequence of work.

The planning process is crucial for substation EPC projects. A study published in 1980 demonstrated that exceptional planning would save 40% of the cost as compared to just ‘reasonable’ or ‘poor’ planning and on average a poorly planned project can create overruns of as much as 50% when compared with a reasonably planned one.²

Project managers typically think of an EPC project as a set of distinct tasks, highly dependent on one another. The dependent of sub-tasks is more formal and complete in CPM schedule techniques. The easiest and most general way to view the task breakdown is by recognizing all activities as described in Appendix 1A.

Project managers must decide the order in which the activities will be performed after the activity list for the EPC project has been developed. The project manager or scheduler must understand the sequencing of activities and know which predecessor activities must be completed before each activity can begin. For example, foundations for the steel structures must be in well along before erecting the steel structures can
start. Site grading and excavation must proceed before installing the steel structure foundations.

*Figure 3* shows the logic diagram of activities to erect substation steel structures.

![Diagram: Logic Diagram of Activities to Erect Substation Steel Structures]

### 1.3.2 Scheduling the EPC Project

The scheduling process is a necessary part of the planning effort for an EPC project. An EPC schedule is a tool that determines the necessary activities, their sequence and the time frame in which these activities should be carried out. The schedule helps to complete a project on time and under budget. Project scheduling consists of estimated time of individual activities and estimated time of the project as a whole.

Project managers would expect all individual activities on an EPC project to be carried out at a normal working day rate. Some activities might be critical to the project and hold up the progress of the other activities if they do not proceed on the schedule on time. Project managers use labor-hours per activity as a basis for project planning.

Project managers can determine how long the entire project should take to accomplish after times for individual activities in a CPM schedule have been calculated. If the Client’s due date falls before the calculated project accomplish date then the project manager might adjust the project schedule to meet the due date by shorting duration of
some of the individual activities by providing more resources to those individual activities.


CHAPTER TWO
LITERATURE REVIEW

Information was obtained from various sources for this Field Project. Books on scheduling, design and construction, previous field projects, and BMcD’s internal documents and reports were researched to develop this report.

2.1 Books


The author defines design/build process, compares traditional construction method, turnkey construction method, fast track construction method, and construction management. The writer compares the design firm as primary contractor, the contractor as primary contractor, and the joint venture as primary contractor. The writer also describes advantages and disadvantages of design/build process for the client, the contractor, and the design firm. The author talks about the procurement of design/build services for the private and public sector clients, and the procurement methods including pre-qualification, selection process, negotiation, bidding, and design process. It points out the theories of liability including breach of contract, tort of negligence, statutory violations, breach of warranty, and strict liability in design-build process, and administration including insurance and bonds. It also includes standard design-build contract agreement forms, licensing requirements, registration requirements, and professional codes of ethics. This book was helpful for this field project.


The writers present requirements for construction scheduling including planning,
Gantt charts including description, size, bar charts, curves, advantages and disadvantages of bar charts. The writers also present about CPM Schedules including definitions, work activities, durations, activity descriptions and codes, and logical relationships. This book shows step by step how to develop a project schedule, and different phases of the project schedule. The authors define Program Evaluation and Review Technique and Linear Scheduling Method. The authors also describe the importance of updating the schedule including bar charts and network diagrams. The writers included duration-cost trade off including crashing activities and total project cost analysis, effective use of schedules, CPM scheduling on microcomputers, and the scheduling specifications. This book was very helpful for this field project.


The authors describe the schedule activities and activity list including immediate predecessors. This book describes the history of the Gantt chart, the network diagram and how to construct them. The writers describe dummy activities, the critical path calculation including earliest start and earliest finish times, latest start and latest finish times, standard deviation of an activity time, slack and the critical path. The writers suggest how to estimate the expected activity time including optimistic time, most probable time, and pessimistic time. The authors describe CPM and time-cost trade-offs, crashing the project, linear programming model, project cost management and project management using Microsoft Project Software. This book was helpful for this field project.

The writers present the design-build history, where and when to use a design-build project, roles of individuals in a design-build project including owner’s responsibilities, design firm’s responsibilities, and construction subcontractor’s responsibilities. The authors describe conceptual estimating and scheduling for design-build projects, contracting and procurement issues, and insurance and bonding issues in design-build projects. The writers suggest types of liability for design-build, the use of construction management on design-build projects, and institutional challenges for design-build. This book was helpful for this field project.


The authors describe project management, project organizational design, and alternative project applications. The authors also describe the strategic context of projects, project leadership, project initiation, and project execution. The writers mention project planning and control including project scheduling, project monitoring, project evaluation and control, risk management, project auditing, project work breakdown structure, and managing costs in projects. The writers also describe project culture and communications. This book was helpful for this field project.

Project Scheduling Handbook: Jonathan F. Hutchings, 2004

The writer describes the construction contract law, project scheduling system, and project operations. The writer also describes the CPM scheduling including developing the scheduling, schedule plan evaluation, project planning, performance targets,
scheduling budgets, and matrix networking. The author describes network scheduling, network diagramming, and project scheduling contingencies. This book was helpful for this field project.


The author describes project management, project control cycle, and pre-construction planning. The writer presents the project planning, CPM scheduling, and scheduling the project including estimating activity durations, and overall job durations. The author also talks about monitoring and controlling the project, resource management, and management of submittal data and procurement. This book was helpful for this field project.

### 2.2 From the Web

**“Determining the Actual Critical Path”**: Ronald M. Winter, 2004

This document discusses an analytical, stepwise method for objectively determining the CPM Scheduling. This article was helpful for this field project.

**“Management of CPM Schedule Submission”**: Ron Winter, 1997

The writer describes the four discrete items about the modern CPM Schedule. The first item the writer talks about is the activity description. The second item the author talks about is the logical relationship between the activities. The third item the writer presents is the constraints and the fourth item is the invisible codes assigned by the scheduler. This article was helpful for this field project.
“The Pitfalls of CPM Scheduling in Construction Projects”: Ian A. Street, GREYHAWK North America, LLC.

The author talks about five different pitfalls in construction projects using CPM Scheduling. The first pitfall the author talks about is the critical path may not always require the most management attention. The second pitfall the writer talks about is the unrealistic activity durations. The third pitfall the writer mentions is the owner does not manage the schedule. The fourth pitfall the author talks about is accepting reports without the electronic file and the last pitfall is the failure to perform timely schedule updates. This article was helpful for this field project.

2.3 Internal Company Documents


The writer describes the terms and definitions of CPM Scheduling and activity relationship for the CPM Scheduling. This document was helpful for this field project


This design manual describes general description of work, substation design criteria and clearances. The document presents the requirements for designing substation bus, conductor, insulators and hardware. The manual shows how to choose major substation equipment and ground them. Shielding, conduit, raceway for the substation equipment is discussed in this manual. The manual recommends type of relays for the substation protection and controls. The manual also suggests types of site work, foundations, structures and control building is required for designing the substation.

This document suggests how the surveying will be incorporated in the project, who will obtain the regulatory permits, how the substation facility will be designed and substation equipment procurement process. It pointed out the roles and responsibility of the substation construction management, safety team and quality control team.

2.4 MGT 835 Field Project Report


This EMGT 835 Field Project provides an overview of the traditional engineering and design-build projects delivery method. This report presents the writer’s engineering firm and changing the engineering approach in order to remain effective and competitive in the design-build market. The author describes the design-build history, and difference between traditional engineering and design-build projects. The writer indicates the importance of establishing design criteria for the design-build project and keeping the design criteria unchanged during the project. The author describes the advantages and disadvantages of design-build for engineering firms and owner. This report was helpful for this field project.


This EMGT 835 Field Project provides an overview of choosing most advantageous construction delivery method among traditional construction delivery, construction management, program management, EPC, turnkey, bridging, and build-operate-transfer construction methods. The writer describes scope, construction organization, contract,
and award the four parts of construction delivery methods. The author talks about Kepner-Tregoe process for the decision analysis. The author also describes the advantages and disadvantages of the seven construction delivery methods. The writer included fixed price, reimbursable, fixed fee, and guaranteed max price contracts and their advantages and disadvantages. This report was helpful for this field project.


This EMGT 835 Field Project provides an overview of project estimating process for design-build using Total Quality Management principles and techniques. The writer describes three types of design-build proposal along with design-build firm’s scope of work, problems, and successes. The author describes the owner’s benefit for doing design-build project and design-build firm's estimating process. This report was helpful for this field project.

2.5 Government Entity


This design guide provides general design considerations including site, environmental, interface, reliability, operating, safety, and maintenance consideration. This design guide also talks about possible documents or studies required for the substation engineering, substation physical layout including initial design parameters, substation profile, different type of substations, protection of substation insulation, electrical clearances, rigid bus design, strain bus design, and mobile transformers and substations. This design guide describes all major equipments that are used in a substation including power transformers, power circuit breakers, switchgear, voltage...
regulator, shunt capacitor, air switches, surge arresters, instrument transformers, coupling capacitors, and coupling capacitors voltage transformers. This design guide explains site design process, drainage and earthwork considerations, road access, erosion protection, and security fence. This design guide also describes substation structure materials, structure types and design. This design guide lays out the substation foundation including soil information, foundation types, oil pollution, and substation grounding including soil resistivity, ground fault current, and ground conductor. This is a very good reference design guide for substation design and was very helpful for this field project.

2.6 Professional Society


This manual suggests grounding methods for electric supply and communication facilities, grounding conductor and electrodes, and ground connections for the electric utility. This manual points out the rules for the installation and maintenance of electric supply stations and equipment. This manual describes the safety rules for the installation and maintenance of overhead electric supply and communication lines. This manual also recommends the safety rules for the installation and maintenance of underground electric supply and communication lines. This manual defines the rules for the operation of electric supply and communications lines and equipment. This is a very good reference codebook for substation design and was helpful for this field project.

This manual describes the wiring and protection for branch circuits and feeders. This manual suggests the wiring methods and materials for different type conductors, junction boxes, outlet, conduit bodies, and fittings. This manual talks about the equipment for general use including fixture, switches, receptacles, switchboards, panelboards, luminaries, space-heating equipment, motors, air-conditioning, generators, batteries, capacitors and reactors. This is a very good reference codebook for substation design and was helpful for this field project although BMcD and utilities are not required to follow the NEC manual but it provides good design practices that BMcD and utilities often follow.

2.7 Institute of Electrical and Electronics Engineers (IEEE)

Following are some important IEEE guides to design substations.


IEEE Std. 693 – 1997: IEEE Recommended Practice for Seismic Design of Substations


IEEE Std. 1379 – 2000: IEEE Recommended Practice for Data Communications Between Remote Terminal Units and Intelligent Electronic Devices in a Substation

2.8 Summary of Literature Review and Conclusions

Substation EPC project, Substation EPC project planning and scheduling information, CPM schedule, preparing CPM schedule, and project work breakdown structure was obtained from various books, articles from website and BMcD’s internal documents.

Substation design criteria information was obtained from Design Guide for Rural Substations and substation project approach information was obtained from BMcD’s internal document.
CHAPTER THREE

CRITICAL PATH METHOD (CPM) SCHEDULE

This section provides basic CPM schedule information including CPM schedule activities, Client's responsibility and BMcD's responsibility for substation EPC project for any substation design engineer. A CPM schedule for an EPC project should be detailed, logical and up to date for clear understanding of the status of the project for both the engineer and Client. Project duration and completion dates are commonly determined by the Client's need for the project.

3.1 Critical Path Method (CPM) Schedule

CPM Schedule is a network scheduling technique where large elements of a project are subdivided based on a hierarchical system (work breakdown structure) into single work steps (activities) and sequenced based on interrelationships such that time usage can be calculated to determine the earliest date work can be accomplished and the latest date work needs to be completed. Some of the terms and definitions of CPM schedule are provided in Appendix 3A.

The critical path is the longest activity path from the start to finish of the project. An activity, which is not on the critical path, will have float. Float is the amount of time an activity can be delayed without it becoming a critical path activity. Any activity on the critical path that experiences a delay will consequently delay the project milestone or completion date or require corrective action.

CPM Schedule forces the scheduler, construction supervisor, and the project manager
to think through the entire project in detail to avoid inefficient and poor sequencing of the project, and helps the project manager to define and plan the work in detail from start to finish. Sequences can be changed to overcome or reduce any impact. As an example, adding additional steel erection crews, additional cranes, or accelerating follow-on work can overcome unexpected delays in substation structural steel delivery.

CPM Schedules support efficient communication between field and office forces. It can assist in a smooth transition for execution of the plan if management staff changes are made during the project. It makes job coordination easier among material suppliers, contractors, subcontractors, Client, and designers.

3.2 Developing CPM Schedule

Professional schedulers of BMcD prepare the permitting, engineering, meeting, procurement, and construction schedules for substation EPC projects, which can be amazingly large, complex, and costly. Completing such projects on time and within the budget is not an easy task. It is not easy to comprehend all the activities and relationships necessary for an entire schedule on a substation project. A detailed schedule for a substation EPC project demands a step-by-step procedure and a sample CPM schedule for a substation EPC project is given into Appendix 3B.

Some of the activities of a substation EPC project may not be started before other tasks or portion of tasks or activities have been completed. As an example, a foundation activity needs to be done before the erecting steel activity can be performed. When multiple foundations are in a group, a portion must be complete before the steel erection
starts. Substation EPC projects may involve hundreds or thousands of such activities. Although there might be thousands of activities in the course of a substation EPC project, perhaps hundreds of them would be critical and need to be watched closely.

Some of the key dates that impact the activities of a schedule are expected project completion date, potential variability of this completion date, start and completion dates for each specific activity, start and completion dates for each critical activity that they must be completed as scheduled, delay of the non-critical activities, resource distribution according to activities, and control on the flows of expenditures for the various activities and budget.¹

3.3 Client’s Responsibility in Substation EPC Project

The Client’s primary function is to create the project and pay for it. The Client decides key aspects of the project including what type of project will be built, where it will be built, when it will be built, and who will build it. The Client also has the corresponding duty to manage how the project will be developed and selecting a project delivery system. A 15-point checklist for Client’s responsibilities, as follows²:

1. Identify project goals.
2. Decide upon a project delivery system, which will give the Client best chance to achieve project goals.
3. Determine whether Client needs assistance of a consultant.
4. Select a representative and determine any limitations on the representative’s authority.
5. Decide upon a procurement process for EPC.

6. Determine the appropriate payment methodology (e.g., cost plus, lump sum) for EPC contract.

7. Identify and allocate project risk.

8. Obtain project financing.


10. Secure agreements with adjacent property Clients.

11. Identify Client-furnished deliverables (e.g., permits, furnishings) and develop process for timely obtaining such deliverables.

12. Review design submissions of EPC.

13. Inspect construction for compliance with contract.

14. Develop efficient change order process.

15. Obtain appropriate project insurance.

3.3.1 Client’s Representative

A Client’s engineer or representative is empowered to implement the project and is responsible for ensuring that the project meets the Client’s plan. The representative will select the project delivery method, material and equipment procurement options, and recommend the type of contract to Client. The representative will communicate along with the Client to the EPC contractor or organization about project function, scope, schedule, budget and design criteria. Client’s representative should have a strong understanding of the Client’s overall project goals and understand internal structure of Client’s organization. This person understands EPC process, trusted by Client, and has the power to administer Client’s contractual obligations.
3.3.2 Client’s Project Team and Management Structure

The Client has an established project management structure and project team for any EPC project. Critical players within the Client’s organization are involved in the project management structure and project team. The project team will determine the type of procurement and contracting system will serve the Client’s interest better and will review the design from BMcD. This team will determine if the Client needs a developer, construction manager, or program manager to give the project its greatest opportunity for success.

The Client hires outside consultants to perform specialized services necessary for the EPC project. The Client often needs technical assistance from outside technical advisors to develop the EPC project, request for proposal (RFP), evaluating the RFP’s, selecting the Prime Contractor, monitoring the contractor’s performance, and quality control programs during construction. The Client also may hire outside legal, procurement advisors, and permitting experts because of the complex and unique nature of the EPC project.

3.3.3 Client’s Program

The Client’s program is very important for the success of an EPC project. This program addresses Client’s intention for the project, proposed site location, project design limitations or specific design and procurement requirements. BMcD often serves as the Client’s consultant to help develop its program if the Client uses BMcD directly and engages with BMcD under a preliminary agreement.
The Client needs to decide which risks it will assume and which ones it will shift to the contractor. The Client’s program will define the contractor’s scope of work and the risks that the Client requires the contractor to assume. Some Clients are interested in having the contractor provide more than simply design and construction services such as site acquisition, environmental permitting, project financing, operations and maintenance, and governmental approvals.

3.3.4 Site Investigation

Most Clients agree to retain most of the responsibilities that relate to the unknown physical site conditions. Client provides survey data to BMcD describing the legal description of the property, boundaries, topography, and reference points for use during construction, including existing service and utility lines. Client also provides geotechnical studies to BMcD describing subsurface conditions, and concealed physical conditions at the site.

3.3.5 Permits and Approvals

The Client of an EPC project typically is responsible for obtaining many permits and approvals and Client may request BMcD for help to obtain those permits and approvals. It is important for the Client to have a clear understanding of its permit obligations and the Client must have a plan in place for obtaining such permits and approvals. Client’s inability to obtain the permits and approvals can result in major delays in the project.

3.3.6 Review and Approval of the Design and Construction

Client will review the project design and construction for conformance with the contract requirements. Client might give BMcD their previous completed project drawings and
specifications to use as a reference. BMcD will develop new engineering and construction drawings and specifications based on reference drawings and specifications. Client will approve the testing procedure for the substation equipments and may witness the testing for approval purpose.

3.4 Roles and Responsibility of Substation EPC Project Design Team

The most important responsibility of substation EPC project design team has to deal with deliverables according to the contract between Client and BMcD. The Electrical engineering group will develop the electrical drawings and the Civil engineering group will develop the civil drawings for Client’s review. The electrical and civil drawings will be issued for construction after Client’s approval. Substation EPC project design team will also review and approve vendor drawings. Project coordinator keeps track of the electrical and civil deliverables and construction activities.

A typical substation electrical and civil drawing checklist is given into Appendix 3C.3

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CHAPTER FOUR

BASIC SUBSTATION DESIGN CRITERIA

This section provides basic design criteria for BMcD's substation EPC project and for the substation design engineer. Design criteria is very important for a substation EPC project because substation equipment, materials, and construction cost will be established using the defined design criteria. Design criteria should remain the same during the EPC project. If design criteria changes in the middle of the EPC project; engineering and construction reworking cost can be expensive for both the Client and BMcD.

4.1 Types of Substations

There are three types of substations and the descriptions are provided in Appendix 4A.

4.2 Project Design Conditions

Project design conditions are information that is applicable to all structure, equipment and material designs. Seismic zone, altitude, annual precipitation, design loading district, wind velocity, and ice accumulation information is useful in substation design and needs to provide to the equipment and material suppliers for use in their designs.

4.3 Project Weather Data

The weather data influences the design for the area of the substation. Temperature, isokeraunnic level, wind speeds, and ice play a big role designing substations and the descriptions are provided in Appendix 4B. Temperature, isokeraunnic level, wind speeds, and ice affect for this project is based on the owner's past experience and recommendations contained in the Design Guide for Rural Substations¹ and National...
Electrical Safety Code (NESC)\(^2\).

### 4.4 Substation Electrical System

Substation electrical system information is required to design the substation properly. The electrical system ratings including nominal system voltage, maximum system voltage, station BIL, available fault current, continuous current, short circuit withstand current, and system frequency is necessary to know before the substation design process starts.

### 4.5 Substation Structure Design Load Cases

The substation structure design load cases are necessary to know before the substation structure calculations starts. The substation structure design load cases including weight of equipment, structure, NESC light, medium, and heavy wind, short circuit and ice loadings determine the size of the structures will be required for the substation.

### 4.6 Substation Bus Configurations

The rigid bus design helps to accommodate alternate feeds through adjacent breakers in the event of required maintenance or line fault. There are six types of bus configuration and the descriptions are provided in Appendix 4C.

### 4.7 Substation Bus Configurations Cost

The Table 4-1 provides a reasonable cost comparison between the bus configurations. The comparison is based on four circuit low profile arrangements with power circuit breakers in all circuits. Power transformer costs are not included.
4.8 Substation Clearances

Electrical clearances for the bus must be maintained to protect people and equipment moving underneath the substation. Table 4-2 lists the electrical clearances for outdoor substation. The values in the table identified as minimum should be maintained or exceeded. Phase-to-ground and phase-to-phase clearances should be coordinated to ensure that possible flashovers occur from phase-to-ground rather than from phase-to-phase.

4.9 Substation Insulators

Insulators are static equipment and therefore essentially maintenance free. Outdoor insulators are used to support rigid bus work and other electrical equipment operated above ground potential. Apparatus insulators are normally manufactured from electrical grade wet-process porcelain and polymer. Impulse withstand voltages are commonly referred to as BIL’s for apparatus insulators. Table 4-3 lists the apparatus insulators are available with BIL ratings.

4.10 Major Substation Equipment

Major substation electrical equipment is custom design, has longer delivery time, and is expensive.

The substation power transformer descriptions and one-lines are provided in Appendix 4D.

The substation SF6 gas circuit breaker descriptions, one-lines and figures are provided in Appendix 4E.
The substation air switch descriptions, one-lines, figures, and table are provided in Appendix 4F.

The substation surge arrester description and table are given into Appendix 4G.

The substation capacitor voltage transformer descriptions, one-lines and figures are provided in Appendix 4H.

The substation battery & battery charger descriptions, battery and battery charger selection methods are provided in Appendix 4I.

4.11 Substation Grounding
Substation grounding protects personnel from touch and step potential. The touch and step voltages produced in a fault condition have to be at safe values and a safe value is one that will not produce enough current within a body to cause ventricular fibrillation.

The substation grounding system consists of driven ground rods, buried interconnecting grounding cables or grid, equipment ground mats, connecting cables from grid to metallic parts of structures and equipment, connections to grounded system neutrals, and the ground surface insulating covering material. Substation grounding systems and ground grid design descriptions are provided in Appendix 4J.

4.12 Substation Shielding
Substation electrical equipment can be subject to abnormal conditions as a result of direct lightning strokes. Shielding design analyzes and recommends procedures for direct stroke protection for the substations and substation equipment. Substation
shielding designs and shielding design methods descriptions are provided in Appendix 4K.

4.13 Substation Conduit and Raceway

Raceway in the form of conduit, tray, and trench, are used in the substations to provide protection and segregation of cables. Raceway sizing is an important parameter in substation design notably for a large installation. Substation non-metallic conduit and cable trench descriptions are provided in Appendix 4L.

4.14 Substation Relaying and Metering

Protective relays detect defective lines or apparatus and initiate the operation of appropriate circuit interrupting devices in order to isolate the defective lines or equipment. Relays also detect abnormal or undesirable operating conditions, other than those caused by defective equipment and either operates an alarm or initiate operation of circuit interrupting devices. The high-speed operation of these relays minimizes damage to the electrical system and helps to maintain service continuity to the rest of the electrical system. The most common indication of defective equipment or abnormal conditions is described in Appendix 4M.

4.15 Substation Relay Selection

The type of relay or relay system selected by the substation engineer for an application is of primary importance. The electric system inputs must be known that will be available to the relay and the speed with which the relay must operate to maintain electric system stability. With this information, the Engineer can apply relays that will measure the identified characteristics of the electric power system in order to operate
dependably and securely in protecting the electric system. Substation relay selection is described in Appendix 4N.

4.16 Substation Relay Types

In order to communicate the relaying functions being used on a system, standard device function numbers and contact designations are used to identify devices in protective relay schemes. Substation relay types are described in Appendix 4O.

4.17 Substation Site Grading

Site work design for a substation yard is to provide an easily accessible, dry, maintenance free area for the installation and operation of electrical substation equipment and structures. Substation site grading is described in Appendix 4P.

4.18 Substation Foundation

A variety of structure types are used in electrical substations and these structures have a wide range of ground line reactions. Typical substation foundation types can be slabs on grade, spread footings, drilled shafts and piling with and without pile caps. Foundations should be designed such that they do not exceed deflection criteria of the structure. Substation foundation types are described in Appendix 4Q.

4.19 Substation Structures

Substation structures are designed to reliably support electrical equipment and maintain clearances. Since excessive structure movement can cause electrical equipment to experience mechanical damage, operational difficulties and electrical faults, structures are designed to meet strength and deflection criteria under a variety of loading conditions. Substation structures description are described in Appendix 4R.
4.20 Substation Control Building

The control building provides a weatherproof and environmentally controlled enclosure for substation equipment including relays, meters, controls, batteries and communications equipment. Additional space should provide for workshops, equipment testing and repair and storage. Substation control building types are described in Appendix 4S.

4.21 Substation Control Building Layout and Communication

Control building layout includes controls, relay panels, DC equipment, AC equipment, cable tray and lighting. Substation control building layout and list of equipments are described in Appendix 4T and substation communication equipments are described in Appendix 4U.


CHAPTER FIVE

SUBSTATION PROJECT APPROACH\(^1\)

This Section describes the substation EPC project approach to provide the scope of work required to design and build a new substation. In addition, this section outlines the general information needed from the Client and deliverables provided to Client by BMcD. Information was obtained for this section of the Field Project from previously used project approach for substation EPC projects.

BMcD assembles an experienced project management, engineering, environmental, procurement, construction management, and construction team to perform all of the services required for a substation EPC project. The Project manager will lead a select team of experienced professionals through the numerous tasks required to provide the client with fully functional, cost effective substation facility. BMcD’s Quality Assurance and Quality Control Program will be invoked throughout the length of the contract helping insure that project objectives are met.

BMcD’s EPC philosophy entails developing and maintaining an integrated and partnered approach focused on meeting the requirements of the contract by involving the Client, the user groups and the design and construction professionals. The Project Manager will have the authority to act for BMcD regarding all aspects of the project. The following narrative outlines BMcD’s methods for managing projects, minimizing risks, assuring quality and providing a clear pathway to success.
5.1 Surveying

The Client or BMcD may perform the substation survey. BMcD will receive the survey data if the Client performs the survey and will incorporate it in the preliminary substation design. The survey information will interface with legal and topographic survey of substation site and will be used as basis for construction surveying including soil boring, structure, and foundation staking. Release of final substation site and assessment/procurement data will be needed from the Client for the substation EPC project.

5.2 Regulatory Permits and Agency Coordination

Based on professional knowledge, the Table 5-1 identifies the federal, state, and local environmental permits, clearances, or agreements that may be required for authorization of a substation EPC project. Where regulations or policies are unclear, the agency will be contacted for clarification or to determine if the regulations apply to the project.

BMcD will initiate contact with the permitting agencies via telephone to introduce the agencies to the project. The purpose of this phone call will be to establish and build rapport with the agency, briefly describe the project, and identify any special concerns the agency may have with permitting the project. BMcD will confirm the applicable rules, approval procedures, and applicable fees with the agency.

BMcD will identify jurisdictional relationships among agencies to facilitate the permitting
process. Pre-application meetings may be requested for permits that have special requirements or issues. These may include wildlife management areas, or other government-owned or managed lands. In addition, pre-application meetings may also include areas where multiple agencies have jurisdiction.

5.2.1 Water and Wetland Resources

If construction in a wetland is required, impacts will be minimized by winter construction or other acceptable means. Even though efforts will be made to minimize disturbance to wetland areas, some temporary impacts may occur should access restraints require equipment to cross water resources. Should this occur, measures such as temporary mats or bridges will be used to allow equipment crossings.

Duration of the placement of such mats will be limited to minimize potential temporary impacts. In order for all jurisdictional agencies to have the confidence that appropriate avoidance and minimization measures are implemented, a Section 404 (for very large projects) Permit will be obtained from the U.S. Army Corps of Engineers. Approval from the state Department of Natural Resources (and the local National Conservation Resource Service as needed) will be sought for wetland or other waters that are solely regulated by the state.

Streams and wetlands will be identified using U.S. Geological Survey topographic maps, National Wetland Inventory Maps, and field delineations where warranted. A qualified biologist and a field assistant will perform wetland delineations as required by
the respective regulatory agency using the Corps of Engineers Wetlands Delineation Manual (1987). Additionally, utility crossings of Public Waters and Wetlands must be approved by the state Department of Natural Resources. Public Waters and Wetlands are identified on state-provided maps.

BMcD will cooperate with the Client in connection with efforts to obtain, maintain, and comply with the major facilities permit from the state Public Utility Commission. Cooperation will consist of recommendations for construction alternatives that may be warranted to avoid or minimize impacts to water resources.

5.2.2 Erosion and Sediment Control

Erosion and sediment control plans will be warranted to minimize deposition of disturbed soils into surface waters. BMcD will obtain general permits for storm water discharges associated with construction activity from respective state and a Storm Water Pollution Prevention Plan will be developed in accordance with permit requirements. Coordination with the state and local National Resource Conservation Service offices will be conducted as needed to obtain concurrence with the erosion and sediment control plans.

BMcD will cooperate with the Client in connection with efforts to obtain, maintain, and comply with the major facilities permit from the state Public Utility Commission. Cooperation will consist of recommendations for construction alternatives that may be warranted to avoid or minimize erosion and sedimentation.
5.2.3 Threatened and Endangered Species

Further coordination with the U.S. Fish and Wildlife Service, the state Department of Natural Resources, and the state Wildlife Diversity Program will be warranted to ensure previously expressed concerns are adequately addressed. BMcD will conduct field assessments as needed to verify that areas where substations will be built contain no native prairie remnants or rare plant species.

BMcD will cooperate with the Client in connection with efforts to obtain, maintain, and comply with the major facilities permit from the state Public Utility Commission. Cooperation will consist of recommendations for construction alternatives that may be warranted to avoid or minimize impacts to protected species.

5.2.4 Other Permits and Agency Coordination

BMcD will initiate agency contact for required notifications and coordination for compliance with federal, state, and local requirements. Notifications to the Federal Aviation Administration for substation structures or construction equipment that may impact air navigation will be made as necessary. Coordination with local agencies to protect and repair drain tiles will be conducted. Permits from governing agencies for road crossing will be obtained.

BMcD will cooperate with the Client in connection with efforts to obtain, maintain, and comply with the major facilities permit from the state Public Utility Commission. Cooperation will consist of recommendations for construction alternatives that may be
warranted to avoid or minimize impacts to respective agency requirements and concerns.

5.2.5 Permit Application and Report Preparation

BMcD will obtain the most current permit application forms and requirements available from each respective agency. The application forms will be completely filled out, noting where additional information is located or where criteria do not apply. BMcD will prepare all required plans, assessments, and reports in accordance with the applicable requirements. All required data will be collected and represented in the document to accurately reflect the project.

5.2.6 Tracking Tools

BMcD utilizes a permit management matrix, a series of logs and flow charts to track progress. A permit log will be developed for the project to document the required permits or authorizations, regulating agencies, target dates and completion dates for milestones and notes related to material issues and resolution. Action items will be identified for each permit or authorization. The action item lists will identify the task, responsible party, target dates, etc. Concerns that may arise and require special attention will be entered in an issues management log and tracked in a similar manner as the action items and permit management. Agency contact records will document conversations, meetings, and written correspondence. Flow charts may be used to illustrate the approval process and relationships to other approvals. The permit management matrix will be updated on a regular basis and provided to the Client document progress.
5.2.7  Permit Notebook

BMcD will prepare a permit notebook. The purpose of the permit notebook is to provide all pertinent information that relates to actions required to ensure compliance with all environmental permits, clearances, and exemptions. Each authorization will be transmitted to the permit notebook with a summary of permit requirements and appropriate reference for detailed information. A copy of the permit notebook will be provided to the Client.

5.3  EPC Substation Facility Design

BMcD will provide detailed civil and electrical engineering design for the substation EPC project. Substation will be designed in accordance with applicable Client’s standards, industry standards and codes, and federal, state or local requirements. BMcD will utilize the latest version of MicroStation or AutoCAD for detailing and drafting applications.

BMcD will develop a project design manual for the Client. The project design manual addresses the specific parameters of the design including applicable standards, codes, and interpretations of codes and standards that may affect the design. The project design manual also addresses the scope of the project and any specialized or unique design techniques used in the development of the design documents.

5.3.1  Subsurface Investigation and Geotechnical Report

BMcD will use a subconsultant to provide a subsurface investigation, testing, and preparation of a detailed Geotechnical Report. BMcD will prepare a subsurface
investigation technical guidelines and scope of work for the geotechnical subconsultant. BMcD will also coordinate and administer all activities of the geotechnical subconsultant, and insure the subsurface investigation; testing and geotechnical report are completed on a schedule that coordinates with the overall schedule of the project.

The subsurface investigation, testing and geotechnical report will provide subsurface information, test results and recommendations for site work and grading design and construction, foundation design and construction, and electrical resistivity for grounding design.

5.3.2 Substation Civil Design

BMcD will perform grading and drainage calculations, erosion control and stormwater runoff calculations, design drawings and details in accordance with Client’s standards and any federal, state or other local requirements. BMcD will design access road, fence and gate drawings and details, transformer oil containment design, drawings, and details in accordance with Client’s standards and applicable federal, state, and local requirements.

5.3.3 Substation Structural Design

BMcD will design a substation foundation Plan; perform calculation for individual foundation; create foundation drawings and details. All foundation design will be performed using the recommendations detailed in the subsurface investigation and geotechnical report.
BMcD will use Client’s steel structure loading diagrams to design substation steel structures and control building loading diagrams to design control building structure. BMcD will review vendor design calculations, shop drawings and erection drawings.

5.3.4 Substation Electrical Design
BMcD will design substation electrical plan, sections and details according to Client’s standards. Substation overall electrical design includes one-line diagrams, three-line diagrams, schematics, and wiring diagrams. BMcD will also design substation electrical, protection and controls, control building plan and sections, raceway, substation grounding according to fault current study and details drawings according to Client’s standards. BMcD will develop cable and conduit schedule, substation equipment, and control building and relay panels bill of materials.

5.3.5 Submittal and Review Process
The construction and support professionals will participate in all aspects of the design phase and review processes. The design and engineering staff will be involved and aware of major construction milestones and field issues. All formal submittals and reviews will be schedule on the master schedule document including the timeframe for client reviews and the timeframe for BMcD to respond to the comments.

5.3.6 Fast Track Construction
The Fast Track construction method requires that the project be designed such that phasing of the work can occur. It is imperative that the phasing plan be developed as early in the project as possible. Determination of the multiple construction packages
and phasing is based on the specific job requirements as determined by the project manager in conjunction with the entire EPC team and any contractual requirements.

The master construction schedule will indicate phasing of construction as well as the multiple design packages necessary to support the Fast Track approach. Individual packages may require review and approval as separate submittals depending upon the overall schedule and program requirements. This will also be indicated in the schedule.

5.4 Substation Equipment Procurement Process and Bid Documents

BMcD will utilize Client’s specifications for substation equipment procurement, provide a comprehensive approach to the procurement process, and pre-qualify suppliers that BMcD trusts to provide timely and technically sound products. Previous experiences will be considered at time of award and packages will be awarded on a best-value basis and Client’s preferred vendors will be utilized. Substation equipment and materials bid documents will include bid forms, general requirements, design condition, major equipments, steel structures, equipment and materials, control building, and relay panels.

5.4.1 Procurement Process

Each major procurement requirement will be assessed and procurement strategies will be evaluated to best support the efficient execution of the procurement packages. BMcD will utilize strong supplier relationships as well as various procurement strategies for sourcing of equipment and bulk materials. BMcD will also utilize all tools including strong contract language, regular schedule tracking and communications, and shop
visits including unannounced visits for reviewing progress and factory condition for critical items.

BMcD will develop an integrated approach to manage the transportation, receipt, and storage of materials and equipment at the jobsite. The BMcD procurement department will monitor supplier progress and will keep the jobsite informed of scheduled delivery dates. Suppliers will be required to contact the jobsite prior to shipment in order to obtain authorization to ship. A materials manager will be assigned to the jobsite to coordinate receipt of materials and equipment with the Client, BMcD’s construction manager, and subcontractors. Upon receipt, the materials manager will log the receipt date, arrange for the necessary receipt inspections, and issue the material receiving reports and Overage, Shortage, and Damage reports, when necessary. Receipt date and status will be logged electronically and make available to the project team.

BMcD’s substation engineering groups will prepare the technical specifications and drawings and the procurement manager will prepare the appropriate commercial documents to complete the Request For Price package. Upon receipt, the substation engineering and procurement personnel will review the proposals. Where required, the Client will be made aware of the major purchases. With input from subcontractors regarding construction and installation costs, recommendations will be made for purchase.
5.4.2 Project-Specific Procurement

BMcD will identify the major supply streams that will affect the completion date of the project. BMcD will meet during the proposal stage with the Client’s approved major equipment suppliers. BMcD will work with a major substation packager to procure high voltage equipment, steel structures, bus, conductor, and miscellaneous items. Where beneficial due to bulk quantity purchase, BMcD may pull some items from the packages. Such items may include disconnect switches and instrument transformers and will definitely include power circuit breakers and capacitor banks.

5.5 Substation Construction Management and Construction

BMcD will select the construction subcontractor and utilize Client’s specifications for substation construction. Substation construction will include construction management, site work including grading and erosion control, installation of fence, major equipments, foundations, grounding, conduit, raceway, control building, relay panels, and steel structures erection and equipment testing.

5.5.1 Substation Construction Management

BMcD’s construction management team will coordinate all construction activities with the Client and the construction subcontractor to insure construction of the substation will be completed in accordance with the contract drawings and specifications, and within the construction schedule. BMcD will maintain an on site presence from construction mobilization through the turnover of the project to the Client.
A project field manager with experienced execution staff and support personnel will be on site during the performance of the work. The project field manager will be in constant contact with the design and procurement team members during the pre-construction and subcontracting selection phase of the project to assure coordination of the work. The project manager, construction manager, engineering manager and their support and technical representatives will visit the site regularly during the construction phase.

BMcD strongly believes that proficient coordination at the site produces success. Formal coordination meetings will be held on a weekly basis at the construction site between the BMcD staff and the subcontractors. Monthly meetings will be held with the client, the site team, key engineering team members, procurement and key subcontractors. BMcD will meet site staff internally and individual subcontractors on a daily basis. The general topics of discussion will include review of schedules and contract requirements, engineering status, procurement status, construction status, job site safety, four-week look ahead of upcoming work and deliveries, review of quality control plans and expectations, coordination of required submittals to insure approvals are made prior to conducting the work, coordination of the day to day construction activities, and identification of any delays or damages based on the type of meeting.

5.5.2 Substation Construction

BMcD will establish the onsite project office and construction subcontractor will mobilize the construction crew and management team to the job site before the substation
construction begins. Subcontractor will perform site reconnaissance and work with local landowners and the Client to determine the locations for receiving and storing substation equipment and materials.

Subcontractor will receive all substation equipment and materials at the designated yard. Material will be inspected and inventoried as received and accepted from the supplier only when it is determined to be in a good and acceptable condition. Quantities received will be checked against packing lists and tracked against total quantities required. All materials received will be stored in a manner to prevent damage or deterioration until it is installed. All materials will be transported, handled and installed using the highest industry standards and in accordance with supplier recommendations and Client’s specifications. Cleanup will be an ongoing process and restoration will be performed at project completion to avoid further disturbance.

5.6 Safety

BMcD is committed to constructing a safe project. The avoidance of any occupational related deaths or injuries is BMcD’s highest priority. As a result of the focus on safety, BMcD is dedicated to assuring the safety of all BMcD personnel as well as managing safe work sites. One of the most critical aspects of producing a successful project safety and health program is to set the goal from the beginning. A “No Tolerance” standard for unsafe workplace conditions and acts will be established. The subcontractors will be made aware from the onset that safety will play a significant role in the success of the project.
A pre-construction meeting will be held between BMcD and each of the subcontractors regarding construction safety. The specific requirements, procedures and submittals will be reviewed with the project manager, field safety coordinator and the construction manager of the subcontractor. Weekly safety and health coordination meetings will be conducted with all subcontractors on site. BMcD will utilize this time to address concerns regarding safety, praise work practices which utilize pre-planning and safe work conformance and allow all subcontractors to address concerns about the project regarding the achievement of safe work practice.

5.7 Quality Control

BMcD’s quality control organization will perform inspections of all items of work to ensure conformance to applicable specifications and drawings with respect to identification. Testing and inspection operations will be reviewed for compliance with contract specifications. Work will be inspected daily to assure continuing compliance with plans and specifications until the completion. Substation engineering team will be responsible for reviewing and certifying shop drawings, catalog data, samples, material certifications and test data that will be performed in coordination with the approved design. No material or equipment will be authorized to release for fabrication or delivery to the job site until the submittals have been approved.

CHAPTER SIX

CONCLUSION

This Field Project provided an overview of the typical substation EPC project delivery method, the work breakdown structure, activities and sequences in the CPM schedule, basic substation design criteria, substation project approach and defines the Client’s, subcontractor’s and Burns & McDonnell’s responsibilities.

Burns & McDonnell Engineering acts as the Prime Contractor in the EPC of electrical substations. The T&D Division designs the EPC substations and the CDB Division purchases the required equipment and materials, monitors substation construction activities and manages all of the field issues. Substation EPC projects involve high risk and high reward.

More activities to keep track in a substation EPC project compare to a just design project. Some of the activities of a substation EPC project may not be started before other tasks or portion of tasks or activities have been completed. For example, foundations for the steel structures must be in well along before erecting the steel structures can start. Site grading and excavation must proceed before installing the steel structure foundations.

The Electrical engineering group develops the electrical drawings and the Civil engineering group develops the civil drawings for Client’s review. The electrical and civil drawings will be issued for construction after Client’s approval. Substation EPC
project design team also reviews and approves vendor drawings. Project coordinator keeps track of the electrical and civil deliverables and construction activities.

Substation will be designed in accordance with applicable Client’s standards, industry standards and codes, and federal, state or local requirements. Design criteria should remain the same during the EPC project. If design criteria changes in the middle of the EPC project; engineering and construction reworking cost can be expensive for both the Client and Burns & McDonnell.

The Project manager leads a select team of experienced professionals through the numerous tasks required to provide the client with fully functional, cost effective substation facility. Burns & McDonnell’s Quality Assurance and Quality Control Program involve throughout the length of the project helping insure that project objectives are met.

Burns & McDonnell will provide design manual, detailed civil and electrical engineering design for the substation EPC project to the Client. The project design manual addresses the specific parameters of the design including applicable standards, codes, and interpretations of codes and standards that may affect the design. The project design manual also addresses the scope of the project and any specialized or unique design techniques used in the development of the design documents.

Client’s specifications for substation equipment procurement will be utilized and will
provide a comprehensive approach to the procurement process, and pre-qualify suppliers that Burns & McDonnell trusts to provide timely and technically sound products. Client’s specifications for substation construction will be utilized and Burns & McDonnell will select the substation construction subcontractor. The subcontractors will be made aware from the onset that job quality and safety will play a significant role in the success of the project.

Work will be inspected daily to assure continuing compliance with plans and specifications until the completion. Testing and inspection operations will be reviewed for compliance with contract specifications. The avoidance of any occupational related deaths or injuries is Burns & McDonnell’s highest priority. Burns & McDonnell is committed to constructing a safe project. As a result of the focus on safety, Burns & McDonnell is dedicated to assuring the safety of all Burns & McDonnell personnel as well as managing safe work sites.
CHAPTER SEVEN

SUGGESTIONS FOR ADDITIONAL WORK

In order to understand and improve the T&D Division’s substation EPC project delivery method additional research or work on substation EPC project needs to be done. The T&D Division should consider using other scheduling method beside CPM scheduling such as Program Evaluation and Review Technique (PERT) and Linear Scheduling Method (LSM). T&D Division should evaluate CPM, PERT and LSM scheduling for the delay claims.

Additional work can be done to find out the requirements for the Private and Public-Sector Clients. Additional work also can be done to find out the time limitations for filing claims for different state, statutes of limitations, statutes of repose, compensatory damages, punitive damages, consequential damages, mechanic’s liens, indemnification, breach of contract, tort of negligence, statutory violations, the betterment rule, and defenses unavailable in EPC project.

Risk analysis, risk management, go-no go decision for the EPC projects, pricing strategy, contract terms and conditions review, contractor and design professional licensing requirements in EPC project, corporate licensing restrictions, responsibility for site safety, dispute resolution, codes of ethics and professional conduct, and bonding issues in EPC project can be done as additional research or work.
Bibliography


CPM Scheduling, Basic Engineering, and Project Approach for Typical Substation EPC Project


APPENDIX - 1A

ACTIVITY LIST
APPENDIX 1A

Activity List

General Activity
  Project Milestones
  Owner Activities
Material and Equipment Procurement Activity
  Power Transformers
  SF6 Circuit Breaker
  Capacitor Banks
  Reactors
  Control cable
  Relay Panels
  Control Building
Substation Structures and Materials
Site Services/Construction Contract
  Construction Subcontract
  Soil Borings
  Site Survey
  Substation Testing
  Substation Relay Settings
Substation Engineering
  One-Line Diagram
  Schematics and Controls
  Site and Equipment Layout Plan
  Site Equipment Elevation
  Control Building Layout Plan
  Control Building Equipment Elevation
Substation Electrical Work
  Control Cable Terminations
  Equipment Testing
  Relay Function Testing
Substation Construction
  Site work
  Foundation
  Structure
  Grounding
  Raceway

APPENDIX - 3A

TERMS AND DEFINITIONS OF CPM SCHEDULE
APPENDIX 3A

Terms and Definitions of CPM Scheduling

Critical Path Method (CPM) – A network scheduling technique where large elements of a project are subdivided based on a hierarchical system (work breakdown structure), into single work steps (activities) and sequenced based on interrelationships such that time usage can be calculated to determine the earliest date work can be accomplished and the latest date work needs to be completed.

Critical Path – the sequence of activities with the least amount of Total Float. The Critical Path can be positive, negative or zero.

Total Float – The difference between the early and late date on an individual activity within a float path.

Free Float – The amount of Total Float that an activity may consume before affecting a subsequent activity.

Original Duration – The amount of work assigned to an activity.

Remaining Duration – The amount of work needed to complete an activity.

Lag – The amount of work days assigned to an ‘un-defined’ activity. Usually used in conjunction with FF or SS relationships.
Relationship – this is used to define the relationship between two activities. These two activities are called the predecessor and the successor. There are four logic types. They are finish to start (FS), finish to finish (FF), start to finish (SF) and start to start (SS).

a. Finish to Start (FS) – This relationship indicates the predecessor activity must finish before the successor activity can start. The activities occur in sequence. This is also referred to as conventional logic. It is the most common logic used in CPM scheduling.

b. Finish to Finish (FF) – This relationship indicates the predecessor activity must finish before the successor activity can finish. The activities occur in parallel. Often times a lag will be used in conjunction with this relationship to indicate that only a portion of the two activity durations are in parallel.

c. Start to Start (SS) – This relationship indicates the predecessor activity must start before the successor activity can start. The activities occur in parallel. Often times a lag will be used in conjunction with this relationship to indicate that only a portion of the two activity’s durations are in parallel.

d. Start to Finish (SF) – this relationship indicates the predecessor activity must start before the successor activity can finish. The activities occur in sequence. This is the least common logic used in CPM scheduling.

Constraint – A fixed date imposed on the start or finish of an activity due to restrictions outside of the boundaries of control. Eg. Contractual Completion Date, receipt of permits obtained by others.
Resource – A commodity necessary for the completion of the work on an activity, such as budget hours, money, equipment, materials, etc.

Work Day – A specified day of the week predetermined as an expected day for work to be performed.

Incremental Curve – A histogram depicting the resource usage in each increment of time.

Cumulative Curve – A graph showing the rate of resource usage at any given point in time.

Planned Date – The date by which the project team intends to execute the work. Usually some time between the early and late date.

Data Date – The date used as a cut-off for updating a CPM schedule with progress for re-calculation of the early and late dates to obtain a more current forecast of the project schedule. The data date is sometimes referred to as the ‘time-now’ line, or the progress date.

APPENDIX - 3B

SAMPLE CPM SCHEDULE FOR A SUBSTATION EPC PROJECT
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**General Milestones**

**Project Milestones**

- **MS1000** Project Award
- **MS1050** Preliminary Design Review Meeting - Substation
- **MS1010** Full Notice to Proceed
- **MS1020** Mobilize to Site
- **MS1055** Initiate Substation Insurance
- **MS1115** Mechanical Completion - Substation
- **MS1120** Substantial Completion - Substation
- **MS1125** Acceptance - Substation

**Client Activities**

- **XCEL-1040** Client Legal Descr of Substation Property
- **XCEL-1060** Client Release for Survey / Geotech - Substation
- **XCEL-1080** Client Scope Verification - Substation
- **XCEL-1090** Provide Substation Permit

**Utility Interface Activities**

- **UTIL-0900** BMcD Define Station Service Req. - Substation
- **UTIL-0910** BMcD Define Communication Req. - Substation
- **UTIL-0930** County Station Service Source - Substation
- **UTIL-0940** Plan & Construct Leased Line - Substation

**Site Acquisition**

**Substation**

- **ROW1A-1000** Permissions to Survey
- **ROW1A-1005** Field Survey
- **ROW1A-1010** Title Work
- **ROW1A-1020** Property Valuation Reports
- **ROW1A-1025** Legal Descriptions from Surveyor
- **ROW1A-1030** Transfer Document Preparation

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### Material / Equipment Procurement

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### Substation Package

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**Submittal & Delivery**

**Site Services / Construction Contracts**

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APPENDIX - 3C

A TYPICAL SUBSTATION ELECTRICAL AND CIVIL DRAWING CHECKLIST
APPENDIX A

TYPICAL SUBSTATION DRAWING CHECKLIST

GENERAL – FOR ALL DRAWINGS
A. COVER SHEET/INDEX
B. LEGEND
C. ELEMENTARY ONE-LINE DIAGRAM(S)
D. RELAY ONE-LINE DIAGRAM(S)
E. GENERAL ARRANGEMENT PLAN
F. SITE PLANS, SECTIONS, AND DETAILS
G. SUBSTATION PLAN, SECTIONS, AND DETAILS
H. FOUNDATION PLAN AND DETAILS
I. STRUCTURE PLAN AND DETAILS
J. GROUNDING PLAN AND DETAILS
K. RACEWAY PLAN AND DETAILS
L. DUCT BANK AND HIGH-VOLTAGE CABLE PLAN AND DETAILS
M. CONTROL BUILDING PLANS, SECTIONS, AND DETAILS
N. SUBSTATION BILL OF MATERIALS
O. RELAY CONTROL PANEL (SWITCHBOARD) LAYOUTS AND WIRING DIAGRAMS
P. THREE-LINE DIAGRAMS, AC AND DC SCHEMATICS
Q. MISCELLANEOUS EQUIPMENT YARD EXTERNAL CONNECTION DIAGRAMS
GENERAL - FOR ALL DRAWINGS

1. Title block.
2. Engineer’s seal (verify whether engineer needs to sign the seal).
3. Drawing dates (input date the drawing is issued for owner approval).
4. Revision block.
5. Signature lines:
   a. Detailed - Detailers name (i.e., J.A. JONES) who initially made the drawing.
   b. Designed - Design engineer’s name (i.e. T.R. SMITH).
   c. Checked - Initials (i.e., L.M.F.) of the engineer who checked the drawing; the same engineer may not check all contract drawings.
6. Symbology is correct per Legend drawing.
7. Drawing coordinate system is provided on border margins.
8. Drawing is of material satisfactory to the cooperative.
9. Drawing is of a size satisfactory to the cooperative.
10. Drawing is identified as satisfactory to the cooperative.
11. All line work and lettering are reproducible.
12. The smallest lettering is readable at the smallest proposed reduction size.
13. Consideration has been given to overall organization of drawing to minimize field inconvenience.
14. Drawing avoids ambiguities, incompleteness, lack of clarity, misleading emphasis, etc.
15. Legends, notes, symbols have been carefully reviewed for correctness and completeness.
16. Appropriate drawings are referenced.
17. All changes are incorporated as required by the cooperative or RUS.
   Additional for Plan, Sections, Elevations, Details, and Panel Layouts.
18. Bar scale (engineer’s scale only).
19. Detail, Section, or Elevation Designation and Title.
   Additional for Plan, Drawings, Detail Plan Views, One-Line and Three-Line diagrams.
20. North arrow (reference to grid, true, or magnetic north).

A. COVER SHEET/INDEX (MAY BE MORE THAN ONE DRAWING)

1. Engineer’s seal
2. Cooperative name
3. Cooperative logo
4. Project description
5. Contract number and name
6. List of contract drawings
7. Vicinity map (with north arrow)
8. List of reference drawings
9. Project number
10. Year
B. LEGEND

Include the “General - for All Drawings” items.

1. List of all symbols used for the drawings (do not have individual legends on other drawings with the exception of complex Civil Site Grading Plans).

C. ELEMENTARY ONE-LINE DIAGRAM(S)

Include the “General - for All Drawings” items

1. Substation names and voltages
2. Breakers with PCB numbers
3. Disconnect switches with numbers
4. Line/major equipment designations
5. Phasing
6. Future equipment
7. Transmission lines:
   a. Length
   b. Conductors/stranding
   c. Transpositions
8. Bus and relative location, physically oriented as possible
9. Interties to interconnecting utilities - phasing difference between utilities
10. Power fuses
11. Other information needed from a switching standpoint to define overall system

D. RELAY ONE-LINE DIAGRAM(S)

Include the “General - for All Drawings” items.

1. Power One-line:
   a. Incoming lines/designations and voltages
   b. Disconnect switches and numbers
   c. Surge arresters/quantity and rating
   d. Power transformers (in equipment box):
      (1) Winding type - auto or multiple winding and tertiary
      (2) Surge arresters
      (3) Phasing
      (4) Bushings/designations
      (5) Neutral/ground connection
      (6) Transformer designations:
         (a) Voltage rating
         (b) MVA rating
         (c) Cooling rating
         (d) HV taps
         (e) LV taps
         (f) LTC (if applicable)
         (g) Impedance for all winding connections
         (h) Winding connection diagram indicating phasing and voltage relationships at bushings

2. Power fuses w/ continuous current rating
3. Station service transformer:
a. Quantity
b. kVA rating
c. Transformer type
d. Voltage ratings
e. Taps
f. Secondary breaker or fuse if located in yard near transformer
g. Reference to low-voltage AC drawing

4. High-voltage bus with designations on main bus and phasing, connection dots

5. Power circuit breakers:
   a. Bushing pole numbers
   b. Cabinet location
c. Designation
d. Continuous current rating
e. Breaker number

6. CCVTs, CVTs, or PTs:
   a. Primary winding
   b. Secondary winding with terminal designations
c. Quantity (if more than one)
d. Phase designation
e. Voltage rating for all windings
f. Ratio for all windings
g. Capacitance of device

7. Line traps
   a. Designation
   b. Phase location
c. Continuous current rating

8. Miscellaneous equipment:
   a. Correct symbol per legend
   b. Designation
c. Phasing
d. Quantity (if more than one)
e. Major equipment ratings

9. Miscellaneous:
   a. Future bus connections
   b. Temporary bus connections:
      1. Clear differentiation between permanent -vs- temporary
      2. Different phases of construction (permanent -vs- temporary)
   c. References to other drawings
d. Bill of material #’s for major equipment
e. Drawing coordinate system

10. Protection/controls:
    a. Current transformers/circuits:
       (1) Correct orientation of symbol
       (2) Multi ratio -vs- single ratio
       (3) Polarity marks
       (4) Symbol for wye or delta connection
       (5) Quantity (if more than one)
       (6) Maximum ratio for multi-ratio
       (7) Ratio combinations for dual rated CTs
       (8) Connected ratio
(9) Shorted if not used
(10) Circuits short as possible to minimize confusion
(11) Fewest line crossings as possible to minimize confusion
(12) Straight through devices - in and out
(13) Test plug arrows pointed properly
(14) Polarizing currents in and out on 45 degree angle

b. Potential circuits:
(1) Potential device secondary winding
(2) Potential device secondary connections
(3) Fuses and contact current ratings
(4) Test points as appropriate
(5) Into instruments on a square angle
(6) Short as possible to minimize confusion
(7) Fewest line crossings as possible to minimize confusion

c. Equipment enclosure boxes:
(1) Transformers
(2) Fuse and terminal boxes
(3) Designations and phasing as applicable
d. Instruments:
(1) Circle or box per legend
(2) Designations or suffixes per legend
(3) Location symbol
(4) Quantity (if more than one)
e. Control logic:
(1) Short as possible to minimize confusion
(2) Fewest line crossings as possible to minimize confusion
(3) Arrowhead toward the direction of action
(4) Arrowhead only where action splits or comes together for a common function
(5) Contact designations where applicable to show correct logic
(6) Diodes where applicable and used to control the logic
(7) If not obvious, primary action of control identified (Trip, etc.)

E. GENERAL ARRANGEMENT PLAN

Include the “General - for All Drawings” items.

1. First transmission structure outside the fence, minimum, with location coordinates
2. Minimum of two survey monuments with elevations and dimensions to the substation base lines
3. Coordinates (or dimensions to base line) of centerline of transmission line termination structure
4. Transmission line voltage and name
5. Transmission line right-of-way with tie into substation monuments
6. Property lines and other utility corridors or rights-of-way
7. Baseline
8. Borrow and waste area
9. Trash area
10. Storage areas
F. SITE PLANS, SECTIONS, AND DETAILS

Include the “General - for All Drawings” items.

1. Site Plan/Grading Plan:
   a. Baseline
   b. Benchmark
   c. Fence coordinates
   d. State plane grid system
   e. New and existing grade
   f. Buried facilities
   g. Borrow area
   h. Access roads

2. Site Sections/Grading Sections and Details:
   a. Sections:
      (1) Fence location
      (2) Baseline location
      (3) Elevations
      (4) New and existing grade
   b. Fence details
   c. Gate details

G. SUBSTATION PLAN, SECTIONS, AND DETAILS

Include the “General - for All Drawings” items.

1. Substation Plan:
   a. Fence
   b. Warning signs
   c. Equipment and structures:
      (1) Deadend structure
      (2) Breakers
      (3) Switches
      (4) Control building
      (5) Instrument transformers
      (6) Power transformer
      (7) Switchgear
      (8) Reactors
      (9) Bus supports
      (10) Static masts
      (11) Capacitors
      (12) Surge arresters
      (13) Cable trench and designated drive paths
   d. Bus and conductor:
      (1) End bells
      (2) Grounding studs
      (3) Bus A-frame connection
      (4) Jumper connections
(5) Strain bus
(6) Bus cutting schedule
e. Phasing (transmission line phases and bus phases)
f. Transmission line voltage and name designation
g. Section reference callouts
h. Detail reference callouts
i. Dimensions (fence to major equipment if dimensions do not show up on
   section drawings)
j. Future equipment
k. Notes
l. Baseline

2. Substation Sections and Details:
   a. Bill of Material callouts (if typical is used, it is only for the section in
      question)
   b. Dimensions (centerline of equipment)
   c. Bottom of baseplate callout (each section)
   d. Conductor and static wire takeoff heights, stranding, and maximum
      allowable tensions
   e. Bus support type callout (may be shown on plan):
      (1) Slip
      (2) Fixed
      (3) Expansion
   f. Detail reference callouts
g. Bus and conductor:
   (1) End bells
   (2) Bus A-frame connections
   (3) Grounding studs
   (4) Jumper connections
   h. Disconnect switches and switch operators
   i. Area lighting
   j. Notes:
      (1) Reference assemblies
      (2) Reference grounding details
   k. Transmission line voltage, name designation, conductor, and stranding
   l. Phasing
   m. Equipment elevation differences to bottom of baseplate; elevation
      differences are noted if leveling nuts are used on some equipment
   n. Elevation breaks in bus
   o. Junction boxes/fuse boxes
   p. Welding outlet locations
   q. Telephone location

3. Substation Details:
   a. Bill of material callouts
   b. Reference notes to other details

H. FOUNDATION PLAN AND DETAILS

Include the “General - for All Drawings” items.
1. Foundation Plan:
I. STRUCTURE PLAN AND DETAILS

Include the "General - for All Drawings" items.

1. Structure Plan:
   NOTE: On most substations it is sufficient to incorporate Structure Plan design with the Substation Plan drawing. Therefore a separate Structure Plan drawing is not required. For more complex substations, a Structure Plan may be required.
   a. Loading table
   b. Baselines
   c. Monuments with coordinates and elevations
   d. Fence
   e. Dimensions - to centerlines of all structures, unless noted otherwise (should match with centerlines on structure details, other dimensions as needed for clarification).
   f. Notes:
      (1) Definition of terms
      (2) Definition of symbols

2. Structure Details:
   a. Loading table.
   b. Notes:
      (1) Definition of terms
J. GROUNDING PLAN & DETAILS

Include the “General - for All Drawings” items.

1. Grounding Plan:
   a. Baseline
   b. Dimension ground grid - if necessary
   c. Reference grounding details
   d. Cable trench ground
   e. Fence ground
   f. Switch operator mat
   g. Riser locations
   h. Bill of material for different size conductor
   i. Designation symbols per legend

2. Grounding Details:
   a. Reference notes to other details
   b. Typical equipment grounding
   c. Typical structure grounding
   d. Typical power transformer grounding
   e. Typical switch grounding
   f. Typical fence and gate grounding
   g. Any specific required grounding

K. RACEWAY PLAN AND DETAILS

Include the “General - for All Drawings” items.

1. Raceway Plan:
   a. Baseline
   b. Raceway schedule (may be a separate database list)
   c. Conduit and direct-buried cable with approximate routing
   d. Conduit and direct-buried cable designations
   e. Cable trench
   f. Yard lighting symbols
   g. Yard receptacles
   h. Detail references
   i. Major equipment identifications
   j. Manholes and handholes

2. Raceway Details:
   a. Reference notes to other details
   b. Conduit installation to equipment
   c. Control and lighting cable installation to equipment
   d. Major equipment identifications
   e. Cable trench details

L. DUCT BANK AND HIGH-VOLTAGE CABLE PLAN AND DETAILS

Include the “General - for All Drawings” items.

1. Duct Bank and High-Voltage Cable Plan and Profiles:
a. Duct bank curve data table:
   (1) Delta
   (2) Radius
   (3) Length
   (4) Tangent
b. Stationing
c. Northing and easting for beginning and end of duct bank
d. Duct bank bearing and identification
e. Finished grade and existing grade

2. Duct Bank and High-Voltage Cable Horizontal and Vertical Profiles, Sections, and Details:
   a. Reference notes to other details
   b. Duct size, quantity, and arrangement
   c. Reinforcing steel
   d. Depth, finished grade, backfill, and clearances

M. CONTROL BUILDING PLANS, SECTIONS, AND DETAILS

Include the “General - for All Drawings” items.

1. Control Building Electrical Plan and Sections:
   a. Equipment Plan:
      (1) Panel boards
      (2) Batteries
      (3) Battery charger
      (4) AC/DC power panels
      (5) Eye wash
      (6) Table & chair
      (7) Fuse boxes
      (8) Fire extinguisher
      (9) Exit sign
      (10) Dimensions
   b. Equipment List:
      (1) Bill of material item number
      (2) Key number
      (3) Equipment description
   c. Raceway Plan:
      (1) Equipment
      (2) Conduit
      (3) Raceway callouts
      (4) Cable tray (if required):
         (a) Tray key:
            [1] Key
            [2] Description
            [3] Size
      (5) Building cable trench (if required)
      (6) Raceway number
      (7) Raceway size
      (8) Circuit numbers (per Circuit Schedule) of each raceway
   d. Lighting and grounding plan:
(1) Lights (with correct legend symbol)
(2) Exit sign location
(3) Switches (location and type)
(4) Receptacles
(5) Circuit designations
(6) Ground conductor locations
(7) Ground connections
(8) Equipment
(9) Cable tray (if required)

2. Control Building Mechanical (HVAC) Plan and Sections:
   a. Design and detailing may be done by mechanical discipline.

3. Control Building Architectural Plan and Sections:
   a. Design and detailing may be done by architectural discipline.

N. SUBSTATION BILL OF MATERIALS

(May be in database format.)

O. RELAY CONTROL PANEL (SWITCHBOARD) LAYOUTS AND WIRING DIAGRAMS

Include the “General - for All Drawings” items.

1. Layouts:
   a. Front view:
      (1) Panel designation
      (2) Mimic bus
      (3) Relays
      (4) Future relays
      (5) Control switches
      (6) Test switches
      (7) Panel dimensions
      (8) Future panels
   b. Rear view:
      (1) Relays
      (2) Future relays
      (3) Panel designation
   c. Nameplate schedule
   d. Relay Bill of Material

2. Wiring Diagrams:
   a. Schematic reference
   b. Notes:
      (1) Definition of terms
      (2) Definition of symbols not shown on Legend sheet
   c. Device Internal Diagrams (may be a separate drawing)
   d. Bill of Material (may be a separate database)
   e. Device graphic showing terminals; device located on Wiring Diagram in general proximity of device location as installed on Layout
   f. Device Designation and Wiring Termination list adjacent to each device graphic
Example:  
   UA  
   1 - CA1  
   2 - BD7  
   L1 - UA2  
   L2 - UA4  

___________  
g. Terminal blocks with external cable and panel-to-panel circuit connections

P. THREE-LINE DIAGRAMS, AC AND DC SCHEMATICS

Include the “General - for All Drawings” items.

1. Three-Line Diagrams
   a. Power Three-Line:
      (1) Three phases
      (2) Physically oriented
      (3) Phasing
   b. PCBs:
      (1) Bushing pole location and number
      (2) Control cabinet
      (3) Breaker number
   c. Disconnect switches:
      (1) Group-operated/single phase
      (2) Switch number
   d. Surge arresters:
      (1) Quantity
      (2) Voltage rating
   e. Line designations
   f. Line voltage
   g. CCVTs, CVTs, and PTs:
      (1) Capacitors
      (2) Drain coil
      (3) Primary winding
      (4) Secondary winding
      (5) Heaters
      (6) Secondary terminal block designations
      (7) Carrier taps, if applicable
      (8) LTU
      (9) Phase identification
   h. Current transformers:
      (1) Correct orientation as one-line diagrams
      (2) Multi ratio vs. single ratio
      (3) Polarity marks
      (4) Ratio combinations for dual rated CTs
      (5) Maximum ratio for multiratio CTs
      (6) Connected ratio for multiratio CTs
      (7) External terminals connected to external circuits
(8) Jumpers
(9) Grounds if applicable

i. Circuit designations:
(1) Each circuit identified per circuit schedule designation
(2) Terminal conductors shown with color coding
(3) Spare conductors indicated
(4) Shield tape or ground indicated
(5) Circuit grounds indicated, if applicable

j. Power fuses:
(1) Continuous current rating

k. Transformers:
(1) Surge arresters
(2) Bushing identification
(3) Phasing
(4) LTC
(5) NLTC
(6) Winding connections
(7) Neutral
(8) Transformer identification
(9) Voltage ratings
(10) MVA ratings
(11) Cooling ratings
(12) Temperature ratings

l. Major equipment:
(1) Power ratings
(2) Voltage ratings
(3) Current ratings
(4) Identification

m. Miscellaneous:
(1) Equipment/cabinet enclosures
(2) Notes as applicable for clarification

2. AC Schematics
   a. Current circuits for power circuit breakers, transformers and generators, and circuit switches and motor-operated disconnect switches:
      (1) Relay and meter current coils, and polarizing, neutral protection, and differential protection circuits:
         (a) Circuit designations:
            (1) Each circuit identified per circuit schedule designation
            (2) Terminal conductors shown with color coding
            (3) Spare conductors indicated
            (4) Shield tape or ground indicated
            (5) Circuit grounds indicated, if applicable
         (b) Location in circuit and proper orientation
            (c) Polarity (if applicable)
            (d) Phase:
               (1) Proper orientation
               (2) Terminal and connection points
               (e) Device connections and terminals
               (f) Current switches normal position: grounded, shared, open, or closed
(g) Circuit ground located at device or at panel
(h) Miscellaneous current devices:
   (1) Fault recorders
   (2) Sequence of events recorders
(i) LTC current circuits:
   (1) Vacuum interrupters

b. Potential circuits for power circuit breakers, transformers and generators, and circuit switches and motor-operated disconnect switches:
   (1) Relay and meter voltage coils and polarizing, synchronizing, and underfrequency load-shedding circuits:
   (a) Circuit designations:
      (1) Each circuit identified per circuit schedule designation
      (2) Terminal conductors shown with color coding
      (3) Spare conductors indicated
      (4) Shield tape or ground indicated
      (5) Circuit grounds indicated, if applicable
   (b) Location in circuit and proper orientation
   (c) Polarity (if applicable)
   (d) Phase
   (e) Device connection and terminal points
   (f) Voltage switches normal position: grounded, shorted, open, or closed
   (g) Circuit ground located at device or at panel
   (h) Miscellaneous voltage devices:
      (1) Fault recorders
      (2) Sequence of events recorders
      (3) Carrier blocking circuits
      (4) Auxiliaries:
         (a) Motors
         (b) Heaters
         (c) Lights
         (d) Miscellaneous
      (i) LTC circuits and controls

3. DC Schematics:
   a. Circuit designations:
      (1) Each circuit identified per circuit schedule designation
      (2) Terminal conductors shown with color coding
      (3) Spare conductors indicated
      (4) Shield tape or ground indicated
      (5) Circuit grounds indicated, if applicable
   b. Relay trip and protection circuits:
      (1) Power circuit breakers:
         (a) Trip circuits:
            (1) Protective relay circuits:
               (a) Internal coils and contacts
               (b) Target coils and contacts
               (c) MOVs and transistors
               (d) Diodes and rectifiers
               (e) Resistors and capacitors
               (f) Relay taps and jumpers
            (2) Auxiliary relays:
(a) Coils
(b) Contacts
(c) Miscellaneous devices
(d) Spare device contacts
(3) Trip-blocking contacts:
   (a) Control switch contacts
   (b) Blocking relay coils and contacts
(4) SCADA control contacts
(5) Contact callout tables:
   (a) Relay contacts
   (b) Switch contacts
(6) Switch nameplates (escutcheons):
   (a) Positions
(b) Close circuits:
   (1) Carrier start/stop circuits:
       (a) Relay terminals and connections.
       (b) Wire and device labels:
           [1] Transmit
           [2] Receive
   (2) Close block circuits:
       (a) Relay coils and contacts
       (b) Switch contacts
   (3) Reclosing relay:
       (a) Coils
       (b) Contacts:
           [1] Relays
           [2] Switches
   (4) SCADA control contacts
(c) Auxiliary circuits:
   (1) Motors
   (2) Alarm points
   (3) Miscellaneous
(d) Breaker Failure Relaying:
   (1) Relays:
       (a) Internal coils and contacts
       (b) Target coils and contacts
       (c) MOVs and transistors
       (d) Diodes and rectifiers
       (e) Resistors and capacitors
       (f) Relay taps and jumpers
   (2) Initiate contacts
   (3) Contact callout tables
(2) Transformers and generators:
   (a) Trip schemes:
       (1) Differential circuits for power transformer, generator and bus:
           (a) Protective relay circuits:
               [1] Internal coils and contacts
               [2] Target coils and contacts
               [3] MOVs and transistors
[4] Diodes and rectifiers
[5] Resistors and capacitors
[6] Relay taps and jumpers
[7] Transformers and power supplies

(b) Trip contacts:
[1] Contact callout tables

(c) Auxiliary relays:
[1] References to breakers tripped and/or devices operated
[2] Internal relay circuits as necessary
[3] Relay terminals and connections

(2) Sudden pressure (transformer):
(a) Protective relay circuits:
[1] Internal coils and contacts
[2] Target coils and contacts
[3] MOV’s and transistors
[4] Diodes and rectifiers
[5] Resistors and capacitors
[6] Relay taps and jumpers
[7] Transformers and power supplies

(b) Sudden pressure switch

(3) Neutral, highside, and remote trip schemes:
(a) Protective relay circuits:
[1] Internal coils and contacts
[2] Target coils and contacts
[3] MOV’s and transistors
[4] Diodes and rectifiers
[5] Resistors and capacitors
[6] Relay taps and jumpers
[7] Transformers and power supplies

(b) Trip contacts:
[1] Contact callout tables

(c) Auxiliary relays:
[1] References to breakers tripped and/or devices operated
[2] Internal relay circuits as necessary
[3] Relay terminals and connections

(b) Alarm circuits:
(1) Relays:
(a) Coils
(b) Contacts

(2) Alarm cutout or reset switches

(3) Circuit switches and motor-operated disconnect switches:
(a) Trip circuit:
(1) Protective relay circuits:
(a) Internal coils and contacts
(b) Target coils and contacts
(c) MOV’s and transistors
(d) Diodes and rectifiers
(e) Resistors and capacitors
(f) Relay taps and jumpers.

(2) Auxiliary relays:
(a) Coils
(b) Contacts
(c) Miscellaneous devices
(d) Spare device contacts
(3) Trip-blocking contacts:
   (a) Control switch contacts
   (b) Blocking relay coils and contacts
(4) SCADA control contacts
(5) Contact callout tables:
   (a) Relay contacts
   (b) Switch contacts
(6) Switch nameplates (escutcheons):
   (a) Positions
(b) Close circuits:
   (1) Relay terminals and connections
   (2) Close block circuits:
      (a) Relay coils and contacts
      (b) Switch contacts
   (3) SCADA control contacts
(c) Auxiliary circuits:
   (1) Motors
   (2) Alarm points
   (3) Miscellaneous

4. SCADA and/or Alarm Schematics
   a. SCADA points:
      (1) Control
      (2) Indication
      (3) Metering
   b. Annunciator(s):
      (1) Contacts and terminals
      (2) Auxiliary equipment and accessories
   c. Miscellaneous alarms
   d. Circuit designations:
      (1) Each circuit identified per circuit schedule designation
      (2) Terminal conductors shown with color coding
      (3) Spare conductors indicated
      (4) Shield tape or ground indicated
      (5) circuit grounds indicated, if applicable
   e. SCADA point list

Q. MISCELLANEOUS EQUIPMENT YARD EXTERNAL CONNECTION DIAGRAMS

Include the "General - for All Drawings" items.
1. Schematic Reference
2. Notes:
   a. Definition of terms
   b. Definition of symbols not shown on Legend sheet
3. Device Graphic Showing Terminals and Terminal Blocks
NOTE: In general, the internal detail is not required or is shown on device manufacturer’s diagrams. The external cable connection is the important data to be conveyed.

4. Terminal blocks with jumpers and external cable connections.
APPENDIX – 4A

TYPES OF SUBSTATIONS
APPENDIX 4A

Types of Substations

Distribution Substation

A distribution substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce subtransmission voltage to primary distribution voltage for residential, farm, commercial, and industrial loads. Figure 4-2 shows basic distribution substation arrangement.

![Figure 4-2: Basic Distribution Substation](image)

Transmission Substation

A transmission substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce transmission voltage to subtransmission voltage for distribution of electrical energy to distribution substations. Figure 4-6 shows basic transmission substation arrangement.

![Figure 4-6: Basic Transmission Substation](image)
Switching Substation

A switching substation is a combination of switching and controlling equipment arranged to provide circuit protection and system switching flexibility. Figure 4-8 shows basic switching substation arrangement.

Figure 4-8: Basic Switching Substation

APPENDIX – 4B

PROJECT WEATHER DATA
APPENDIX 4B

Project Weather Data

Wind Speeds

Design wind speeds affect the required strength of the wire, insulators, hardware and supporting structures. They also are used to determine the structure geometry required to maintain the electrical clearances. Figure 2-1 shows the basic wind speed and substations should be resistant to wind velocity as a minimum.
Notes:

1. Values are 3-second gust speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category and are associated with an annual probability of 0.02.

2. Linear interpolation between wind speed contours is permitted.

3. Islands and coastal areas shall use wind speed contour of coastal area.

4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

Figure 2-1: Basic Wind Speed\(^1\)
Seismic Zone

The seismic zone affects the design of required strength of the insulators, hardware and supporting structures. Figure 2-2 shows the seismic zone map of the United States.

![Seismic Zone Map of the United States](image)

Figure 2-2: Seismic Zone Map of the United States

Ice

The design radial ice thickness affect the required strength of the wire, insulators, hardware and supporting structures.

Isokeraunic Level

The isokeraunic level is the number of thunderstorm days in a year. It is used in calculations for substation shielding angle, shielding failures and back flashes.
Temperature

The minimum and maximum ambient temperatures combined with resistive heating are used to predict the minimum and maximum conductor temperatures used for the conductor sag calculations.

APPENDIX 4C

Substation Bus Configurations

Single Bus

A single bus configuration consists of one main bus that is energized at all times. All circuits are connected to the bus. This arrangement is the simplest but provides the least amount of system reliability. Bus faults or failure of circuit breakers to operate under fault conditions may result in complete loss of the substations. Figure 4-9 shows the single bus arrangement.

Figure 4-9: Single Bus

![Typical One-Line Diagram](image1)

![Plan View—Typical Bay](image2)

![Elevation—Typical Bay](image3)
Sectionalized Bus

This arrangement is basically two or more single bus schemes and each tied together with bus sectionalizing breakers. A bus fault or breaker failure causes only the affected bus section to be removed from service and thus eliminates total substation shutdown. The sectionalized bus arrangement is shown in Figure 4-11.

Ring Bus

A ring bus configuration is an extension of the sectionalized bus arrangement and is accomplished by interconnecting the two open ends of the buses through another sectionalizing breaker. This closed loop or ring with each bus section separated by a circuit breaker and each section should supply only one circuit for maximum reliability and operational flexibility. Figure 4-14 illustrates a ring bus configuration.
Main and Transfer Bus

A main and transfer bus configuration consists of two independent buses. The main bus is normally energized under normal operating conditions. All incoming and outgoing circuits are fed from the main bus through their associated circuit breakers and switches. The integrity of circuit operation can be maintained through use of the bypass and bus tie equipment if a breaker needs to be removed for repairs or maintenance. Figure 4-12 illustrates a main and transfer bus configuration.
The breaker-and-a-half configuration consists of two main buses normally energized. There are three circuit breakers electrically connected between the buses and a circuit
is connected between each two breakers as diagramed in Figure 4-15. The three circuit breakers are used for two independent circuits.

**Figure 4-15: Breaker-And-A-Half Bus**

**Double Breaker-Double Bus**

The double breaker-double bus configuration consists of two main buses each normally energized. There are two circuit breakers electrically connected between the buses and a circuit is connected between the breakers as diagramed in Figure 4-16. The two circuit breakers are required for each circuit.
Figure 4-16: Double Breaker-Double Bus