354

GUIDELINES TO COST REDUCTION OF AIR INSULATED SUBSTATIONS

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Guidelines to Cost Reduction of Air Insulated Substations

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PREFACE

The objective of this Working Group (WG) was to produce a set of guidelines for effective and efficient design, construction, and commissioning processes to minimize the need for re-design, re-work, and multiple checks. The WG also considered current cost reduction opportunities that can be achieved by using pre-engineered, pre-fabricated, pre-tested integrated equipment and installations typical for AIS.

Although application may vary from one company to another depending on local requirements and conditions, common value release opportunities have been identified.

The WG has:

1. Identified efficiency improvement opportunities for AIS in the :
    - Design phase, e.g. standardization and consistency in the use of standards, maintainability and constructability issues, use of new design/drafting tools, use of new technology equipment (major equipment, integrated equipment), etc.
    - Construction phase, e.g. use of modern equipment, construction methods, quality control of workmanship check lists, etc
    - Commissioning phase, e.g. elimination of duplicated testing, well documented commissioning check lists
2. Prepared case studies for cost reductions in AIS

    The following topic areas are discussed in this brochure:
    - Equipment standardization
    - Design standardization
    - Use of new design and new technology
    - Requirements such as engineering, construction
    - Quality control
    - Testing and commissioning
    - Documentation

Guidelines to Cost Reduction of Air Insulated Substations

1 INTRODUCTION

Substations are a critical part of the transmission system and act as switching points between power stations and the regional electricity distributors.

Air Insulated Substations (AIS) represent in many countries the bulk of substations. Many of these substations, built more than 40-50 years ago are approaching their end of life. Retrofitting of these substations is vital for the reliability of a transmission system. Also increased demand for power in the world requires bringing new substations into service.

Construction of new substations and retrofitting of existing ones represent a significant investment from the companies which own them. In the increasingly competitive arena where power providers are facing significant pressure for greater system reliability, and improvement of customer satisfaction, the focus is placed, amongst others, on cost reduction whilst providing appropriate performance.

Deregulation of the power industry, globalization of manufacturing and engineering activities as well as more stringent environmental regulations and public acceptance puts lots of pressure on the organizations involved in equipment manufacturing, design, construction and commissioning of substations. To cope with such demands and increase returns for the stakeholders, electrical companies increasingly need to identify their mandatory expenditure requirements and maximise optional investment.

Reducing the cost of building new and/or retrofitting existing substations is a key driver for any public utility/owner, yet achieving such savings while also maintaining business continuity and improving service levels can often prove difficult to achieve. Through the innovative use of technology, design concepts, construction and commissioning activities however, organizations can fulfill all these objectives and gain a clear business advantage as a result.

Cost reductions in substation construction starts with the conceptual engineering where the basic substation concept is developed. At this stage significant savings can be achieved by selecting the most appropriate single line diagram for the application, by selecting the most cost effective equipment which will satisfy the requirements of the diagram, and by using standard design solutions to the maximum extent possible. All this while making sure that customer reliability, constructability, extendibility, interchangeability, and maintainability requirements are met.

The content of major equipment specifications plays another important role in controlling the cost of substation construction. Development of clear and detailed technical specifications, prequalification of suppliers, establishment of strategic alliances and blanket purchase orders with suppliers, and rigorous factory and site acceptance tests contribute to the overall cost control and reduction.

Another important factor in substation construction cost control is the selection of the overall philosophy of how to manage the project. There a number of solutions available, ranging from the totally turnkey approach (in which the owner retains a third party for execution of the entire project) to the totally in-house approach (in which all activities of the project are done by the appropriate branches of the utility/owner of the substation). These approaches all have pros and cons and choosing the right method can have significant impact on the cost, quality and timely completion of the project.

This brochure presents the most important stages of substation construction (from conceptual engineering to site clean-up) and highlights factors that contribute to cost reductions. A number of case studies are included in the document to show how cost reductions have been achieved by various utilities.

The goal of this brochure is to assist in identifying benchmarked values and develop guidelines for effective and efficient design, construction and commissioning processes in order to minimise re-design, re-work, and multiple checks.

The authors of the brochure hope that the information contained in this document will provide the reader with an overall view on the issues which influence the cost of substations and how these costs can be controlled.

2 DESIGN PROCESS

2.1 Introduction

Issues influencing the design of a substation vary both in their source and in their impact. Some are controllable by the designer while others are dictated by external factors. In addition, some of these factors can impact the whole project, while others affect only specific areas of the substation. They can include:

- Mandatory requirements such as safety codes, environmental and local regulations, etc.
- Customer needs such as system connections, and power supply capacity enhancements from new power suppliers
- Power system constraints such as short circuit levels, system control and operating requirements, and reliability
- Operating and maintenance requirements, including operability, major repairs, spare parts availability, and availability of suitable skills.

Minimizing the overall substation cost is achieved by ensuring the initial concept design is carefully and thoroughly executed and that the design incorporates:

- A rigid design process with design reviews at all key stages
- Life-cycle considerations
- Careful consideration of the practicality of construction
- Standardisation to the maximum extent practical
- Selection of reliable equipment that is readily interchangeable with alternatives
- Equipment configurations that utilise optimised technology and provide for future extension and replacement
- A high level of quality control

The design should also facilitate accelerated construction including provision for as much early design, off-site manufacture and pre-testing and pre-commissioning as possible.

2.2 Cost Saving Opportunities Under Conceptual Engineering

The concept design establishes the key parameters for the substation and so careful attention must be paid at this stage to ensure that the design addresses the key concerns of all stakeholders. The concept design should reflect the general business development guidelines and maintenance strategies of the network operator and should be deduced project-wise from a long-term orientated template.

From another viewpoint, conceptual engineering should lay down all basic specifications that have a major influence on network cost, network reliability and societal acceptance and are in the intimate interest of the network owner. On the other hand conceptual engineering should offer the opportunity to stimulate competition among the potential service providers and should offer the network owner the flexibility to either allocate detail engineering in-house or to outsource it, depending on the availability of resources.

Major input to the concept design of substations is provided by network planning:

- Network load development defines the most favourable location of the new substation or the substation to be up-graded. Once there is an envisaged location, environmental and societal concerns must be taken into account. A well defined conceptual engineering template will offer adequate solutions for standard situations regarding noise emission, protection of ground and water resources, safety related concerns and visual impact.
- The availability of suitable land and its cost are other important factors. As this strongly influences the type of substation to be built (AIS, GIS or Mixed Technology), this decision should preferably be made during the concept design phase.
- Network planning also provides the necessary input for dimensioning of the substation. Actual and future loads define voltage levels, transformer capacities, nominal currents and short circuit levels. Nodal position within the grid and reliability considerations give implication to the number of bays needed, bus bars, bus bar intersections and bus-couplers. With respect to cost effectiveness the above-mentioned engineering template should limit the available solutions to the fewest number of configurations that can be up- and down-scaled by modular additions. In this way the template can be used as a tool box for concept engineering. The number of pre-engineered modules depends on the number of voltage levels applied in the network. Preferably the main equipment data (short circuit withstand capability, nominal current ratings, insulation coordination, power rating of transformers etc.) should be reduced to a minimum set per level covering the standard applications. A minimum set of modules per voltage level incorporates bus-bar section, line feeder and transformer bay, accompanied by instrument transformer and earthing bays, cross and in-line couplers if needed.
- A proper concept design should also provide additional space for future extensions. This is an easy decision in the case of an air-insulated substation in rural environment, where the price of land is relatively low. The decision becomes more difficult in the case of an in-door substation in a metropolitan area, where not only is the price of land high but also the cost of the additional building volume has to be taken into consideration. In that case financial tools such as cash flow analysis and consideration of risk management should be applied when weighing alternatives. The decisive questions are: date and probability of the needed extension, and cost of the alternatives. Decisions will be balanced between taking future development into consideration in order to avoid costly refurbishments on the one hand whilst avoiding too early or completely unnecessary investments on the other hand.
  In the case where additional space is provided for future extensions, installation of additional equipment has proven to be unnecessary, if it is not certain that the extension will be needed within a year. The planned substation should be built to meet the current requirements with adequate connections to provide for future extension, i.e. extendable

last bus-bar section, connection points to cable-ducts, etc.

- As new or refurbished substations will operate in a networked system there are quite a number of requirement which should be laid down in a set of basic specifications and should form an approved part of the concept design. These specifications can cover the following items, for example:
    - Communication interfaces and equipment
    - Local and remote control (schemes, physical set-up, data transfer lists, communication protocols)
    - Line and transformer bay protection schemes
    - Station building layout
    - Requirements for service operations (working clearances, connections for portable earthing equipment etc.)
    - Station lighting
    - Earth grid design and lightning protection
    - Documentation requirements

  The extent of the listing varies and depends on the degree of standardization applied by the network operator. In general these specifications are developed interactively between network owner (asset manager), engineering service provider and network operations in order to assure adequate functionality, operability and maintainability.

  These basic specifications should cover all items having a relevant impact on life-cycle cost and thus being of interest for standardization. If detailed engineering is provided in-house an agreement on technical facts may be sufficient. If detail engineering is given to a contractor the specifications must be more rigid, i.e. detailed and measurable in quality.

2.3 Cost Saving Opportunities Under Detailed Engineering

The integrity of the design of the substation has a large impact on its final cost, ease of completion, operability and maintainability. In order to provide a least-cost solution the designer must, where possible, incorporate features that are standardized within the owner's system while selecting an optimized technology that minimizes construction and maintenance costs. This creates a tension between the desire to standardize whilst being innovative and must therefore be carefully managed.

Incorporation of standardization, repeatability, and extendibility aims at reducing the project duration and overall cost in order to provide a high operating reliability. It also assists in working smarter rather than working harder. The following details various initiatives that may be undertaken to achieve this.

2.3.1 Standardization

Standardization of designs is a desirable goal for all utilities as it:

- Allows the asset owner's design philosophy to be rigorously applied to each new asset

- Leads to the use of a common set of primary and secondary equipment
- Permits the production of common design templates for substation bays at a range of voltages
- Minimizes spares holdings
- Minimizes required skills
- Reduces the risk of operator error due to the commonality of layout between substations.

Detailed analysis of a number of prevailing standard schemes or single line diagrams reveals that there are very few basic variants of design with only minor customer-specific changes.

Standardization is essentially the multiple use of an identical design for a substation to reduce design time and cost. A focused approach to standardization leads to a net reduction in utilization of scarce engineering resources.

For a substation contractor, standardization is adopted in order to optimize the entire execution process including engineering, procurement, construction and commissioning. Basically, engineering is the driver for reducing cost and time and consequently engineering standardization aids the generation of early error-free input, activity planning, and the meeting of project schedules.

Standardization can be implemented between utilities and manufacturers with whom they have a high volume of business. For a particular utility/industry the following may be standardized to reduce engineering time and cost.

2.3.1.1 Single Line Diagram (SLD)

Typically, individual countries only adopt a limited number of popular bus configurations specific to different voltage levels and this can be documented in a modular way. Depending on the composition of feeders for the installation, a complete single line diagram can be created by suitably integrating various standard modules.

Although the design is modularized, a few variations are still observed in the requirements of utilities and industry customers. These are summarized below:

- Location of the earth switch on disconnectors
- Current transformer location, ratings, and number of secondary cores
- The Control, Metering & Protection philosophy to be adopted

At a micro level of standardization it is desirable to convert a modular standard bay-wise SLD catering for three or four major variants covering the requirements of the majority of utilities and industry. This, however, will require a certain percentage of project-specific editing. Typical commonly used modules for different bus switching schemes are shown in ANNEX 2.1.

2.3.1.2 Layout Engineering (Plan & Section Drawings)

Given that countries typically only adopt a small number of bus configurations specific to different voltage levels, the layout of each bay (specific to a particular bus configuration) can be documented in a modular way. These bay modules can then be simply arranged for a particular substation to create the required configuration for the overall substation layout.

The criteria for selection of a particular switching scheme are dependent on:

- System reliability
- System operation
- Ease of maintenance
- Limitation of fault level
- Simplicity of protection system
- Ease of extension and replacement
- Availability of land
- Cost

Generally, utilities have few variants in their requirements, such as:

- Position and number of cores of Current Transformers
- Type of disconnectors used
- Bay width
- Single level or multi level switchyard
- Types of equipment support structure and gantry structure
- Shape of plot available for substation and feeder orientation.

At a micro level of standardization it is desirable to produce modular standard bay-wise plan and section drawings for each bay (line, transformer, bus coupler, transfer bus, etc.) specific to three or four major bus configurations. These standard modules will require a certain percentage of project-specific editing. Examples of typical bay modules (line, transformer etc) for different bus switching schemes are shown in Annex 2-2.

2.3.1.3 Engineering Calculation

Calculations form a very important part of engineering a substation. They are the tools which help in authenticating substation design. There are a number of calculations which are used in substation design and some of these are listed below:

- Short circuit forces
- Earthing design
- Temperature rise
- Conductor sag and tension
- Wind force
- Battery sizing
- Shielding design
- Insulation coordination
- Audible sound level
- CT / VT Application
- Illumination level

These calculations are backed by national or international standards, which have standardized the basic procedure for performing the calculations. For the purpose of easy access to these calculations it is possible to store them in a single calculation package and access them as and when required and thus not having to repeat calculations for same situations in future projects.

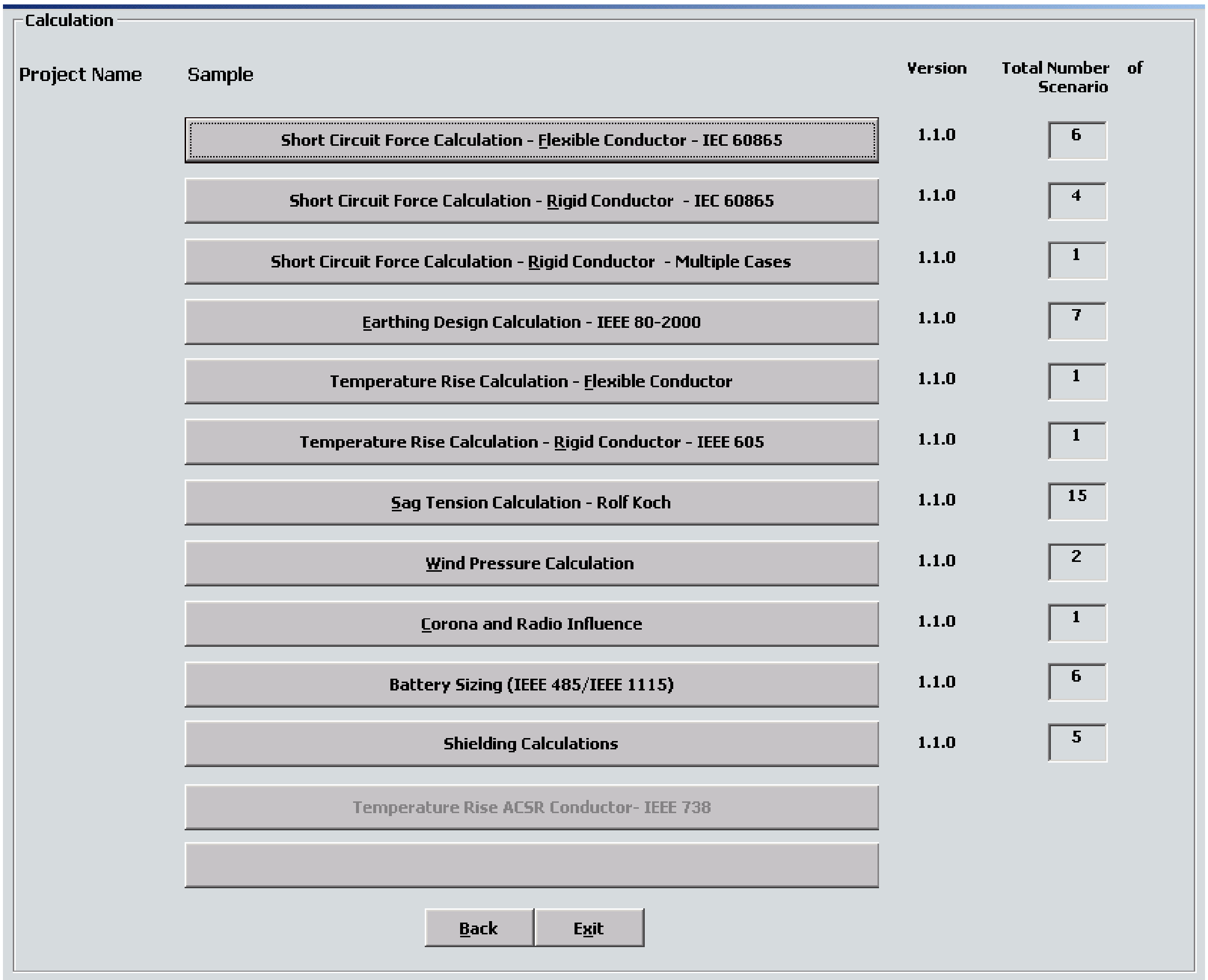


Figure: 2-1 Standardized Substation Electrical Calculation Package

Such calculations and standardized output format with all the backups assist in easy completion and error-free output results, avoiding rework and saving valuable man-hours.

Although the international standards are a most effective approach to solve these issues, it seems the respondents still expect further improvements.

With respect to shielding calculations (refer to Summary Of Questionnaire), 16 out of 17 respondents to the WGB3.15 survey reported that they are satisfied with available international standards. However, with respect to grounding design, 14 respondents find the international standards satisfactory whilst four commented that international standards are too restrictive for some special soil applications. Comments were also made on the lack of coordination between various international standards such as IEEE, IEC, and IEE.

2.3.1.4 Structures Database

Structural engineering design is one of the critical activities from the project completion point of view. There are distinct bottlenecks of structure standardization. This can be understood from the following.

Structural design is based on the following basic factors:

- Static loads
- Short-circuit forces
- Wind velocity/wind loads
- Seismic forces
- Snow and ice loading
- Bus bar height

By a suitable choice of layout for a given voltage level, static load, short circuit force and busbar height can be standardized without compromising economy. However, wind velocity varies geographically. If structures are standardized for the highest wind velocity, cost-effectiveness is adversely affected for sites in relatively low wind zone areas.

It is very difficult to standardize structures for different voltage levels and bus configurations for an entire country when considering the highest wind velocity. This turns out to be uneconomical in a competitive environment.

For utility/industry projects where structures are to be estimated by a substation contractor, location-specific design needs to be made, taking into account the applicable wind velocity and actual short circuit forces. The optimum solution may be to combine several wind zones and create a few variants of the structure design for a given voltage level / bus configuration.

2.3.2 Optimized Technology

In optimizing the switchyard the overall cost structure must be kept in focus. Optimization attempts are normally made in areas of high potential, based on the substation cost structure.

Generally, optimization is attempted with respect to:

- Switch yard area
- Earthing
- Layout
- Cable philosophy
- Structural and civil quantities.

Optimizing the required substation area reduces the required:

- Lightning shielding
- Switchyard lighting
- Switchyard surface gravel for earthing.
- Site preparation costs.
- Quantity of boundary security fencing.

The area occupied by the switchyard can effectively be reduced (optimized) through careful layout design. In addition, adoption of alternative technology switchgear to AIS can further reduce the substation footprint as multiple functions/ components are combined in one unit.

Following are some measures that can be implemented to achieve a compact layout:

2.3.2.1 Bay Width Reduction

Bay width reduction is a possible measure that can be achieved by using double-break disconnectors instead of horizontal center-break disconnectors and re-evaluating the magnitude of short circuit forces. Bay width can also be reduced by using vertical-break disconnectors instead of horizontal center-break disconnectors. Note that clearances under maximum sag conditions need to be checked prior to adopting vertical-break disconnectors. In this case the height of the structure on which the main busbar is strung must be increased. For a double busbar scheme, staggered disconnectors may be used to take the through connection.

2.3.2.2 Multilevel Switchyard

This type of substation is generally preferred where land is difficult to obtain or there are some other practical constraints.

- Using the optimum 'equipment to equipment' clearance: this will primarily depend on the statutory requirement of each country.
- Using the optimum clearance at substation periphery between last gantry structure and fence will help in reducing the substation area.
- Provision of access roads only at critical locations: often vehicular access is provided between equipment in the substation resulting in increased switchyard area.
- Location of the substation with respect to the incoming and outgoing lines: dead-end towers may be so located that the termination angle of the incoming line increases to the extent that required clearances are not obtained. This can result in the width of one line bay being skipped in order to maintain clearances. However, the problem can be avoided by proper planning of transmission lines and incoming line corridors.
- Frequently layouts are also planned systematically to reduce the substation area.

When adopting the abovementioned measures, some design aspects must be carefully reviewed. With regard to structure design, reinforced design against wind, ice and earthquake should be considered. Earthing design also must be reviewed to obtain required grounding resistance in the reduced substation footprint. As a design review result, overall costs may increase because land cost in suburban areas may not be expensive compared to the additional construction cost. In addition, you must consider the balance between optimization and maintainability. Some measures, such as staggered-disconnectors, may sacrifice maintainability and safety for maintenance staff.

2.3.2.3 Earthing

Recent advances in analytical earthing design allow much more accurate modelling that overcome weaknesses arising when empirical calculation methodology is used. This enables design optimisation with respect to human safety and the size and quantity of buried electrode.

The empirical design approach has traditionally been adopted to simplify manual earthing design calculations. Typically this includes adopting a soil resistivity structure that is homogeneous (using, for example, the soil resistivity test mean or median value), whereas in practice a large variation may exist in the test results. This can lead to significant errors in the calculated Step and Touch Voltages.

An in-depth knowledge of the soil properties is required to enable cost reduction of the earth grid (and for accurate evaluation of human safety). The necessary steps are:

- A large soil investigation, in which data is collected to a depth of 20m or more, will provide an accurate view of the substation soil. The more accurate soil model will be selected for comparison with the soil measurement. Generally a multi-layer (2 layers) soil model will give the best results.
- Better identification of weak points in the earthing grid with respect to Step & Touch Voltages. This can only be achieved by utilizing an analytical methodology that incorporates finite element analysis. This will result in an increase in the earth grid density in some locations, but mostly will reduce the grid conductor spacing.

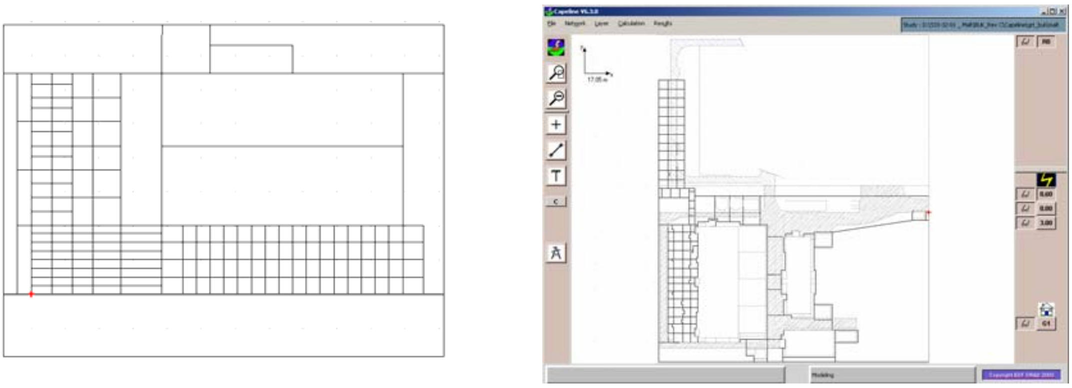
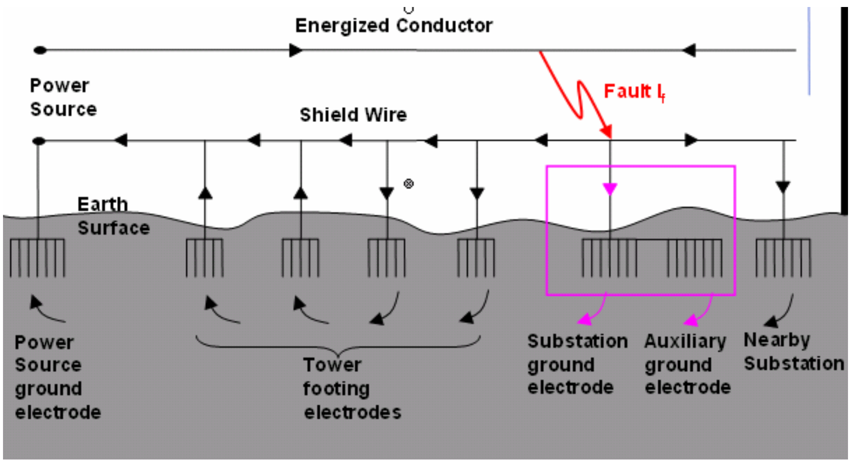


Figure:2-2 Examples of optimized earth grid, checking with finite element method

Another key aspect to aid cost reduction is a detailed knowledge of the short circuit current flow itself (duration and size of current flowing from the earth grid to the ground).



Significant additional savings can often be made through utilizing parallel earthing paths, such as cable screens or overhead earth wires, to reduce the amount of current flowing into the soil from the earth grid. However, care must be taken to ensure that dangerous voltage rises are not transferred to a site remote from the earthing system

The designer / utility must consider the duration of the short circuit for conductor thermal sizing, generally including a safety factor in order to take into account corrosion and the expected life of the grid. A value of 1 s or 3 s is a conservative value adopted for very corrosive soils. For non-corrosive soils a value of 0.5 s or 1 s can be used. Evaluation of earth grids at existing substations located in the same area can provide an accurate indication of the corrosiveness of the soil.

Another cost driver regarding short circuit duration is the length of time the human body is exposed to electric shock. Analysis of the protective device operating time, circuit breaker operating time, breaker failure setting (if any) enables a realistic "shock duration" to be adopted for a pragmatic approach to body short circuit exposure. For example, the primary device fault clearing time can be around 80 -100ms, rising up to 250-300ms for a 400 kV circuit breaker failure.

The final technical cost driver regarding an earth fault is the short circuit level itself, where an in-depth evaluation to establish actual levels can lead to a cost reduction.

IEEE80, which is the commonly used industry standard for earthing, can be complemented by IEC 60909-3 (Short circuit current calculation in three-phase a.c. systems) for a better understanding and optimization of short circuit distribution.

2.3.2.4 Calculation of Short Circuit Forces

Short circuit forces are evaluated in accordance with the IEC 60865 standard; when the value of the fault current is high the value of the short circuit force will also increase, which will reduce air clearances, increasing terminal load and having an impact on civil and structural engineering.

In order to reduce the value of the short circuit forces:

- The actual fault clearance time is evaluated,
- Finite element methods are used in order to find realistic values of the forces acting at the equipment / gantry terminals.

Often, based on actual fault analysis/system studies, the value of the short circuit currents can also be reduced. Power engineers / customers frequently insist on doing calculations based on the equipment rated fault current, e.g. 25kA, 31.5kA, 40kA, 50kA, etc. However,,on doing actual fault analysis /system studies, it is often found that, due to the impedance offered by the grid (transformer impedance, transmission tower footing resistance etc), the value of the actual fault current at the substation location is less. On the other hand, the DC offset in the interruption current must be considered, especially when the fault level is near the rated value for the equipment, and for switchgear located near power plant.

A balanced view should be adopted by appropriately allowing for future load growth.

2.3.2.5 Reduction of the Effect of Seismic Loading

When substations are located in high seismic zones, spring bases are often used to protect equipment and improve their seismic performance.

2.3.2.6 Reduction of Structure and Civil Loading

In order to reduce the value of sag, as well as static and short circuit tension, light, high current carrying capacity conductors are used. This will optimize the conductor, and will also result in a high cost saving in structural and civil engineering. As an example, at a 400kV substation, instead of using quad ACSR Moose conductor, twin AAAC conductor was selected, which optimized structural and civil engineering and improved clearances by reducing conductor sag.

2.3.2.7 Conduits Compared to RCC Cable Trenches

Many substations utilize pipe trenches with provision of pull pit chambers / man-holes at regular intervals. This solution has been adopted in lieu of providing RCC cable trenches. Experience has shown that, as far as cost is concerned, both options prove to be comparable. However, the construction time using conduits proves to be significantly less than for construction of RCC trenches, reducing the project duration.

Figure: 2-3 Man Hole for Pipe trenches

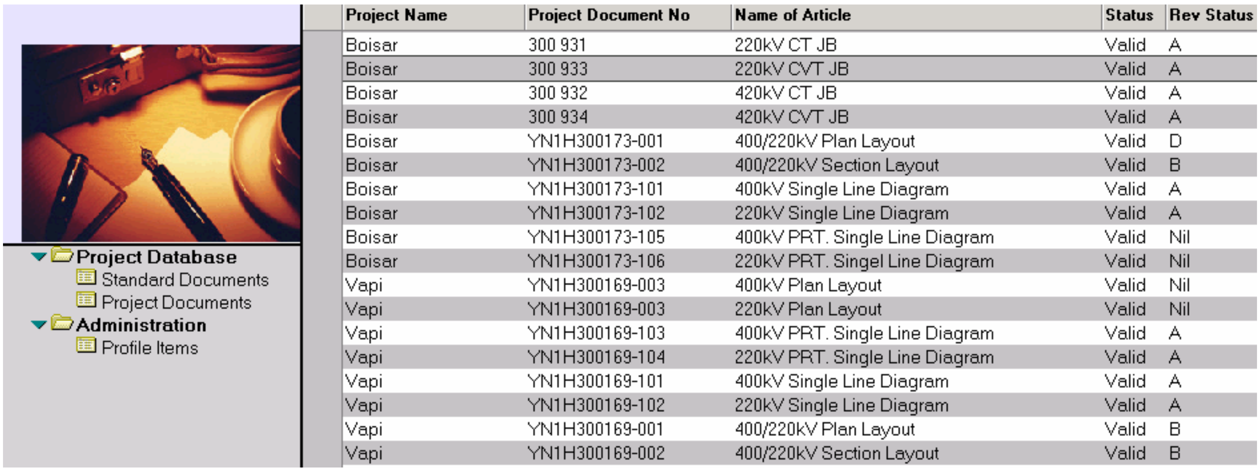
Figure: 2-4 RCC trenches

2.3.3 Repeatability

Design repeatability is a crucial issue in achieving a cost reduction through savings in execution time (covering engineering, procurement and construction) and is an extension to standardization.

When adopting standardization the Single Line Diagram and Layout variants must be restricted. Project specific documentation is prepared by editing the nearest similar variant.

For the purpose of repeatability there must be a very good document management system where all executed and finalized documents can be stored in a structured manner. The project specific documents should be selectively uploaded into the system which should have a powerful search facility as well as a project specific repository and standard drawing library. A typical screen shot of a system is attached below



Project Name	Project Document No	Name of Article	Status	Rev Status
Boisar	300 931	220kV CT JB	Valid	A
Boisar	300 933	220kV CVT JB	Valid	A
Boisar	300 932	420kV CT JB	Valid	A
Boisar	300 934	420kV CVT JB	Valid	A
Boisar	YN1H300173-001	400/220kV Plan Layout	Valid	D
Boisar	YN1H300173-002	400/220kV Section Layout	Valid	B
Boisar	YN1H300173-101	400kV Single Line Diagram	Valid	A
Boisar	YN1H300173-102	220kV Single Line Diagram	Valid	A
Boisar	YN1H300173-105	400kV PRT. Single Line Diagram	Valid	Nil
Boisar	YN1H300173-106	220kV PRT. Singel Line Diagram	Valid	Nil
Vapi	YN1H300169-003	400kV Plan Layout	Valid	Nil
Vapi	YN1H300169-003	220kV Plan Layout	Valid	Nil
Vapi	YN1H300169-103	400kV PRT. Single Line Diagram	Valid	A
Vapi	YN1H300169-104	220kV PRT. Single Line Diagram	Valid	A
Vapi	YN1H300169-101	400kV Single Line Diagram	Valid	A
Vapi	YN1H300169-102	220kV Single Line Diagram	Valid	A
Vapi	YN1H300169-001	400/220kV Plan Layout	Valid	B
Vapi	YN1H300169-002	400/220kV Section Layout	Valid	B

Figure: 2-5 Typical Document Management System

To a large extent the DMS makes a good case for "Reuse" (repeatability). The richer the database is, the greater is the usage of the same. The DMS can store all equipment drawings, purchase specifications, equipment type test reports, and vendor documents that have been approved for a particular project. Such documentation can also assist in expediting approval at the customer's end for other projects that are being executed.

In order to obtain the maximum benefit of repeatability, suppliers should be kept the same to the extent possible. Documents from standard suppliers should be uploaded into the DMS. Whenever suppliers are changed for any reason, documentation from the new suppliers should also be uploaded to the DMS for future use as this will ensure in continuous enrichment of the DMS.

2.3.4 Reliability

When planning a new substation, or extending an existing one, the selection of a busbar scheme is one of the most important initial steps of the substation design. Among the matters that affect this decision are operational flexibility, system safety, reliability and availability, ability to facilitate system control, and costs. In this topic the focus is on reliability studies for definition of the busbar scheme.

Several methodologies and computational models have been developed to evaluate the reliability of substation arrangements (Ref.[1]~[4]). The majority of the methods use the minimum cut set technique to select the failure modes of the substation arrangements and classify them in outage categories, such as: passive and active failure; active failure with stuck breaker; temporary failure isolating the damaged elements; stuck breaker failure, etc. The minimum cut sets are determined through the minimum path between the feeding sources and the loading points, using the technique known as predecessor's technique. The use of this technique requires the construction of logical diagrams representing the physical arrangement of the substation, and therefore the operation knowledge of several switching schemes.

Despite the fact that the objective of this topic is not to detail how to calculate the reliability, it provides guidelines to reduce the cost of Air Insulated Substations. Normally the design engineer can use the companies' computational programs to do this evaluation, or use new analytical methods for the reliability analysis of bulk power system substation schemes. (Ref.[5])

Usually, the mandatory requirements, such as local regulations and standard criteria, define the possible busbar schemes for a new substation. But there are three main ways to reduce the design cost, simplifying the scheme without reducing the availability of the substation:

- **First:** using new component technology (different from traditional ones), such as mixed technology (compact solution).
  In this way, the design engineer uses the manufacturer's evaluation, which must compare the traditional busbar scheme and the new one developed by the manufacturer. This study can be required as an initial part of a turn-key specification, or even when the design engineer is planning and doing the basic substation design.
- **Second:** using traditional technology for new substations (conventional equipment).
  In this way, the design engineer has to develop the studies using available failure statistics that are normally based on an older generation of apparatus. This last aspect is one of the most critical points of the reliability evaluation, and sometimes, it is necessary to collect data from another system, even from guides, scientific papers and other companies. Aside from these problems in the data base of the evaluation, it is possible to use the reliability analysis, because the significance of the study is the comparison between two or more busbar schemes. In other words, it is an evaluation to compare rates, both of them using the same data bases. Another task that could be done is to develop a sensibility analysis of the evaluation scheme of the busbar scheme.

  A typical example of this study (Ref. [6]) can be seen below, where there is a comparison between the inclusion of either four or five switches in a double busbar:

Table 2-1 Reliability analysis

Scheme \ rates	**Failures/year**	**Outages** (hours)	**Unavailability** (hours/year)
Double-busbar with 4 switches	0.106	0.86	0.091
Double-busbar with 5 switches	0.118	0.98	0.115

In this is example the reliability study shows that the design could eliminate one switch for each bay, and the availability of the substation will improve.

It is important to remember that this kind of evaluation may not be necessary because mandatory Local Regulation may not permit an alternative scheme without changing the technology.

- **Third:** using traditional technology for extension of an old substation (conventional equipment).

  In this way, the design engineer has to develop the studies using available failure statistics that are again normally based on an older generation of apparatus. For instance, to decide whether to use two switches or only one to section a busbar, an easy reliability study could be done.

Finally, independent of the way we reduce the cost, we need to remember that the evaluation of how the availability of substation elements influence the overall performance of the substation is not an easy task. In the development of this task, some points must be considered:

- The substation is not isolated and it is necessary to consider it in a meshed transmission network;
- The technology applied in the planning of the substation, because the reliability performance of each component depends on the component technology
- Calculations can give only approximate results, because the available failure statistics are always based on an older generation of apparatus, or, in the case of new generation equipment, there is no experience.

Nevertheless, for a comparison of different schemes, the reliability calculation is a valuable instrument for the substation engineer and can assist in the choice of scheme and layout.

2.3.5 **Extendability**

Power system development can be very dynamic. Looking at the infrastructure development taking place in different parts of the world, electric power is in very high demand. Power system planning engineers are designing the system making all the provisions for future extendibility. Generally, air insulated substations are built to provide power to consumers at different voltage levels. As soon as the load demand increases, extension of the AIS becomes inevitable.

If proper planning is not done then it can create a lot of hurdles resulting in time and cost overrun at a later stage. Compared to construction of a new substation, extension to an existing substation needs a lot of care to ensure safety, because the existing system is energized. Many diverse techniques may be employed in order to curtail additional cost and ensure reliable supply.

2.3.6 **Interchangeability**

AIS design should also take into consideration the possibility of interchanging equipment in the future. This issue is relevant not only for its individual parts (single equipment – devices), but also all pre-fabricated units. The design should focus on minimizing the future cost of the following:

- Interchanging equipment with the same parameters but from different manufacturers (i.e. independence from specific equipment design and manufacturer) – cost reduction of replacements and AIS refurbishment
- Replacement by upgraded equipment in order to meet future higher transmission capacity demands and to increase the short-circuit withstand ability of AIS elements (bays), or of the whole AIS.

The Interchangeability requirements should be considered in all partial stages of an AIS design process. That concerns namely the following:

- Layout design of all individual devices and their combinations (units)
- Individual devices mutual interconnection design and design of their interconnection to busbar and outlets
- Utilization of standardized support constructions and their foundations
- Design of cabling and cable ducts
- Location of all roads and areas for transport, assembly and maintenance

To provide for optimized Interchangeability, type and standard solutions and advanced technology must be adopted.

2.3.7 Constructability

Constructability of AIS is influenced by the whole AIS design process, starting from the feasibility study (conceptual engineering), via AIS parts standardization and optimization, and ending with type and repeated AIS designs and technological solutions used in the following:

- Substation civil design – foundations of support and towers, cable ducts, earthing grids, and drainage
- Substation technological design – individual devices and their pre-fabricated units, cable systems, protection and control systems, access for lifting and other mechanisms
- Substation layout design – location (buildings) of substation components (auxiliary power supply, protection and control systems), location of cable ducts, internal roads and areas for transport, erection and maintenance, location of local lighting, location of lightning protection components, fences and physical protection in general.

All of these design considerations should also provide for possible future substation extension needs, together with future cost minimization.

Simultaneously it is always necessary to meet particular local conditions at the construction site, i.e. to cope with local conditions such as:

- Terrain - optimization of a method and the extent (volume) of site work during preparation of the site for construction
- Soil – appropriate foundation construction
- Hydrological conditions – underground water level, drainage of underground and surface water, distance from water streams and rivers

- Climatic conditions – influence of usual weather and seasonal characteristics on civil and technical construction procedures and adopted methods (including transport conditions), as well as on civil and technological AIS design to ensure reliable future AIS operation
- Environment – permitted emission limits at the construction site (namely noise emission, radio interference, oil, and gas leakage limits) and other special environmental protection requirements (e.g. protection of drinking water sources, aesthetic and countryside requirements)
- Special conditions – e.g. seismic conditions, influence of plants, insects and animals, local air pollution, etc.

Another very important aspect of construction preparation is an optimized construction procedure and time schedule. The procedure has to consider the following:

- Layout and technological connections to existing equipment and grids
- Minimization of the number, duration and extent of forced outages of existing equipment resulting from the construction
- Coordination of work to minimize the number of forced outages
- Minimization of any negative impact of the environment (climatic and seasonal conditions, noise, dust, waste, etc.)

2.4 ENGINEERING QUALITY CONTROL

As stated earlier in the document, the overall substation cost can be minimized by:

- A rigid design process with design reviews at all key stages,
- An appropriate level of quality control.

At the top of the engineering quality control scale are the companies (consultants) that are ISO 9001 1994 or ISO 9001 – 2000 certified. These companies have a completely documented and periodically audited quality system which includes the requirements of design review, design verification, design validation, document control, etc.

Companies not certified to ISO 9001 should develop an overall quality plan for a specific project.

At the start of each new contract, representatives of the disciplines involved in a project should perform a review of the specifications and requirements and determine the level and method of quality planning implementation necessary to meet the specific quality requirements.

2.5 ACCELERATED COMPLETION

The aim is optimization of the project execution process and, if it is achieved, the result is a considerable reduction in project cycle times. In order to minimize the time required to finish the project, all the tasks needed in each stage must be improved, the aim being to facilitate and minimize the tasks in the next stage. As a consequence, the necessary work on site is considerably reduced.

2.5.1 Pre-engineering

Because of the standardization and the design repeatability, the client has different solutions in order to solve different problems. Depending on the design basic parameters (voltage level, short circuit current, maximum allowed risk, etc.) it is possible to define not only the preliminary design alternative from a technical point of view (layout, one line diagram) but also the primary and secondary equipment, engineering drawings and the complete project.

It is only necessary to validate the standard design to take into account the individual site characteristics, such us geotechnical and topographical surveys or environmental requirements. Thereafter, the recalculation or redesign of civil works and electromechanical drawings can be done if necessary. Control and protection drawings will usually be correct.

In most cases the normalized engineering will be adequate.

By using design templates the time required for project design can be considerably reduced and similarly costs will also be reduced.

2.5.2 Pre-Fabrication

Utilities use technical specifications for the substation equipment (primary and secondary systems). They also have equipment fabrication plans and stock ready for use.

The use of standard prefabricated equipment has different advantages as follows:

- Reduced time to acquire equipment.
- Discounted prices through purchasing an amount of equipment each year.
- Ability to replace damaged or faulty equipment.

When planning for fabrication it is necessary to take into account the real needs, the length of time for delivery of materials, and optimization of the schedule in order to minimize the amount of reserve stock.

Another concept is to reduce the amount of work done on-site. Factory assembly is easier, faster and cheaper than on-site. Depending on the voltage level, nowadays there are modules of AIS or GIS pre-assembled at the factory including all electrical connections between the module components and the local control cubicle. Even detailed pre-adjustment, setting, testing and comprehensive preliminary commissioning can be carried out at the factory. It is also important to take into account transportation as the equipment must be disassembled into transportable modules.

It is more difficult to find modular AIS solutions for the highest level voltages. In these cases it is only possible to have compact solutions for the secondary systems; prefabricated buildings, including control and protection cabinets, electrical connections, settings, testing and preliminary commissioning. It is only necessary on-site to connect the primary and secondary systems and commission this interface

2.5.3 Pre-Testing

Equipment testing is essential to ensure the required quality level. Assuming that the type tests are carried out and approved in the standardization process, elimination of duplicated tests is a way to reduce costs. It is necessary to establish a criterion in order to distinguish every test such as a factory acceptance test (FAT) or a site acceptance test (SAT).

There is also another consideration; off-site tests are performed to verify proper performance of individual components and equipment items prior to shipment to the site in order to reduce costs. If a high level of prefabrication is achieved it will be easier to improve the pre-testing stage. However, on-site pre-commissioning is always still necessary. In any case it is advisable to test the equipment on-site to ensure no damage has occurred during transportation.

This point is discussed in detail in Chapter 5.

2.5.4 Pre-commissioned

Pre-commissioning tests are performed on-site to validate that individual equipment items have been properly installed and are functionally operating prior to subsystem testing. Pre-commissioning testing does not required high-voltage energization but may require station service power (ac and dc). Pre-commissioning tests typically include ones that verify:

- Equipment is installed in accordance with manufacturer's instructions and station design drawings
- Wiring, fiber optics and grounding connections
- Insulation
- Capacitance, reactance and resistance measurements
- Turns ratio and polarity
- Timing checks on circuit breakers and switches
- Contact resistance measurements on disconnectors and circuit breakers
- Transformers turns ratio on each tap changer position
- Communications

Commissioning is the last stage of the process and ensures the proper working of the whole system. It is essential to check all the main protection and control functions; for the remainder of the functions, those devices pre-tested in previous stages do not require re-testing. However it will always be necessary to test all the works done on-site.

Changes and updates that result from the commissioning procedure will require updating of drawings to show the final status of the commissioned equipment and systems. It is very important that all the changes are recorded for future projects.

ANNEX 2-1 Example of Commonly used SLD

Typical Line and Transformer Modules for Single Bus Arrangement

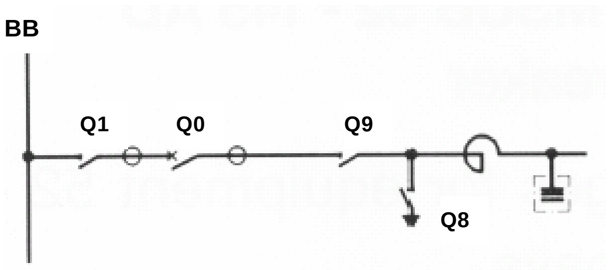


Figure: A2-1-1 Line Module

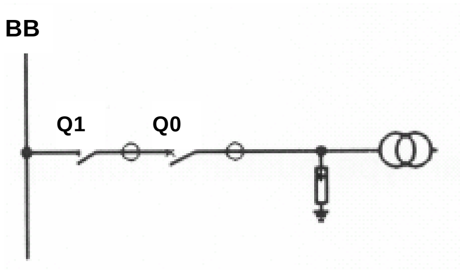
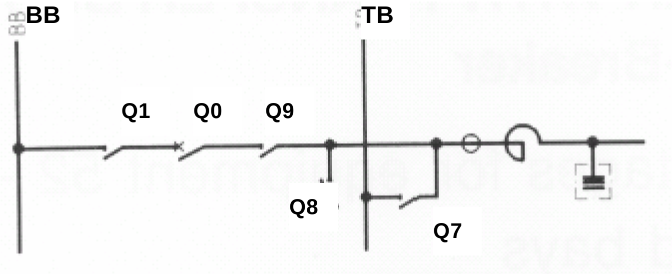


Figure: A2-1-2 Transformer Module

Typical Line, Transformer and Transfer Bus Coupler Module for Single Main and Transfer Bus Arrangements



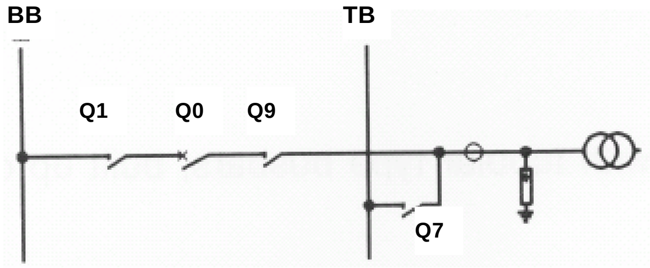


Figure: A2-1-3 Line Module

Figure: A2-1-4 Transformer Module

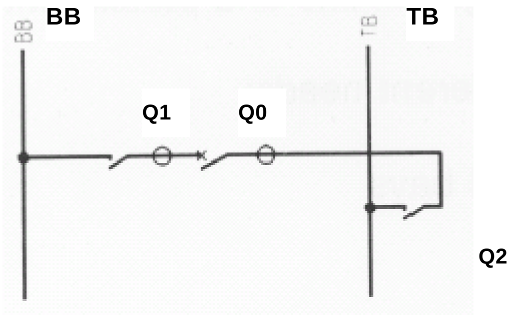


Figure: A2-1-5 Transfer Bus Coupler

ANNEX 2-2 Example of Typical bay modules

Example of Standard Modules for Single Bus Scheme (Combination of Line and Transformer Modules)

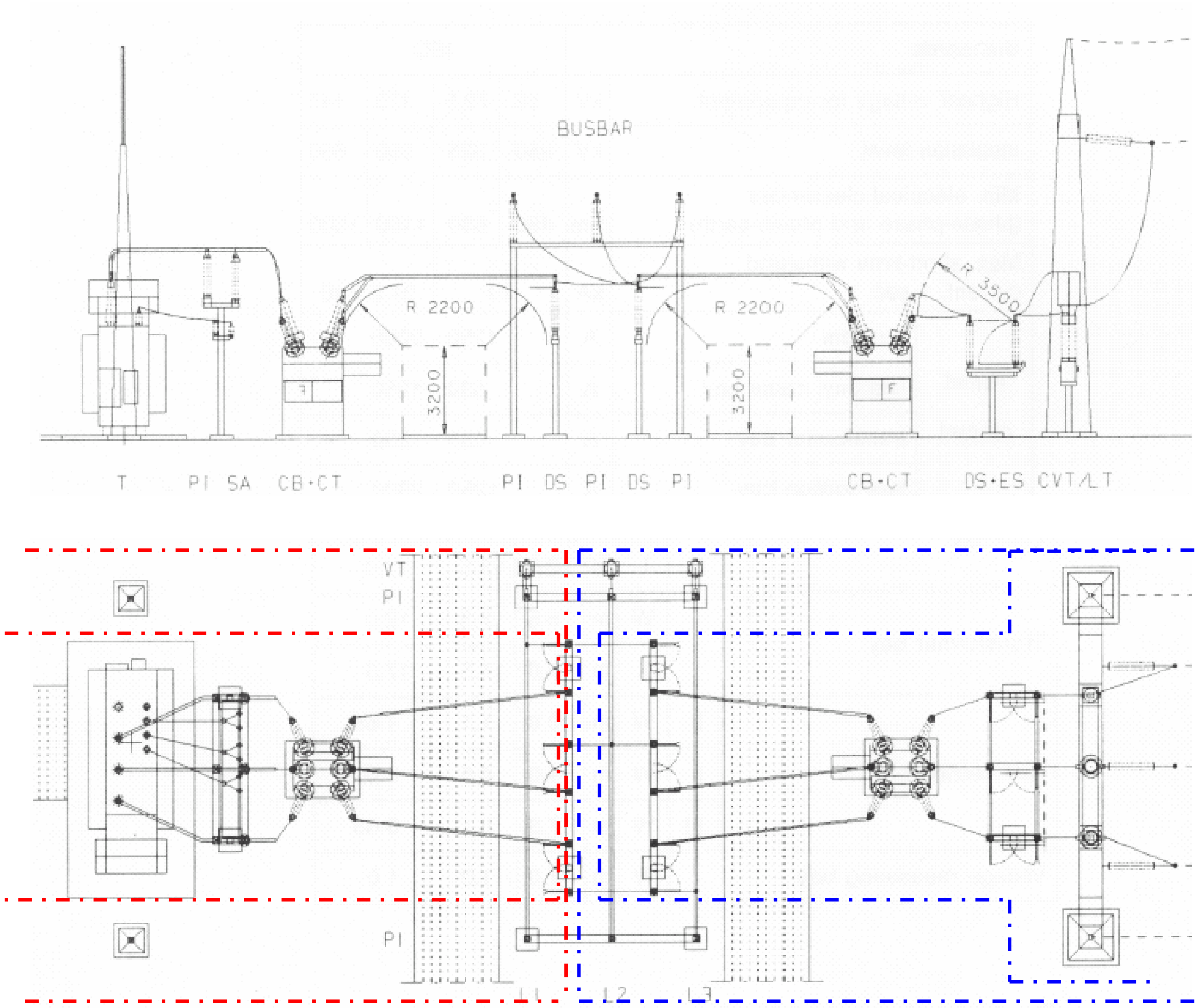


Figure: A2-2-1 Plan & Section layout for single bus scheme

Transformer Module

Line Module

Example of Standard Modules for Single Main & Transfer Scheme

Line Module

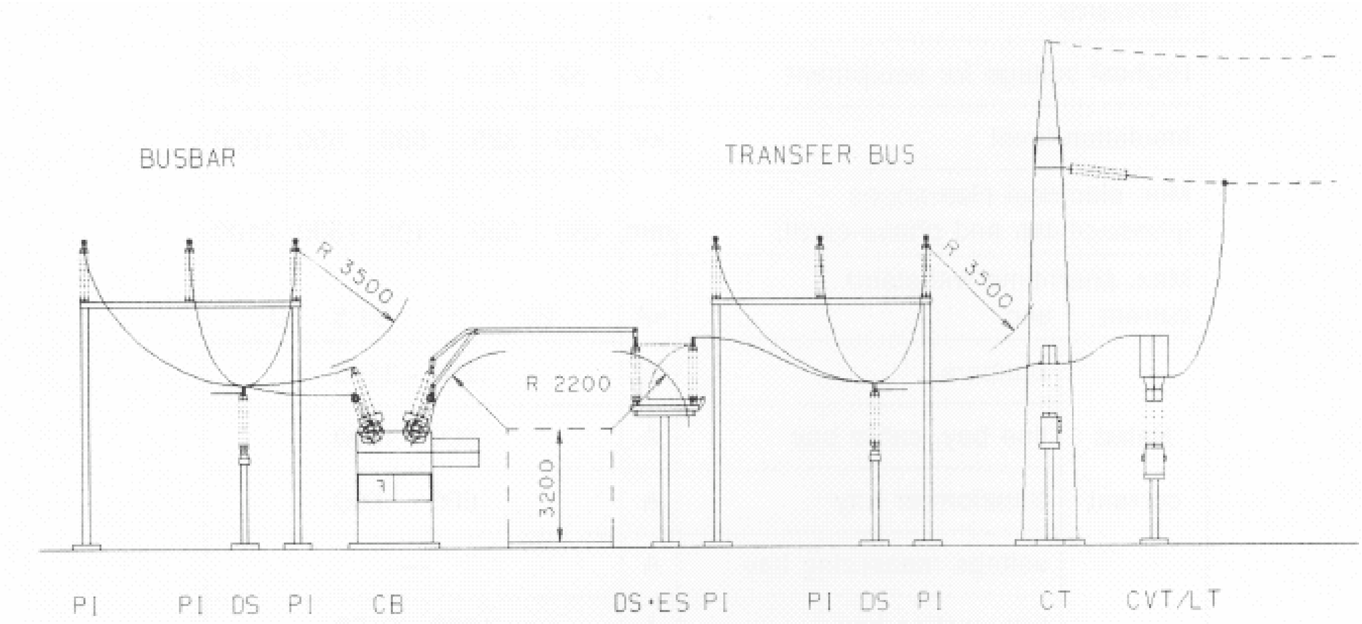


Figure: A2-2-2 Section view of line bay

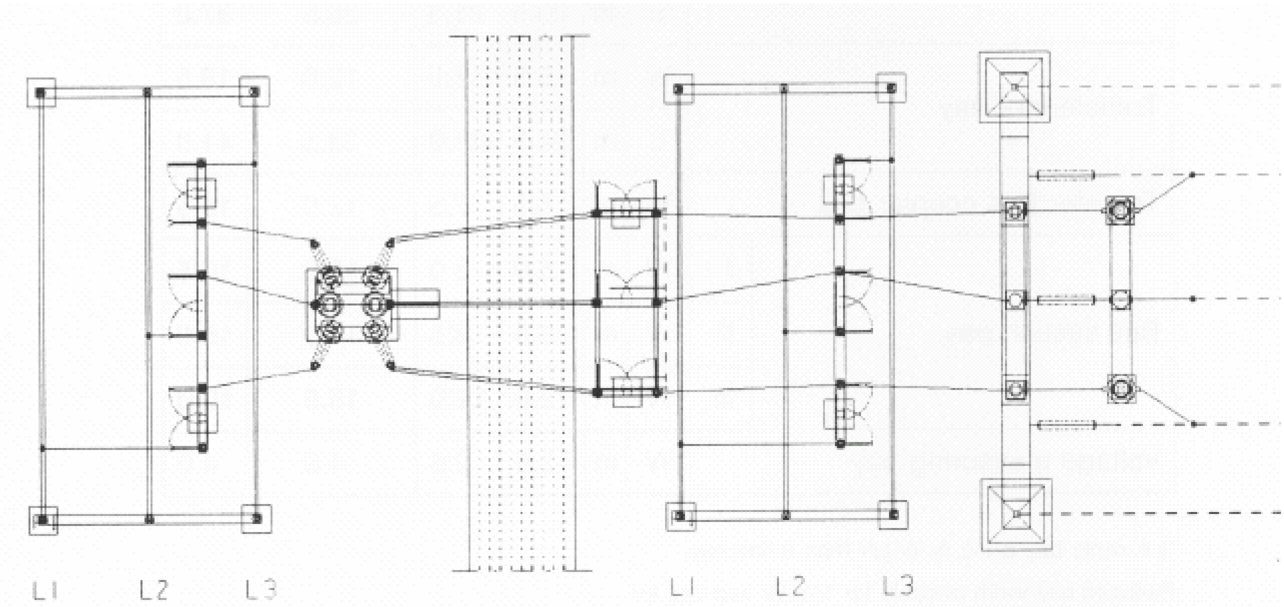


Figure: A2-2-3 Plan view of line bay

Example of Transformer Module

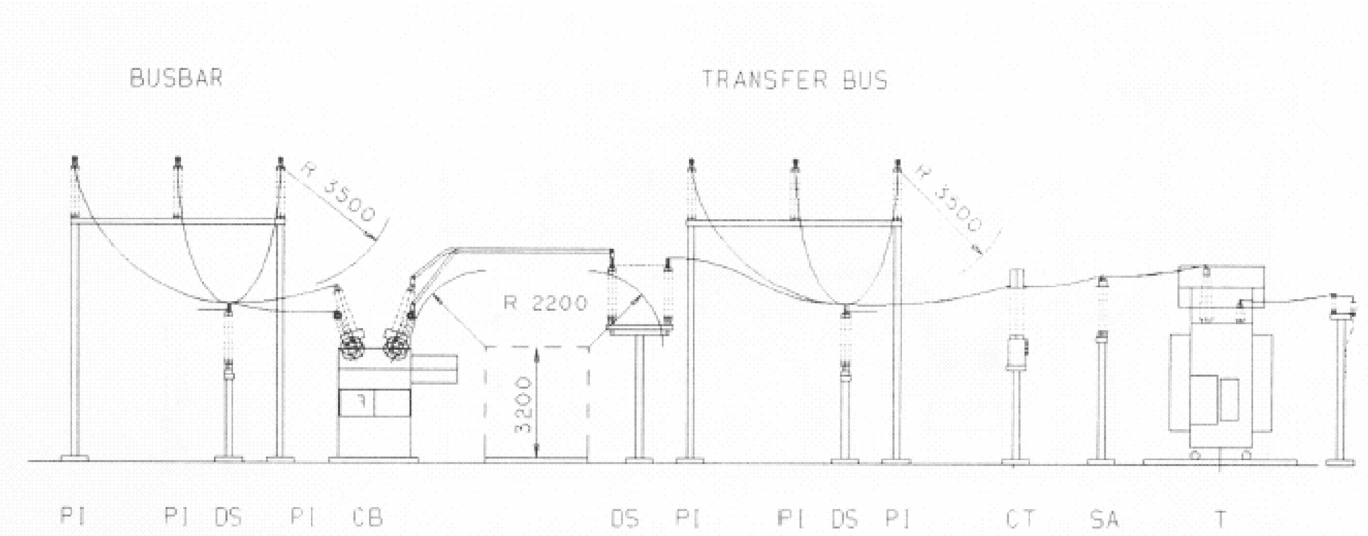


Figure: A2-2-4 Section view of transformer

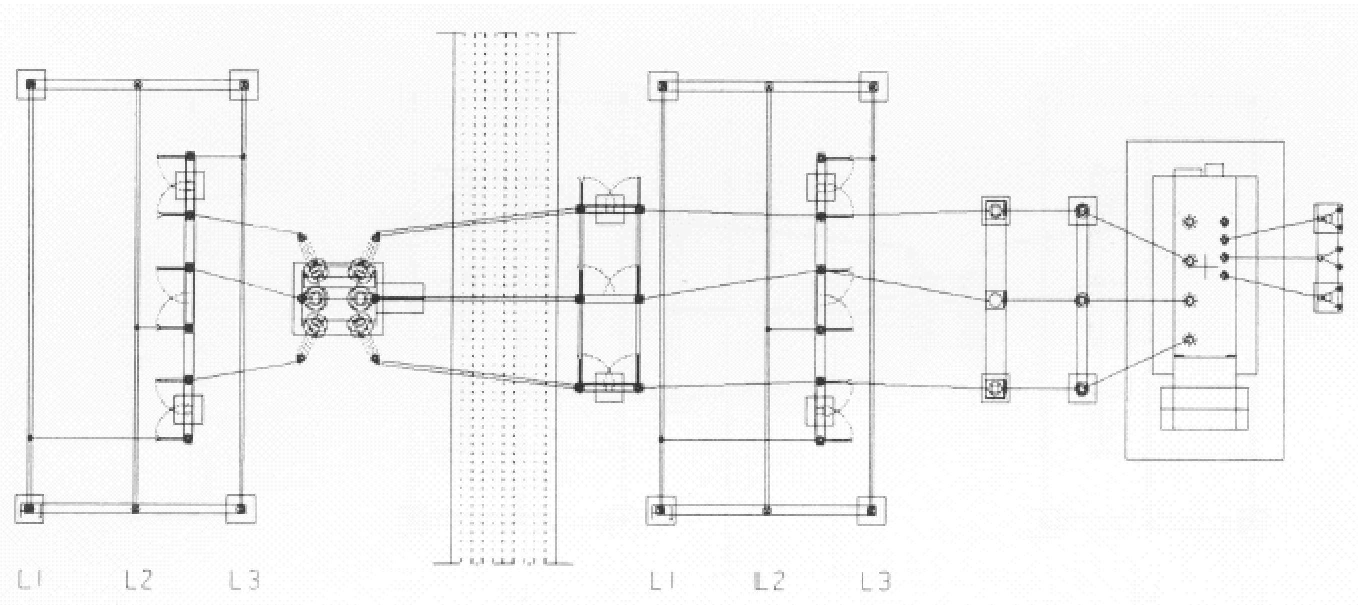


Figure: A2-2-5 Plan view of transformer

Example of Transfer Bus Coupler Module

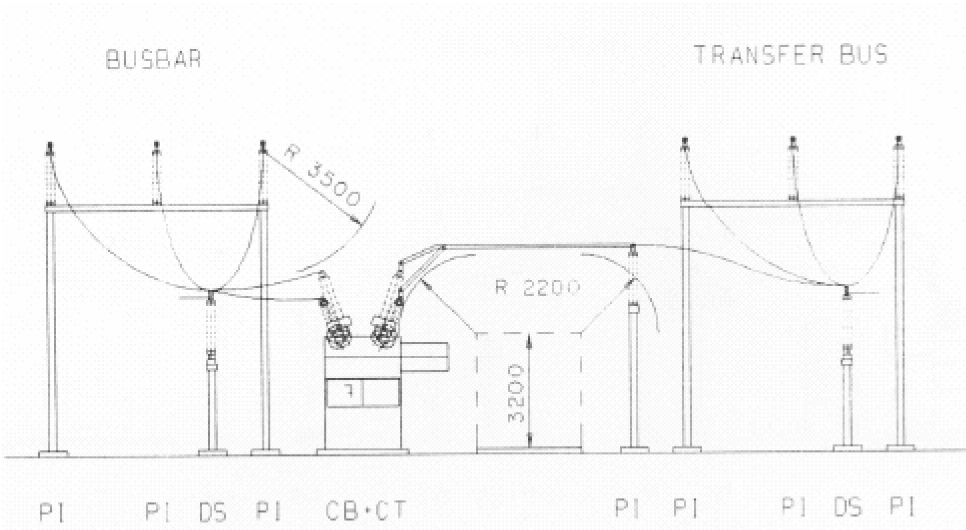


Figure: A2-2-6 Section view of transfer bus coupler

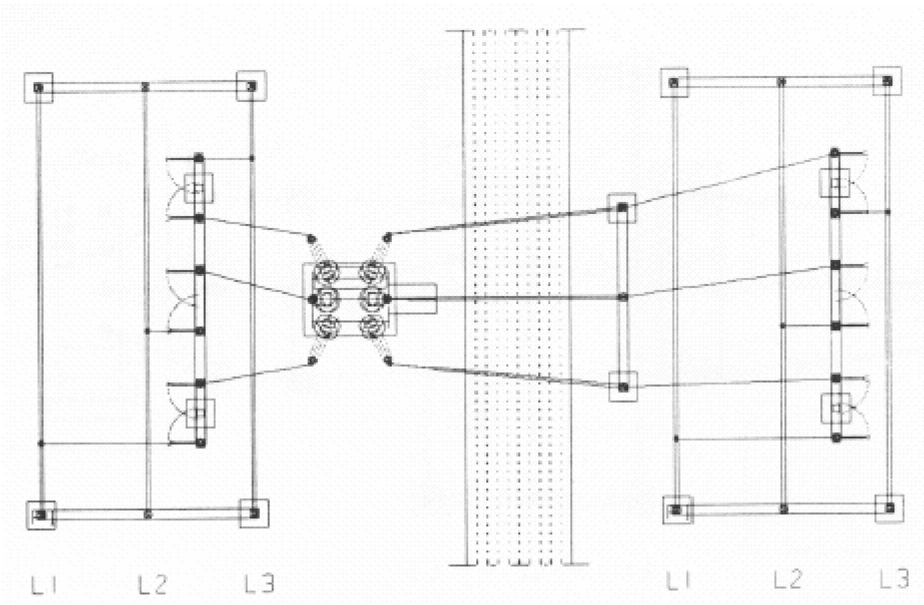
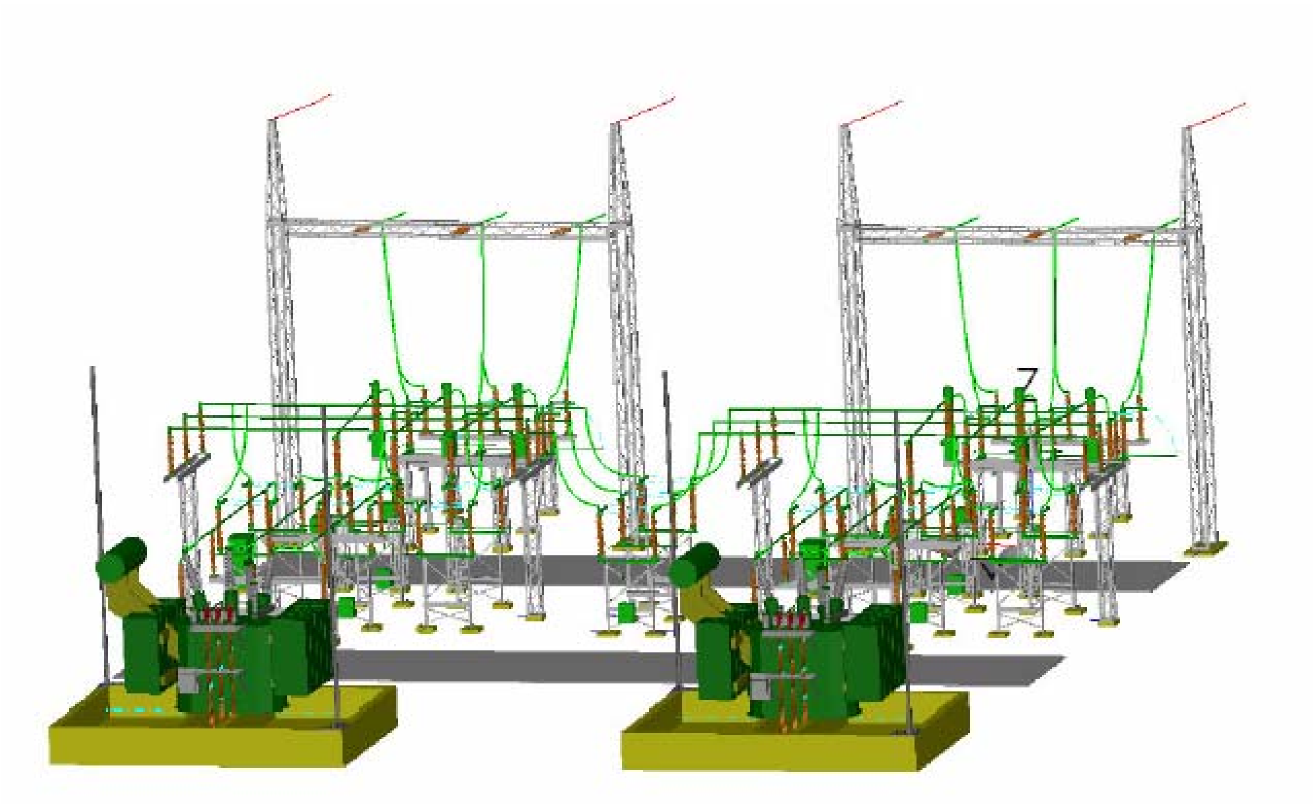
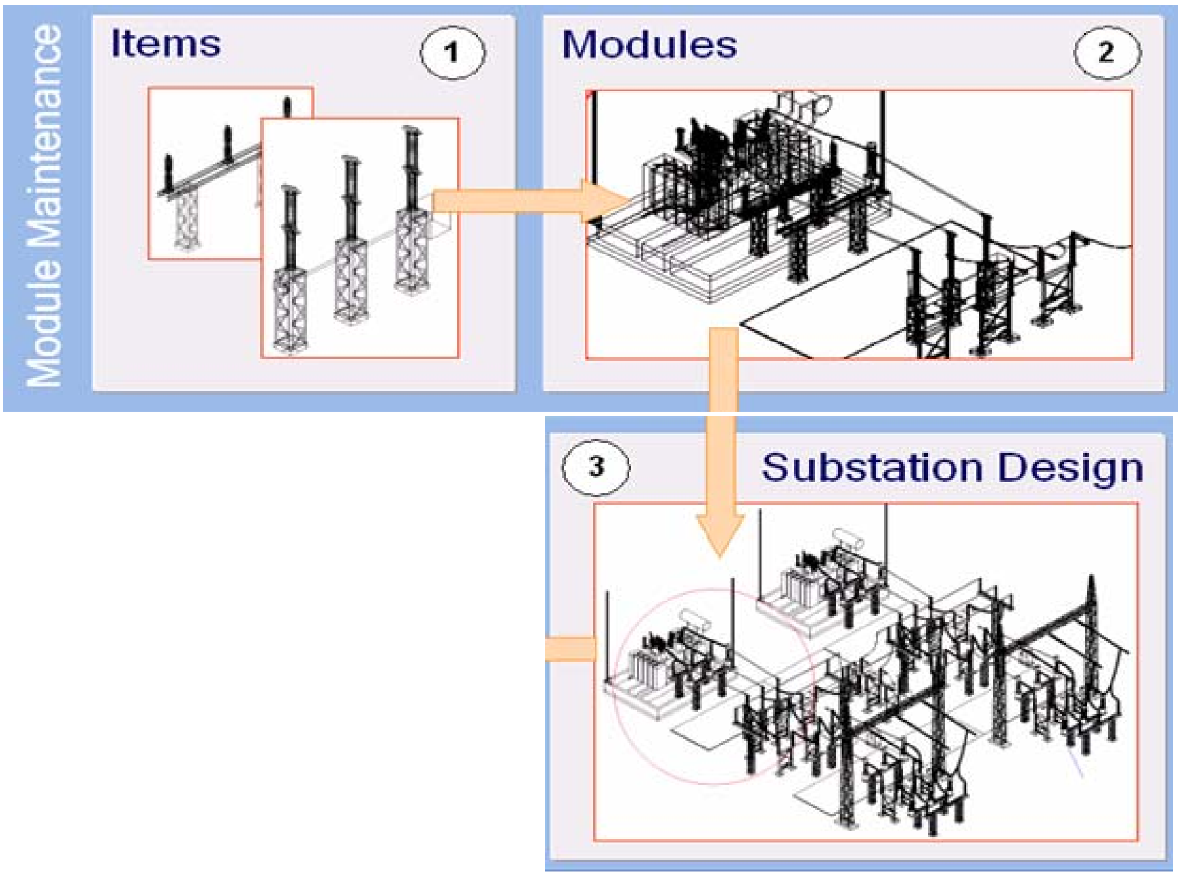


Figure: A2-2-7 Plan view of transfer bus coupler

Figure: A2-2-8 Modular Substation



Once bay-wise modules have been prepared, it becomes straightforward to integrate them and produce a complete layout. A typical step-by-step procedure is illustrated below, along with the final output result.



3 PROCUREMENT PROCESS

3.1 INTRODUCTION

As part of the effort to reduce the total cost of building new or renovating existing AIS, the Procurement Process is the most obvious target for extraction of cost reductions. However, to obtain maximum benefits, every aspect of this process must be subjected to a thorough review, and all associated practices scrutinized, no matter how deeply ingrained they are in the utility policies and procedures.

Turn-key substations are no exception from such efforts. There are two major approaches to the procurement process:

- Tendering the project as a whole package, with the turn-key supplier given a free hand in the selection and installation of all equipment – called here “package”
- The utility selects and purchases the major equipment (power and instrument transformers, circuit breakers, etc.) and supplies it to the turnkey contractor – called here “free-issue”.

While the first approach can result in lower overall costs, the latter has the advantage of retaining tighter control over the quality of equipment supplied, personnel safety and future maintenance costs.

Following is a list of the activities normally grouped together under the Procurement Process that attempts to cover both approaches, with their advantages and disadvantages:

- Evaluating the scope of work with regards to technical requirements and reviewing the possibility of introducing technical innovation
- Prequalification of suppliers for turn-key services and for the major equipment in the substation.
- Writing/reviewing the technical specifications for the turnkey substation, including those for major equipment used in AIS
- Strategic Alliances or long term Blanket Orders - reviewing the commercial terms and conditions, for compatibility
- Producing the Form of Tender to reflect changes in technical and commercial terms and the Evaluation of Tenders – technical and commercial aspects, as well as setting up Blanket Orders or Alliances and issuing Release Orders for required major equipment
- Drawing Approval Process
- Factory inspection, test witnessing and shipping of major equipment to site

Notable points described in this chapter are;

- While both the “package” and “free-issue” approaches can be used, feedback from various utilities that have tried them appears to lean towards the “free-issue” approach. Initial possible savings resulting from the “package” approach seem to vanish quickly when the utility is faced with maintaining non-standard equipment, sometimes having to introduce special maintenance procedures to mitigate safety lapses (e.g. the need to use special arc protection suits when servicing non-arc-resistant switchgear), occasional de-rating of the new equipment due to improper type tests, etc.
- The “free-issue” approach guarantees that at least the major equipment will meet all operating and safety requirements, and existing maintenance procedures will be applicable. It also allows for tight quality checks and simpler warranty administration.

A succinct list of potential savings that can be realized through the Procurement Process:

- Prequalification of suppliers will result in limiting the number of submissions to a tendering process, thus cutting the engineering and contract administration costs of evaluating too many tenders.
- A thorough review of the technical specifications used for tendering can result in significant savings via adopting new technologies or a revision of the requirements to better reflect the actual conditions at site.
- Setting up long term Blanket Orders for major equipment saves the cost of repetitive engineering and procurement efforts
- Streamlining the drawing approval process will also harvest significant savings in engineering and contract administration hours.
- Factory inspection and test witnessing will allow a reduction of the commissioning effort, with associated lower costs.
- A proper selection of warranty coverage can significantly reduce in-service expenditure in the event of failure.

3.2 Evaluating the Scope of Work

As soon as the Planning Specification has been completed and in parallel with Conceptual Engineering, it is necessary to proceed with a review of the technical equipment required. This process requires in-depth knowledge of major equipment available on the market, including ratings and variations, long-term performance of various types, strengths and weaknesses of particular equipment, advantages conferred by reduced maintenance and better reliability, etc. The review should consider recent innovations that may drastically alter the project Single-Line Diagram – e.g. the use of Mixed Technology Switchgear (MTS) - hybrid circuit breakers which integrate the disconnect/ground switches and CT’s within one unit – a bay), or recent Protection and Control (P&C) developments that may allow extensive condition monitoring in the AIS. Any such possibilities that may result in significant cost savings should be discussed with the Planning department before they are integrated within the Technical Specifications for major equipment, or the specification for turn-key AIS.

If there is no in-house expertise to produce the Technical Specification for a particular piece of complex equipment (i.e. Static Var Compensator, HVDC substation) it is recommended that a Consultant be retained. The Consultant should review the requirements of the Planning Specification and should provide recommendation to the Planning Department so that the Planning Specification takes advantage of all the characteristics and performance of the equipment. Also, the Consultant should provide support to Equipment Engineering in preparing the Technical Specification.

3.3 Prequalification of Suppliers for Major Equipment (applicable for free-issue option)

This activity should be performed well in advance of the start of the Procurement Process and involves two distinct steps: technical prequalification and commercial vetting.

Technical meetings with potential suppliers for major equipment should be a regular feature with the aim of obtaining the latest information on various products the suppliers offer. Such meetings will allow suppliers to present the latest innovations they are introducing, or extension/increases in existing ranges/ratings of equipment previously offered. Meetings with potentially new suppliers will complement the data and may result in increased competition and ultimately lower equipment prices. These meetings should be followed up with requests to the potential suppliers for copies of type tests backing up their performance claims and references from previous users.

3.4 Writing/reviewing the technical specifications for major equipment used in AIS (applicable for both options)

Even if the technical specification has been updated regularly, a review is indicated every time a major contract is in preparation. The technical review should be performed with particular emphasis to the equipment ratings required and the latest information regarding recent field performance of similar equipment and new developments.

Occasionally utilities tend to specify equipment with higher ratings than actually required, based on information that is sometimes obsolete. Such ratings can be too low, but often also too high (e.g. short circuit interrupting or Transient Recovery Voltage (TRV) requirements for switching equipment, or MVA ratings for power transformers). Electrical arrangements should also be reviewed, as sometimes a better arrangement can result in reduced ratings, hence lower equipment prices.

In the same manner the recent performance of similar equipment should be scrutinized, and any learned lessons introduced into the technical specification. Often, that involves review of, and changes in the auxiliary systems (e.g. better anti-condensation systems for cabinets, adding automatic oil filtering plants for load tap-changers, specifying non-painted surfaces for cabinets/support structures, etc.), or major policy changes to improve safety/performance of major equipment (e.g. non-oil free-standing CT's and bushings, composite insulators, etc.).

Other important issues to be decided for switching equipment are acceptance of surge arresters and Point On Wave (POW) controlled switching versus conventional switching with closing resistors, mixed gas versus pure SF6 and tank heaters (and as part of this a review of minimum temperature zones and associated risks).

The technical specification also contains requirements for production testing, which must be reviewed from recent performance history perspective. This is the time when any new test requirements can be introduced, or previous ones removed.

3.5 Strategic Alliances/Blanket Orders (applicable for both options)

Few other efforts to reduce the overall cost of AIS are more effective than the use of long term contracts, variously known as Strategic Alliances (also applicable for turn-key services), or Blanket or Standing Orders (for major equipment). Such long term contracts can run anywhere from 3 to 5 years, sometimes with renewal options up to 7 years.

At this particular time most utilities are faced, in addition to normal expansion of the system, with ageing equipment in their substation that will require replacement in the very near future. Hence it is more important than ever to combine requirements for new substations with those for equipment replacement in existing installations and set up such long term contracts with major equipment suppliers. Contracts for turn-key services can also be set up for longer terms or more than one substation.

A short enumeration of the advantages such contracts offer follows:

- Long term contracts save Engineering costs to the utility, by removing the need for repeated technical reviews of the specifications, evaluation of tenders, evaluation of type tests, repeat drawing approval process.
- Such contracts save tendering costs to the utility and the suppliers, which are then able to pass such savings back via lower prices.
- Long term contracts intensify competition among suppliers and result in lower costs.
- Long term contracts allow a degree of equipment standardization, thus resulting in reduced requirements for spare parts, standardized maintenance practices and ultimately lower life-cycle costs for the equipment.
- These contracts significantly reduce the delivery lead time to site, by allowing the sometimes lengthy procurement process to be completed well ahead of the planning for new substations or the replacement programs.

To set up such contracts, the commercial terms and conditions must be thoroughly reviewed as part of the overall procurement process and all issues vetted by the legal department.

In short, unless a utility is faced with an emergency that requires individual procurement, it is recommended that long term contracts be set up and administered in such a way that at no times individual contracts be required. The utility's internal planning process should ensure that new long term contracts be initiated and placed shortly prior to expiry of existing ones.

The request for tenders should also contain the required validity period for the tender. This is an important subject, as such period should be sufficient to allow for a thorough tender evaluation, yet not exceedingly long that it leads to bureaucratic procrastination. For most major equipment, a period not to exceed 3 months from the tender closing day should be sufficient.

3.6 Producing and Evaluation of Tenders (applicable for both options)

Reviewing the Form of Tender is essential to obtaining clear and accurate tenders from the major equipment and services suppliers. It should contain a summary of the payment items, clearly defined in terms of ratings and application (e.g. indoor/outdoor and temperature zones in Northern climates, special requirements such as switching capacitors, reactors, long lines, special TRV requirements), options (e.g. with or without closing resistors, POW switching control devices, condition monitoring equipment, etc.). For turn-key AIS, the documents should include such requirements as oil spill containments (if applicable), grounding, fencing, security, control building requirements, fire protection systems, etc. The Form of Tender should be structured in such a way to allow for clear pricing, including if necessary any escalation over the period of the contract, and any foreign exchange variations as applicable.

It is also advisable to request, in the same Form of Tender, prices for major spare parts and that such prices should be valid for the life of the contract. It is well known that after-sale cost of spare parts can be prohibitively expensive, and such foresight to fix the price of spare parts can often offer major savings, at least for the life of the contract.

The Form of Tender should also contain the Major Equipment Data Sheets – forms summarizing all technical data, CT curves, diagrams, etc. for major equipment that should be filled in by the manufacturers/turn-key suppliers at the time of tendering. It should also request that manufacturers/turn-key suppliers provide a complete type test dossier for the equipment/services tendered.

Last, but not least, the Form of Tender should contain space for any exceptions – commercial or technical – that suppliers may want to file, and space for date, seal and signature by authorized company principal.

Evaluation of tenders must include both technical and commercial aspects, as they are equally important. The tenders should be carefully scrutinized for technical compliance. As well every commercial detail must be analyzed and every issue resolved before an order can be placed.

In most cases Tender Review meetings must be arranged with the potential suppliers for equipment/services. Given the major expense associated with such meetings (both to the utility and the suppliers), they must be thoroughly prepared and organized, to ensure that all outstanding items are dealt with during one sitting. A comprehensive agenda for the meeting should contain both technical and commercial issue to be discussed, and key participants notified well in advance, to prevent no-shows.

The minutes of the meeting should record all agenda points discussed and the required action/follow up. The agenda and minutes must become part of the contract, for future reference.

If there is no in-house expertise for technical evaluation of tenders for complex equipment it is recommended to retain a Consultant. It is recommended to use the same Consultant who was retained for production of the Technical Specification. The Consultant should review the tenders and should provide its assessment of the tender's technical compliance with the requirements of the Technical Specification. The Consultant should participate in the Tender Review meetings along with Equipment Engineering staff and should support them in the final technical evaluation.

Once the tenders' evaluation process is complete, it is necessary to set up the actual contracts immediately, within the validity of the tenders. Requests for extension of tenders' validity can result in revised terms and conditions, an unwanted complication.

The contracts must contain all payment items and associated requirements for testing/inspection, including the full technical description and ratings. As well, prices, any escalation or foreign exchange variation must be clearly spelled out.

Reference to all key documents, such as the tendering document, minutes of tender review meetings, faxes and letters, commercial conditions, etc. must be included.

Information as to drawings submission (specific drawings, submission schedule, approval process, etc.) must be included in the contract, as well as Warranty terms.

Terms of delivery for major equipment are very important and all associated conditions must be included. The advantage of placing the risks onto the contractor (who is most knowledgeable about such risks) must be considered as part of the evaluation process.

The Blanket/Standing order should also contain accurate information for the supplier regarding billing procedures (where should the invoice be addressed, etc.). For turn-key services, requirements for progress payments, holdback payments and their release conditions must be clearly determined. It is customary to set up the Blanket order and the first release order at the same time; however this is not obligatory.

If the Blanket/Standing order has been properly structured, the Release purchase order is a simple document that need only contain the minimal information:

- Payment Item and quantity required
- Required delivery date and notification of shipping
- Delivery point such as EXW (Ex-works), FOB (Free on Board) , CIF(Cost, Insurance and Freight),DDP(Delivered Duty Paid) etc., and contact information.

3.7 Drawing Approval Process

The process of submission, verification, correction and approval of the manufacturer's drawings and instruction manual is an essential step in ensuring that all the specified parameters of the equipment have been noted and included in the manufacturing of the equipment.

The process must be thoroughly organized and the schedule for submissions and approval of drawings monitored closely, as they have a direct impact on the manufacturing, delivery and completion of the project. The drawings must be routed for comments to various departments involved, and one-point contact with the manufacturer is advisable.

Drawings must be marked up clearly, to indicate corrections required and to avoid any confusion – such as interpretation by the manufacturer as design change requests. Thorough records of submissions, corrections and approvals must be kept. The accountable engineer must carefully check that all previous comments and corrections were incorporated into the final submission, before they are stamped as approved.

From the potential savings point of view, the drawing approval process offers significant targets, particularly in the case of Blanket Orders.

In such cases the drawing approval process should be set up as type approval, i.e. submissions by manufacturer should be one-time submissions on a per type (Blanket Order item) bases. All drawings and instruction manuals for a particular type of equipment should be reviewed and approval should be final for the respective type. No other submission for similar equipment should be necessary for the duration of the Blanket Order – unless the manufacturer introduces changes to the equipment. This approach can harvest significant savings in engineering costs on both sides, which can lead to lower overall costs of the substation.

3.8 Factory Inspection, Test witnessing and Shipping (applicable for free-issue option only)

No other activity provides more confidence in the ability of a manufacturer to deliver quality product on time than plant and equipment inspection.

The first plant inspection should take place at the Design Review meeting stage – if such meeting is planned. Design Review meetings are a must for a first delivery of major equipment, as they allow an in-depth look at all aspects of design, testing and manufacturing of the equipment. As with the Tender Review meeting, it is advisable to prepare a detailed agenda of the items to be discussed. Minutes of the meeting should record the decisions and action items. One of the important items is the quality assurance (QA) the manufacturer is adhering to. It is not sufficient to check that the manufacturer has adopted, say, ISO 9001 in the plant. How the implementation and indoctrination of personnel has been done is very important. Spot checks during plant visit can be very useful (e.g. is proper calibration of the tools up-to-date and traceable to an approved standard, are work procedures and tolerances readily available to plant personnel, is segregation of failed/non-acceptable components enforced, etc.). The importance of cleanliness and organization in the plant cannot be overemphasized.

Discussions with key Engineering personnel around the specific equipment are also important.

Finally, the higher complexity of the equipment, the more important witnessing of production test is. Additional tests (which must be spelled out at the time of tendering) can provide further confidence (e.g. requirements for circuit breaker to be subjected to 150 mechanical operations as a routine test can reveal inherent weaknesses that may not be apparent otherwise).

Shipping major equipment to site is also an important task. Many a piece of equipment has passed all routine tests successfully, only to be damaged in transit to site for lack of attention to this important step in procurement.

At the risk of repetition, it is best to leave this activity to the manufacturer, who has the best knowledge on the equipment itself as well as ways of shipping it to site. If the delivery point has been agreed as site, the supplier will also retain all liability over the equipment's safe shipping and delivery by the contractual date.

With some major equipment it may be necessary to stipulate in the contract that impact recorders be mounted within the shipping enclosure. The difficulty with such devices is that they may not be entirely accurate or sensitive enough. The utility may be faced with a situation where, with the equipment delivered at site, impact recorders indicate possible damage, yet none such is visible or easily inspectable. In such cases difficult decisions may have to be taken. One solution to such a predicament – not completely satisfactory – is to negotiate a warranty extension with the supplier (if the contract provides for delivery up to site).

3.9 Warranty

The standard warranty offered by manufacturers for major equipment covers the first year after in-service date, or 18 months after delivery at the specified delivery point. The warranty coverage must be clearly stated in the terms and conditions of the contract. Such issues as cost of transportation to and from manufacturer's plant, cost of dismantling and re-installation, cost of utility personnel assisting in the process (switching, grounding, etc.) must be clearly assigned.

Most utilities recognize that the cost of undelivered power and other consequential costs cannot be included in the warranties, as no manufacturer will accept open-ended expenditures.

Similarly, manufacturers will not accept unlimited liabilities as a result of an explosive failure. Most limit such liabilities to the cost of the equipment. Often a compromise between local laws governing the utility and irrational costs may be necessary on this issue.

Manufacturers will often offer extended warranty at an additional cost. Essentially, accepting such extended warranties should be done on the bases of a risk evaluation. The factors that come into play in such evaluations are:

- Manufacturer's reputation on quality of products and after-sales support
- Long term performance track record of similar equipment
- Duty for which the equipment will be used (e.g. difficult applications such as equipment for switching capacitor banks or reactors may warrant purchasing the extended warranty)
- In-house capability for on-site diagnostic and repair
- Availability of spare parts at hand for the purchased equipment
- Duration of the extended warranty (normally varies from one to five years)
- Cost of extended warranty

Occasionally, in very competitive situations, some manufacturers will negotiate "free" extended warranties for a larger slice of the business being tendered. Another common offer may involve "free" extended warranties on condition the equipment is commissioned by the manufacturer. In such case, the cost of erection supervision (which often is expensive) must be factored into the evaluation.

4 CONSTRUCTION PROCESS

4.1 INTRODUCTION

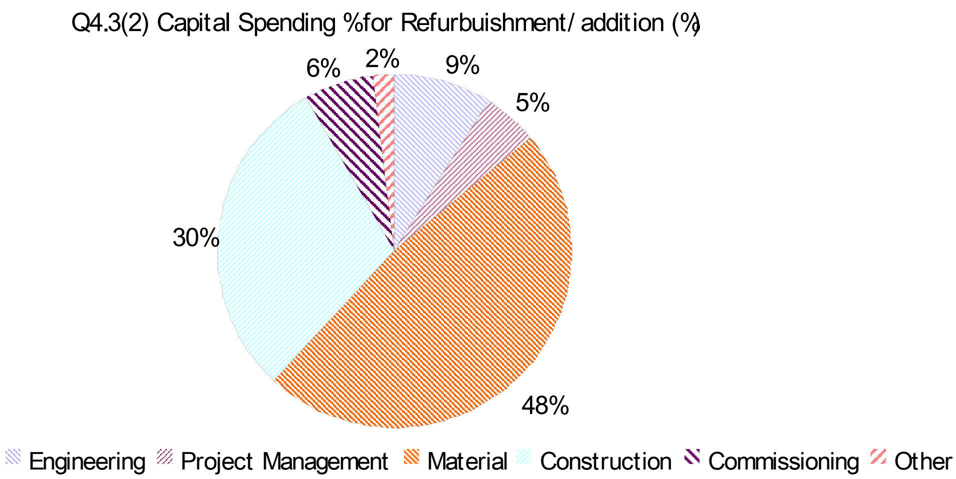
The construction process is the process of using the engineering drawings and specified material to construct a new substation or add to an existing substation as required. It also involves the physical transformation of a piece of land into a substation plot. The construction process is affected by variable and differing conditions for each project, under limited circumstances depending on the real condition of the substation site. The following is a guideline of how to approach the construction process in a substation project. Many processes come together during the construction process such as:-

- Site preparation / Logistics
- Construction of equipment foundations
- Construction of control buildings
- Fabrication of equipment support structures
- Delivery of equipment to project site
- Unloading and unpacking of equipment
- Erection of substation equipment
- Installation of the balance of plant such as LV systems and connecting cabling between equipment as total systems

With such a variety and multitude of tasks, it is important that construction processes are methodically planned and sequenced in order to optimize construction costs. Otherwise, additional construction time and unproductive work will occur, resulting in unexpected / unplanned costs.

Regarding the allocation of total project cost for AIS, the results of the questionnaire indicate that the average capital spending for project management and construction is about 32%, and for refurbishing a substation, the capital spending for these items is about 35%. This figure is significant and eliminating fluctuations in these costs is one of the steps required to maintain a standardized construction cost.

The following diagrams indicate the proportion of capital spending for new and refurbished substation projects, based on responses to Item 4.3 of the questionnaire.



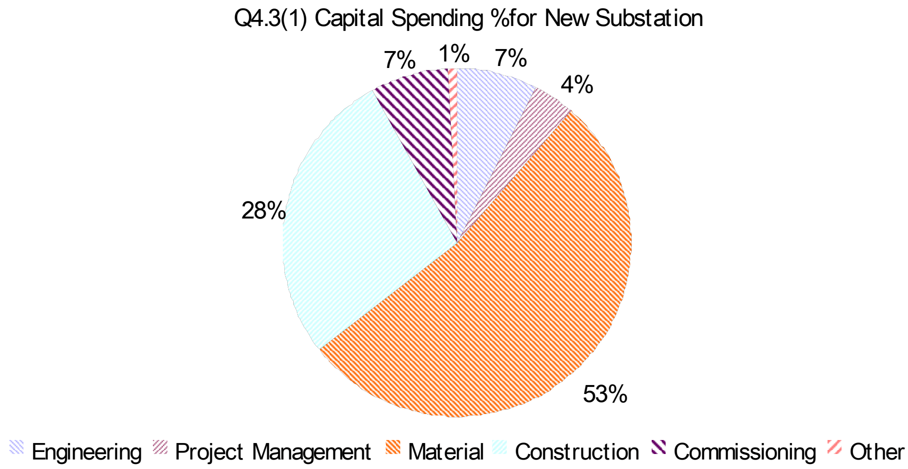


Figure 4-1: Proportion of capital spending on substation construction

Generally, the approach to cost reduction of AIS should concentrate on minimizing construction time and eliminating mis-sequencing of construction activities. This could be achieved by standardization of design and construction processes and methods.

The questionnaire responses show that some of the negative forces experienced by utilities for optimizing and cost reduction of AIS construction are :-

a) Land construction increases, driving costs up
b) Shorter civil construction period to build a new substation
c) Restrictions on transportation of equipment
d) Requirement for a short installation period

At the same time these are the items, especially b) & d), that should be improved together with the standardization of design and construction processes and methods.

According to the questionnaire results the average time for 1-bay expansion is about

12 months and for 1-bay replacement / upgrading is also about 12 months. As part of the effort to optimize and reduce AIS construction costs, several important factors must be considered as follows:

- Accurate and detailed engineering.
- Availability of material.
- Experienced and well trained construction crews.
- Time available for construction and coordination with operation.

The effect of these factors is discussed below:

Accurate and detailed engineering: This is one of the most important factors that affect the construction cost of the substation. Construction crews use the drawings to construct the different element of the substation. An error in the engineering will result in construction delays and higher cost for substation construction. Some of the common engineering errors are listed below:

- Selecting complex bus arrangements that require more equipment and require longer time to construct.
- Use a complex design for certain elements of the substation which require more material and require more time to construct.
- Miss-coordination between the substation and overhead line design, requiring substation re-work which adds to the substation cost.
- Failure to verify electrical clearance requirements in certain areas of the substation.
- Specifying the wrong material for the substation.
- Designing an overloaded relay rack that cannot be constructed.
- Specifying the wrong equipment rating.

Availability of material: It is highly recommended that all required material be on hand before the start of construction. A missing piece of hardware can stop the construction process. All material must be verified, organized and stored in a proper place for easy access.

Construction crew's experience and training: An experienced construction crew with the proper training is an important factor in reducing the cost of the substation construction. With an experienced construction crew, the substation construction can be completed on time and costly errors prevented. It has been found by experience that, when construction people provide input to engineering and verify the constructability of the engineering plans during the design process, many errors can be prevented, resulting in reduced construction costs.

Time available for construction and coordination with operation: The time available for construction has a significant impact on construction cost. When the allowed time for construction is inadequate, construction crews must work overtime to meet the commissioning date. This will increase construction costs due to the overtime cost, which amounts to one-and-half to two times the regular hourly rate. When the construction is associated with an existing substation expansion/addition, coordination of work activities with substation operation is very important in order to prevent delays due to inability of construction to work on part of the substation. Construction must be aware of the additional work that may require minimizing the outage time.

4.2 Construction Method

There are several contracting options (construction methods) available to the Utilities for constructing a substation. However in this survey, the questionnaire specified (as per Table 4-1) that substations could be constructed by one of the following methods:-

a) Turn-key
b) In-house engineering / procurement / construction
c) In-house engineering / procurement and giving out construction to a contractor
d) In-house engineering and giving out procurement and construction to a contractor

Utilities may choose to adopt a different type of construction method depending on the nature of the project.

The responses to the questionnaire indicate that most utilities adopt Option (c) above; i.e. in-house engineering / procurement and giving out construction to contractor, especially for expansion and replacement projects. This is also true for new substations, although turnkey construction appears to be a popular choice as well.

Table 4-1 Summary of Construction Methods Specified in Survey

	Engineering	*Procurement*	*Construction*	*Remarks*
Turnkey	By Contractor	By Contractor	By Contractor	• Less coordination for Utility • Less risk for Utility • Project time is normally shorter
In-house Eng, Procurement and Construction	By Utility	By Utility	By Utility	• Higher risk for Utility • Utility should be experienced • Utility should be resourceful
In-house Eng & Procurement and giving out Construction	By Utility	By Utility	By Contractor	• Utility has control of equipment selection and cost
In-house Eng and giving out Procurement & Construction	By Utility	By Contractor	By Contractor	• Suitable for upgrading / replacement projects

For each of the contracting options, it is useful to study how it is possible to minimize the cost for each design, construction process and construction method.

For example, in the case of the Turnkey construction method, a utility may prepare several design concepts (such as A, B, C) for the contractor to select. By providing such pre-defined general design concepts, this will minimize the time for discussion and negotiations with the contractor. By minimizing the time for such discussion, this will subsequently minimize some of the project cost.

4.2.1 Turn-key

In selecting a turn-key construction method, the Utility is considered to have transferred the responsibility to a solitary turn-key or EPC Contractor for the entire substation project, consisting of engineering, procurement, construction, erection, testing and commissioning processes.

The Utility may choose to issue a set of technical specifications which outline the expected standards of engineering, manufacturing, procurement, testing, construction, commissioning, etc. to be observed by the Contractor in the course of the project. Otherwise, the Utility may request the Contractor to provide a set of turn-key specifications detailing the entire scope of work for the contract.

In offering a full turn-key solution, the Contractor is expected to undertake the following scope of work:-

- Design of substation primary equipment and structures, civil works, substation secondary equipment and balance of plant
- Procurement of equipment
- Construction of civil works, fabrication of structures
- Transportation and delivery of equipment from manufacturer's works to site
- Erection of all substation equipment
- Site testing and commissioning of the substation

The Contractor is expected to coordinate the activities of several teams such as designers, manufacturers, erection team, and testing team in order to successfully execute the project. Often the Contractor who undertakes the project on a full turn-key basis is a main equipment manufacturer or an experienced EPC contractor who will purchase the primary equipment from an OEM.

4.2.2 In-house engineering / procurement / construction

All of the engineering, procurement and construction are conducted in-house by the Utility. In this form of construction, the Utility implements the entire project by using in-house resources for the design, procurement, construction, erection and testing process.

This form of construction is normally used by experienced and large Utilities with adequate engineering and construction resources.

4.2.3 In-house engineering / procurement and giving out construction to contractor

Based on the responses to the questionnaire, this form of construction is the most popular for all types of AIS construction (new, expansion and replacement).

In this method, the utility undertakes the engineering work and the procurement of substation primary equipment such as transformers, circuit breakers, disconnecting switches, earthing switches, CT's and VT's. In some cases, the civil engineering is outsourced if the utility does not have the required technical capability.

The utility has the advantage of retaining absolute control over the selection of the primary equipment. This form of construction method may be suitable for :-

- Utilities having a Strategic Alliance or long term blanket orders with a Manufacturer or Supplier for the supply of primary equipment.
- Utilities that have a specific preference for the type and make of primary equipment.

As the Utility has more leverage over the cost of the primary equipment, this form of construction method is effective in controlling the cost of the primary equipment and overall project cost since material cost is approximately 50% of the total AIS project cost.

4.2.4 In-house engineering and giving out procurement and construction to contractor

This method was reported in the survey to be more popular for expansion and replacement projects but is not so popular for new substations.

In this method, the utility performs the engineering using their in-house capability and resources, while giving out procurement and construction to a contractor.

4.2.5 Process to reduce construction cost

In order to reduce construction cost, the following construction process is recommended:

- Material receiving and delivery to the substation Site.
- Site Preparations.
- Equipment elevations and installations.
- Installations of substation control and protective equipment
- Commissioning and testing.

Sections 4.3 - 4.5 elaborate in more detail the construction process, focusing on steps and processes to reduce construction cost.

4.3 Site Logistics

During the course of the substation project, delivery and storage of materials and equipment require much coordination to ensure that the materials are delivered on time and stored properly in order to minimize costs arising from delivery waiting times and the transportation strategy. Another method to reduce waiting time is for the Utility to establish long term orders or alliance with equipment suppliers.

Material receiving and delivery to the substation Site: Before construction starts, all material ordered must be verified, received by the appropriate people and stored in a specified place to prevent theft and for easy access. Warehouse material must be also verified and stored in the same place. The availability of equipment at the time of construction is very important for construction to achieve its objectives and reduce cost.

4.3.1 Storage Facility

The Utility has several options to define the delivery of major equipment for the project such as :-

- On time delivery
- Storage at the Manufacturer's site
- Storage by the Utility

This is referred to in questionnaire Item 3.2.

For standard items, it is possible to consider bulk purchase of the equipment which is then stored by the Utility. This is useful for standard designs and will reduce the cost of the equipment since it is purchased in bulk.

4.3.2 Logistics Management

Effective management of the site construction logistics is one of the factors which affects the cost of the substation project.

During power substation realization there can be disturbances related to lack of delivery of necessary materials in due time. In such a case, capacity for execution of other tasks within the same facility is checked. If such a possibility arises, the realization potential is transferred to other assignments that can be executed.

If, due to delay, it is not possible to install and store the equipment within the facility, especially if devices have already been manufactured, a place for their temporary storage is selected. The place of storage may be at the manufacturer's, contractor's or client's stores.

This is referred to in questionnaire Item 3.2.

4.3.3 Time Coordination

During the preparation period the schedule is fixed. The schedule accounts for works execution and materials delivery. The main purpose of the schedule is the coordination of the progress of civil engineering works with the dates of equipment delivery.

A properly devised schedule guarantees that e.g. a transformer is supplied after a stand for it has been completed.

It is the producer who is usually responsible for the transport of the equipment, as the contract covers the delivery to the place of installation. The task of the contractor is to ensure conditions are appropriate for temporary storing of the apparatus. In order to reduce costs, deliveries are so coordinated with the progress of works that the apparatus is installed directly after supply. Local building materials are often used in order to reduce the cost of transport.

4.4 Transportation

In a substation project, transportation is the key process which ensures that the equipment is delivered to the construction site safely and on time. As transportation is uniquely affected by the geographical characteristics of the construction site, it is necessary to develop a project specific transportation plan which addresses the individual requirements of each construction site and project.

We have considered that standardization is one of the key factors for cost reduction. The same concept could be applied to transportation. Several obvious ideas for standardization of transportation would be to specify standard packing sizes, unit preferable design, standard maximum heights which could reduce the cost of transportation. These kinds of standardizations should be considered in a transportation plan.

Some of the quality control measures from survey questionnaire Item 3.4 which could be included in transportation plan are :-

- Acceleration record during transportation and installation
- This is otherwise known as an impact recorder / indicator which is used to determine whether the equipment was subjected to excessive impact during transportation.

- Dry Air / Nitrogen Gas Filling Transportation
- This is normally adopted for transportation of transformers.

- Carrier Certification
- This will certify the quality of the transporter. In some cases, the utility may specify the carrier to be used for the project.

- Pre-Road Survey
- This is done to study any obstruction or limits which may occur during transportation.

- Test Run
- A transportation test run is seldom conducted as it is a costly option. Less than 50% of respondents indicated that they used Test Run for transportation.

4.4.1 Transportation Plan

A project transportation plan should include as a minimum, the following components:-

- Freight instructions / specifications
- Pro-forma packing lists
- Nominated freighting and forwarding companies
- Procedures for shipping release
- Route of land transportation
- Unloading procedures
- Heavy lifting plan for bulky consignments / cargo
- Timing of freight and delivery

The project transportation plan coordinates the construction activities, equipment fabrication, erection and transportation.

The timing of delivery to site is essential. If the equipment arrives early, the civil structures may not be ready and hence storage space would be required to store the equipment until such time when it can be installed and erected at site. A detailed transportation plan identifies the total cargo for the project and the shipping timing of each type of equipment, based on the site erection schedule.

The transportation mode of each type of equipment should also be addressed in the transportation plan. For example, some cargo may be suitably transported as container freight. Some other bulky cargo may require special freighters such as open top container vessels. Other smaller cargo may be transported by land or by air.

In other cases, bulky consignments such as transformers may require special ships and trailers for transportation. Effective transportation planning, especially for bulky cargo, is necessary to reduce the overall cost of substation project.

In addition, transportation restrictions may occur due to the physical size of equipment. In such a case, utilizing a standardized design or a special design could overcome transportation restrictions. This is especially important for transportation of large transformers and switchgear.

Some of the possible options from the responses to questionnaire Item 3.3 are :-

- 3-phase 5-leg core type transformer
- 3-phase in 1-tank type transformer
- 3-phase in individual tank type transformer
- OLTC/ULTC separation
- All-in-one transportation of transformer
- All-in-one transportation of one GIS bay
- Grouping transportation of GIS (2 or more bays)
- Lowering lightning impulse level voltage
- Graded insulation to neutral of transformer
- Dry air / nitrogen gas filling transportation

4.4.2 Pre-road survey

Most of the primary substation equipment is bulky and requires special consideration during transportation. As part of the transportation process, it is important to conduct a pre-road survey to identify the following items:-

- Entire route of transportation
- Any traffic restrictions for movement of large trailers
- Obstacles such as gantries, overhead lines, bridges
- Limitation of road & bridge widths
- Limitation of allowable axle load on bridges
- Temporary roads at construction site (required or not)

Figure 4-3 Pre-road survey of bridge for transformer transportation

For large transformers, such as 400 kV units, the project allows for the selection of a route for road transport. The route is examined with regard to its capacity for transporting a transformer of the given dimensions and mass, mainly with respect to the bridges along the proposed route. Should the bridges or roads be inadequate they are reinforced and roads and bends are widened if necessary.

4.4.3 Transportation License requirements

The requirement for transportation licenses varies from country to country. Some countries require that a certificate of origin be issued by the equipment manufacturer. Other countries may require special clearances before shipment.

Material safety data sheets may also be required, depending on the type of cargo.

In order to avoid inconvenience for the road users, transport of transformers takes place mainly during the night under police supervision.

4.4.4 Transportation Conditions

As part of the quality control, it is normal to provide impact recorders and/or acceleration recorders on sensitive cargo. Upon delivery to site, these recorders are checked to determine whether the cargo has suffered any serious impact or damaging movements during transportation.

Other criteria, such as dry air / nitrogen level checks, are also conducted prior to shipping of transformers.

4.5 Construction Quality Control

Quality of construction is one of the key areas where cost can be reduced by minimizing construction errors and deviations.

As part of the construction quality control, the following questions were posed in the questionnaire :-

- Do you control construction deviations from design?
- Do you have a formal feedback process from construction to modify engineering standards?
- Do you involve constructors during the conceptual stage?

From the responses to the questionnaire, it can be concluded that construction quality control is implemented widely by most utilities.

Most utilities have a standard practice / procedure to evaluate construction deviations from the design. In general, any construction deviation has to be reported by site inspection teams and approved by design engineering teams. This ensures that all deviations are properly recorded and evaluated before the deviation is approved.

Some respondents to the questionnaire indicated that a formal feedback process is available in their organization to learn from the experience of site construction (from survey questionnaire Item 2.3). This is normally in the form of working groups or project design review, which is conducted upon completion of the project. In such instances, it is important to include the site construction staff in the review process.

Most utilities will also involve the constructor in the conceptual stage of a project provided that the constructor is part of the utilities' own organization. This is important to ensure that construction aspects are considered in the design of the substation and to minimize any construction deviations in the future.

During construction, the construction quality can be controlled by diligent site supervision, adherence to ISO requirements, material quality, and so on.

Contractors should be required to submit a quality control plan which would document all the necessary procedures and steps for construction. It should be noted that over-zealous quality control measures and unnecessary requirements will add to the overall project cost.

The whole period of construction is supervised, pursuant to the decision of the Client. The supervision is executed by specialists of various branches who control the whole realization process. The main objectives are compliance with the design. Partial commissioning also takes place with regard to consecutive stages of the assignment. For each stage, the contractor provides documents confirming adequate quality of materials used and, in some cases, results of tests. The final commissioning covers functional tests that confirm proper execution of the task.

<u>Site Preparation:</u> Construction normally starts with all required under-ground work, referred to as site preparation. For new substations this process consists of site work such as clearing, surfacing, grading and fencing, installation of foundations, the grounding system and the trench and conduit system, including any surfacing material. For existing substations, the site work may not be required but all other may be required.

<u>Equipment elevation and installation:</u> To prevent accidental equipment damage, it is recommended that heavy steelwork be installed first; equipment can next be installed and

tested, and bus work will follow. The final step will be installing the jumpers.

Installation of substation control and protective equipment: One of the cost effective methods used to reduce the cost of the substation control, metering and protection equipment is to fabricate, install, wire, and interconnect this equipment locally in the shop. This process has the following benefits:-

- Reduced travel time, which could be up to 20% of the total construction labor cost.. In addition, better time control can be achieved. For projects located outside the work location require addition cost for subsistence. This cost is eliminated when the work is accomplished in the shop.
- The work is optimized since all required material is found in the shop. No travel from and to the job is required.
- The assembled panels can be tested and verified in the shop.

Once the panel has been assembled and tested in the shop, the equipment can then be shipped to site. Major equipment is then connected to the panels as required.

Commissioning and testing: This is the final step in the construction process. A well-trained test technician can accelerate the process and therefore reduce the cost.

4.6 Outage Management

Outages are required in projects which involve existing 'live' substations such as extensions, upgrading or replacement of transformers, switchgear feeder bays, bus section and bus coupler bays.

Normally, the Utility will try to minimize the outage during the construction period. Outage schedules are usually coordinated with transmission/grid regulators to minimize the outage period.

The most popular choice is to provide a partial shutdown; very few utilities adopt a full shutdown approach (from questionnaire Items 3.6.1 and 3.6.2). Mobile substations may be used to prevent the need for any outages for voltages up to 170kV; it appears that it is not practical to adopt this approach beyond 170kV based on responses to questionnaire Item 3.6.1. In this sense, it becomes important to adopt standardization of design, equipment and construction to minimize the outage time and reduce errors during site construction.

According to the responses to questionnaire Item 3.6.2, it is possible to require only a 2-day shutdown for the replacement / upgrade work. This is one of the challenges which would reduce the cost of AIS projects.

3 Test and Commissioning Process

3.1 Introduction

Substation components experience a set of tests along the different phases of their life cycle as identified by IEC standards. Annex 5.1 gives a summary of typical identified phases during the product's life cycle together with a general view of the tests and verifications expected to be accomplished.

Basically, the tests on a substation component can be classified with reference to the materials, subcomponents, or the whole unit, namely:

- **Sample Tests.** These verify the characteristics of the component, which depend on the manufacturing quality and the material used (i.e. polymeric housed components).
- **Design Tests.** These verify the suitability of the design, materials and method of manufacture (technology). When a component is submitted to the design tests, the results shall be considered valid for the whole class of components which are represented by that which has been tested having the same material and design and manufacturing method.
- **Type Tests.** These verify the main characteristics of the product (whole assembled component or similar sample). The type test shall be repeated only when the type or the material or the manufacturing process of the component is changed.

In general, typical classes under which the product standard groups the type tests, for example Questionnaire Item [5-1], are:

- dielectric tests
- radio interference voltage tests
- measurement of the resistance of the circuits
- temperature-rise tests
- short-circuit tests
- tightness tests
- electromagnetic compatibility tests
- tests on auxiliary and control circuits.

- **Factory Routine Tests - FATs**

Routine tests are for the purpose of revealing faults in material or construction. They do not impair the properties and reliability of a test object. The routine tests shall be made wherever reasonably practicable at the manufacturer's works on each apparatus manufactured, to ensure that the product is in accordance with the equipment on which the type tests have been passed.

In general, typical classes under which the product standard groups the routine tests, for example Questionnaire Item [5-1], are:

- dielectric tests
- tests on auxiliary and control circuits.
- measurement of the resistance of the circuits
- tightness tests

- design and visual checks.

By agreement, any routine test may be made on site.

- **Site Acceptance Tests – SATs (commissioning tests)**

On completion of erection work, equipment should be inspected and tested to confirm that transportation and storage have not introduced any damage and to prove that the component is entirely suitable for commercial operation. In addition, when a large part of the assembly and/or the adjustment is performed on site, these tests are required to confirm compatibility of the sub-components and the satisfactory nature of both the site work and the functional characteristics dependent upon it.

After all connections have been completed commissioning tests verify the in-service functionality of the component.

As an example of a possible commissioning tests program, the relevant standard for circuit-breakers, Questionnaire Item [5-2], in its last revision offers guidelines as follows:

- general checks of conformity of the assembly to manufacturer's drawings and instructions
- checks on tightness, fastening, fluids systems, control devices, external insulation, corrosion protections, operating devices, earth connection
- checks of electrical circuits: conformity of wiring, correct operation of signalling (position, alarms, lockouts,..), of heating and lighting
- checks of the insulation and operating fluids (filling pressure/density, quality)
- mechanical tests and measurements
- dielectric tests on auxiliary circuits and measurements.

However, in general, apart from the circuit-breakers, product standards for substation components do not include details for a commissioning test program; this is usually left to the manufacturer to arrange, or even to the agreement with the purchaser. Commissioning tests may include deferred routine tests only where they are made after all site adjustments and tightness checks are complete.

3.2 ELIMINATION OF DUPLICATED TESTING (TESTS COST OPTIMISATION)

A search for a possible tests optimization should consider the role of the different tests, the context where they are required to be performed, and the relevant degree of their compulsoriness in such a context.

To this respect, two approaches can be taken, namely:

(1) Avoiding duplication of the same test in different phases of the life process (reduction of the number of tests). Considering the compulsory aspects of the type and routine tests required by the relevant product standards, this approach asks minimising the repetition on site of the tests already performed in the factory during the relevant acceptance phase.

Responses to Questionnaire Item [5-3] show the same test item occurs at the different test contexts. The following summarises the reported most-repeated tests for power transformers and circuit-breakers respectively:

- Power Transformers
  - oil tightness test
  - function test for protective accessories
  - visual and dimension inspection
  - voltage ratio
  - polarity and phase relationship
  - insulation power factor and capacitance
  - inspection of on-load tap changer
- Circuit Breakers
  - visual inspection
  - tests to verify the resistance of tripping and closing coil
  - resistance of main circuit
  - test to verify insulation resistance
  - mechanical operating tests

It can be appreciated that on-site activities represented by SATs and Commissioning Tests offer a possibility for optimization (reduction), provided that the same operation can be performed once at the factory.

To this respect, a compact-mixed (SF_6, air) technology leading to pre-fabricated solutions, even for higher rated voltages, may help in achieving such a goal. One result from the survey was confirmation that the application of mixed-technology switchgear is considered for cost reduction purposes.

Within this context it should also be considered that somewhere electrical utilities may release customized specifications for substation equipment integrating the product standards with special requirements, usually driven by specific events experienced in the past by the utility. Such events can be the result of unique configurations, climatic exposure, specific seismic or geographical features, or other.

As an example of this possible customized “extension” of the standards, Annex 5.2 reports an excerpt of the routine and site tests specified by two Canadian utilities. As can be observed, both utilities plan on minimal site acceptance tests, with high reliance on factory tests.

(2) Arranging for the on-site tests a tests grouping and planning a tests sequence aimed at optimising the daily working shift(s) available for the tests (optimisation of the testing time). This approach would also require minimising the execution on-site of those tests requiring a consistent engagement in personnel, time duration and testing means. This may be more affordable in the case of compact solutions.

ANNEX 5.1 Life cycle of product (excerpt from IEC60300-2 [10], 1995)

- **Concept and definition phase**

  The product life-cycle phase during which the need for the product is established and its requirements specified. During this phase the foundation is laid for the product's dependability♣ and its life-cycle cost.

  Decisions made during this phase have greatest impact on the product and its life-cycle cost. The dependability activities in this phase should concentrate on reaching the correct requirements for the product and its future support and for establishing the dependability plan used as a basis for the control of dependability during the subsequent phases.

- **Design and development phase**

  The life-cycle phase during which the product's hardware and/or software is created and documented as detailed manufacturing/coding specifications, and other product documentation such as use and maintenance instructions are produced.

  The prime objectives of dependability activities during this phase are to ensure that:

  - the requirements of the dependability specification are taken into full consideration during the design process
  - analysis and prediction activities are implemented and used to achieve dependability of the product
  - validation, verification and test procedures and criteria are defined and executed based on dependability requirements
  - dependability requirements allocated to any part of the product provided by second level suppliers or customers are complied with
  - maintenance support planning and engineering activities are coordinated with the product design to ensure compliance with dependability requirements
  - disposal requirements are defined.

- **Manufacturing phase**

  The life-cycle phase during which the product is produced, software replicated and the product assembled.

  Dependability activities during this phase should be directed at ensuring that dependability performances of the product achieved during design and development are not degraded during the manufacturing process. The dependability programme should state procedures to be followed during the production of systems and equipment to ensure that dependability meets

  specified levels.

  The principle dependability activities during this phase are:

  - reliability and maintainability testing
  - production testing

♣ dependability: collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance

    - reliability stress screening.

- **Installation phase**

  The life-cycle phase during which the product is installed.

  Dependability activities should be directed at ensuring that the dependability performances of the product are not degraded during installation.

  Procedures and instructions should be provided for conducting acceptance inspection and testing of systems and components by verifying compliance with the initial specification and design.

  Prime dependability activities during this phase are:
    - acceptance testing
    - commissioning tests
    - reliability growth testing
    - reliability and maintainability demonstration
    - data collection and analysis
    - initial failure control.

- **Operation and maintenance phase**

  The operation and maintenance phase is the life-cycle phase during which the product is used for any purpose and is maintained and supported. During this phase, essential preventive and corrective maintenance actions are taken, as necessary, and the product's performance is monitored.

  In order to ensure that required levels of dependability are consistently achieved during this phase, it will be necessary to provide:
    - operating instructions
    - maintenance instructions
    - warning instructions
    - training
    - spares.

  The useful life of the product ends when its operation becomes uneconomic due to increased maintenance cost or other factors, or when the product becomes technically obsolete.

- **Disposal phase**

  The disposal phase is the life-cycle phase after the operation and maintenance phase, during which the product is removed from its use site and dismantled, decommissioned, destroyed or stored if necessary in a protected environment.

  This phase may include disassembly of the product in order to perform activities such as:
    - tests and wear analyses
    - feedback of data to the supplier in order to
    - improve reliability and maintainability
    - recovery of materials for recycling processes.

ANNEX 5.2 Example of User Tests Specifications

A5.2.1 Specification (Example A)

- **Routine (Production) Tests**

  Routine tests shall be made in accordance with ANSI C37.09 Section 5 in the presence of the inspector. In addition the following tests are required.

  - Rated Low Frequency Withstand tests in accordance with ANSI C37.09 shall be conducted on each fully assembled breaker.
  - Alternatively, for breakers that are not fully assembled prior to shipment, component testing in accordance with ANSI C37.09 shall be carried out. User strongly prefers that production tests be carried out on fully assembled breakers.
  - Routine tests shall include a total of 150 circuit breaker operations (CO's), including operations at maximum and minimum pressures, and maximum and minimum control voltages.
  - Leak tests shall be conducted on all welds, seals and pipe fittings on each completely assembled breaker with dry air or nitrogen at a pressure not less than 1.2 times the normal operating pressure of the breaker. The test pressure shall be maintained for a minimum period of 10 minutes and for such additional time as may be necessary to conduct the examination for leakage. The leak test shall be a soap solution (bubble) test with the aid of a sound detector or SF6 detector, if SF6 has been added as a tracer. Leaking areas shall be marked and repaired in accordance with approved procedures.
  - Following the routine mechanical test (item 3) each open circuit breaker or interrupter assembly, including grading capacitors, shall be subject to a partial discharge test at 1.5 times rated voltage. The maximum discharge level shall be less than 5 pc. Alternatively, Doble (capacitance and dissipation factor) measurements shall be carried out.
  - Each gas density/pressure monitoring device shall have its calibration verified at the prevailing ambient temperature during the final equipment assembly. In addition each device shall have QA documentation to show that the effectiveness of the temperature compensation feature has been verified (this verification would preferably be over the range +20°C to -20°C).
  - Mechanical and electrical testing of bushings and insulators shall be in accordance with ANSI C76.1 and 2.

- **Field Tests**

  Except for the normal operational and timing tests, no other field tests are intended. Requirements for additional field testing should be clearly identified in the tender. The costs of the tests will be considered in the evaluation of the tender. User generally conducts field tests on circuit breakers for special purpose applications.

A5.2.2 Specification (Example B)

- **Routine Tests**

  The following routine tests shall be performed on each circuit breaker to be supplied:

  - *Low-Frequency Withstanding Voltage Tests on Major Insulation Components*

    For gas circuit breakers, low frequency withstand voltage tests for 1 minute shall be made on each phase of the assembled breaker in accordance with ANSI/IEEE C37.09. For other circuit breaker types, the low frequency withstand voltage test procedure shall be subject to the acceptance by User's Representative.
  - *Low-Frequency Withstand Voltage Tests on Control and Secondary Wiring*

    The low-frequency withstand voltage tests on control and secondary wiring test shall be performed in accordance with ANSI/IEEE C37.09.
  - *Electrical Resistance of Current Path Test*

    The electrical resistance of current path test is performed in compliance with ANSI/IEEE C37.09.
  - *Resistors and Heaters Check Test*

    The resistors and heaters check test shall be performed in accordance with ANSI/IEEE C37.09 and shall include verification of correct operation of the thermostats.
  - *Relay and Operating Coil Range Check Tests*

    The relay and operating coil range check tests shall be performed in accordance with ANSI/IEEE C37.09 but including the following:

    - measuring and recording resistance of all relays and operating coils.
    - measuring and recording minimum pickup voltages of all relays and operating coils.
    - energizing all relays and operating coils at 140 V dc for maximum pulse duration for normal operation; no detrimental effects or degradation shall occur.
  - *Grading Capacitor Tests*

    The grading capacitor tests shall include but not be limited to the following:

    - the capacitance of each capacitor unit shall be measured and the value shall be recorded on the nameplate.
    - the dissipation factor at rated voltage and 20°C shall be measured and the value recorded on the nameplate.
    - the partial discharge level shall be measured during the hi-potential test on each capacitor unit; the units shall be discharge-free, <10 pc, at the rated maximum voltage across a complete pole, on reducing the test voltage from the 1 minute withstand level.
  - *Resistors*

    After assembly in the individual interrupter modules, the total resistance value per interrupter shall be recorded. The measured values shall be within the design limits.
  - *Filled Enclosure Tests*

Every enclosure shall be pressure tested to meet the requirements of CAN/CSA standard that applies to the particular design of the enclosure.

A certificate or certificates, identifying each enclosure by serial no. shall be submitted to user's Representative, stating that the enclosure has been designed, constructed and tested to meet the said standard.

- *Leakage Tests*

  The leakage tests shall be performed on all components which are subject to pressure in-service as specified in ANSI/IEEE C37.09.

- *Hollow Insulator Tests (Including Bushings)*

  All hollow insulators shall be routine tested in accordance with IEC 60233, IEC 61462 or IEC 61264 as applicable.

- *Mechanical Operations and Timing Tests*

  The mechanical operations and timing tests shall be performed in accordance with ANSI/IEEE C37.09. Correct operation of the auxiliary switches, position indicators and the anti-pumping service shall be verified. During the timing test, the operating times for O, C, CO and OCO operations at rated control voltage and operating pressure shall be recorded. Travel and motion timing charts shall be provided for each circuit breaker and shall be included with the routine test report and the instruction manuals.

  The final timing tests shall be proceeded by a minimum 150 close-open operations to verify the mechanical integrity of the circuit breaker.

  The method of attachment of the travel sensor for the timing tests shall be the same as the proposed mounting of User's own travel sensor as described in Section 2.11.

  Where tests are made on individual modules, allowances should be made to compensate for the length of all hydraulic and compressed air control and supply piping.

- *Current Transformer Tests*

  Each current transformer shall be tested mounted in place in the circuit breaker.

  Current transformer tests shall be made in accordance with Standard CAN/CSA-C13-M and the results included in the test report.

- *Ratio and Phase Angle Tests*

  Each current transformer shall be tested on all tap positions. The actual primary and secondary currents shall be recorded.

- *Saturation Curve*

  The saturation curve of each current transformer shall be taken. Three check points near the saturation knee shall be taken for each current transformer.

- *Resistance Measurement*

The resistance measurements shall be performed on each current transformer with the "bridge" method. The measured resistance shall be corrected to 75°C.

- *Insulation Test*
  All current transformers and the associated wiring shall be subjected to a 60 Hz, 1 minute insulation test at 2500 V.

- **Conformance Tests**

Conformance tests shall be performed once to demonstrate compliance with particular requirements of the Contract.

- *Operating Coil Current Tests*

The operating coil current tests shall be performed by measuring the current required to operate the closing control device and the trip coil. The current shall not exceed 15 A at 125 V dc per 3-phase circuit breaker and the trip coil shall reset for currents up to 50 mA.

- *Minimum Duration Closing Signal Test*

The minimum duration closing signal test shall be performed to demonstrate that the circuit breaker will close on a close signal of 60 ms duration.

- *Stored Energy System Test*

The stored energy system test shall be performed in accordance with ANSI/IEEE C37.09 to demonstrate that the requirements specified in Subsection – Mechanical Requirements are met.

- *Gas Filled Enclosure Burst Test*

Burst test shall be performed on one enclosure of a particular design in accordance with the procedure prescribed in the CAN/CSA standard for that design.

- **Field Tests**

User's Representative may conduct any field tests considered necessary to prove that the operation of the circuit breakers meet the requirements of the Detailed Requirements.

6 PROJECT CLOSE OUT

6.1 INTRODUCTION

At the end of the project, after successful commissioning of the substation, it is finally handed over to the customer / user.

Typically, at this final stage of the project, a certificate is issued by the customer / user to acknowledge that the substation installation has been satisfactorily completed and taken over. This certificate is commonly called an Acceptance Certificate or Taking-Over Certificate.

Some of the requirements to close out the project include the compilation of project documentation such as drawings, manuals and so on. Other activities would include cleaning up of the construction site.

For the final inspection of the substation facility, a defects list (sometimes known as punch list or snagging list) is generated by the customer / user. The Contractor is then required to rectify all the defects during the project warranty period.

Generally speaking, for any outstanding work that remains after energizing, the progress of completing the outstanding work becomes slower which eventually drags the completion time and cost of the project. Therefore, the cost for outstanding issues in a project cannot be ignored. Furthermore, construction staff is normally required in order to clear the outstanding issues. Hence, the outstanding issue must be finalized while construction staff is still on site.

In summary, quick resolution and expediting the project close out is the most effective approach for cost reduction.

6.2 DOCUMENTATION

Documentation represents the historical account of the project and is the most important aspect of project close out. It is essential that project documents are prepared correctly and compiled in a systematic manner to allow easy retrieval in the future.

Over the life of the project, hundreds or in some cases, thousands of documents such as drawings, specifications, test records, material data sheets, calculations, etc are generated. The important points are when and how such documents can be effectively and precisely finalized with corrections.

3.2.1 As-built documents

Modifications made during construction shall be marked on the relevant document for final updating and incorporated into as-built documents. As-built documents (drawings, calculations, etc) are an integral part of project documentation as they reflect the actual constructed details of the substation installation.

As-built documents are important as the only source of information in the event of future modification or upgrading of the existing substation installation. There have been many cases where as-built documents were not recorded or stored properly. This leads to future problems such as:

- Missing drawings and documents
- Difficulties in future engineering for expansion or modification work
- Inefficient maintenance especially if instruction manuals are not properly provided and maintained.

The majority of respondents to the Questionnaire Item 6.1 agreed that the following documents are required as completion (as-built) drawings:

- Substation plan drawing and layout drawing
- Foundation drawing
- Architectural, civil drawings and calculations
- Earthing drawings and calculations
- Equipment layout
- Power cable layout
- SCADA / Relay Panel layout, manual
- Equipment instruction manual
- AC power supply single line diagram
- DC power supply single line diagram
- Control cable connection drawing
- LV AC/DC calculation
- Power cable current calculation
- Insulation coordination study document
- Assembly drawings for steelwork
- Equipment detail drawings
- Protection and control schematic drawings

As-built documentation is extremely useful and important for modification works; proper as-built records are essential to ensure that modification or extension schemes are correctly interfaced between existing and new equipment. This will reduce potential errors and miss-engineering during modification and extension work.

This as-built drawing must be checked and revised by site project staff before staff is transferred. Every point of checking must be completed by that time. Project print – marked up to be applied, quality assurance, prevent abortive engineering work.

3.2.2 Factory Inspection & Site Test Records

During the course of the project, all of the major substation equipment will be subjected to factory inspection and some of these tests may be conducted in the presence of an independent testing authority or customer / user's representative, so that the condition of the equipment could be confirmed before shipping. Site Test Records are useful as well for confirming the site equipment conditions before completion and energizing substation.

Some of the test data will be compared between the data of factory inspection and the data from site testing to ensure quality control of transportation and site installation were satisfactory. Updating and proper storage of these documents will contribute to minimizing the life cycle cost from strategy maintenance point of view. This has a big influence on cost reduction.

There will not be much difficulty in submitting these documents on time but because these testing activities are mostly repeated items for several projects, each with contractor's experiences, standardization of the testing and document format, etc will contribute to cost reduction and early completion of works.

3.2.3 Instruction Manuals

After handing over of the substation installation, operation staff from the Utility will operate the substation. As part of the operation procedures of the substation equipment, it is essential to provide instruction manuals and training, if necessary, to the operating staff.

Proper instruction manuals coupled with effective training will lead to more efficient maintenance of the substation by operation maintenance staff. This would lead the customer / user to optimize the strategic maintenance plan which will result in a significant cost reduction impact to the Life Cycle Cost. It is important to allocate sufficient time and resources for mutual discussions between owner and contractor about future planned maintenance as instruction manuals are useful only for normal maintenance, not for strategic maintenance.

6.3 SITE CLEAN-UP

Upon completion of the project, it is necessary to clean-up the construction site prior to handing over. Normally, site clean-up is conducted by the Contractor. Planned cleaning up during construction will lead to cost minimization at the project closing out stage.

6.3.1 Temporary office

Temporary offices may have been set up on the construction site area. These should be dismantled and removed upon completion of the project.

6.3.2 Temporary facilities

Temporary construction facilities such as sanitary facilities, temporary generators and water supply facilities should be dismantled and removed. In some instances, it may be possible and more cost-effective to convert the temporary facilities into permanent facilities for the substation. In order to do this, it is necessary to consider the possibility during the conceptual engineering stage.

6.3.3 Construction debris

All construction debris should be removed and disposed of in the safe and approved manner. Minimizing the volume of debris and scheduling the time of removal depend on the planned arrangement.

6.3.4 Others

In some cases, general landscaping such as re-planting of trees is implemented around the substation area and a boundary fence is installed around the substation site. In urban areas, surrounding elements (such as access roads, adjacent properties, etc.) which have been disturbed during construction may be required to be re-instated.

It is good practice to use a pre-commissioning check-list in order to identify any missing items during commissioning. This will save time in the event that missing items are identified during commissioning.

Any out-standing issues and a target completion date are recorded in a defects list.

7 CONCLUSION

This brochure attempts to provide a set of guidelines for effective and efficient design, construction, and commissioning processes in order to minimize re-design, re-work, and multiple checks. It also presents cost reduction opportunities achieved by using pre-engineered, pre-fabricated, pre-tested integrated equipment and installations typical for AIS.

In the first instance WG B3-15 issued a questionnaire to assess the opportunities for optimizing the engineering and construction costs of Air Insulated Substations (AIS). The questionnaire received 24 responses from 18 countries which were used in the preparation of the main body of the brochure. A summary of responses to the questionnaire (include the questionnaire) is included in the brochure.

This brochure provides a range of important information which contributes to optimizing the construction cost of AIS substations from the conceptual engineering stage to project close-out as follows:

- Design process, e.g. standardization and consistency in the use of standards, maintainability and constructability issues, use of new design/drafting tools, use of new technology equipment (major equipment, integrated equipment) , etc.
- Construction process, e.g. use of modern equipment, construction methods, quality control of workmanship check lists, etc.
- Procurement process, e.g. development of detailed technical specifications, prequalification of suppliers, establishment of strategic alliances and blanket purchase orders with suppliers, etc.
- Construction process, e.g. construction method, site logistics, transportation, construction quality control, as well as outage management.
- Test and commissioning process, e.g. elimination of duplicated testing, well documented commissioning check lists
- Project close out, e.g. documentation and site clean-up

An engineering checklist that picks up important points from the design process through to project close out, as discussed in the brochure, is included as a practical aid for substation construction projects.

A number of case studies are also included in the brochure to show how cost reductions have been achieved in practice by various utilities.

The authors of the brochure believe that it will provide the reader with a practical overview of the issues influencing the cost of substations and how these costs can be controlled.

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Appendix A: ENGINEERING CHECKLIST (for COST REDUCTION OF AIS)

This check list has been arranged for the following purpose.

(1) As one of the tools for easier understanding and applying engineering checks to initial planning / design stages of the project.

(2) Description of check points have been compiled by using the same sentences written in the brochure with reference chapter and clause No.

(3) Select the Check items with describing Focus Points, if any for your project.

(4) As for the column of Result, categories of 1st check and Approval check are just examples and depend on the user's actual organization.

This document has been prepared for User's own brain storming about how to use this brochure, for example planning of check items, finding non checked items and way of thinking in order etc., for real cost down projects. And our WG B3.15 expects that this check list will be updated, revised and improved by Users in line with their own practice.

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
1	-	Do you understand that "**Earlier actions** in initial stage, more effective and easy as cost reduction approach"?				√	√
2	PREFACE	The objective of this Working Group (WG) was to produce a set of guidelines for effective and efficient design, construction, and commissioning processes to **minimize** the need for **re-design**, **re-work**, and **multiple checks**.				√	√
3	1	Cost reductions starts with the conceptual engineering and savings can be achieved by selecting the **most appropriate single line diagram**, by selecting the **most cost effective equipment** and by using **standard design** solutions to the maximum **extent possible**.				√	√
4	1	All this while making sure that **customer reliability**, **constructability**, **extendibility**, **interchangeability**, and **maintainability** requirements are met.				√	√
5	1	The content of major equipment specifications plays another important role in controlling the cost of substation construction. Such as **detailed technical specifications**, **prequalification of suppliers**, establishment of **strategic**				√	√

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
5 cont.		**alliances** and **blanket purchase** orders and **rigorous factory** and **site acceptance** tests.					
6	1	The selection of the overall philosophy of **how to manage the project**. There a number of solutions available, ranging from the totally **turnkey** approach to the totally **in-house** approach with significant impact on the **cost**, **quality** and **timely** completion of the project.				∨	∨
7	2 / 2.1	Check the following factor's **impact** "**safety codes**, **environmental** and **local regulation**, power supply capacity enhancements **from new power suppliers**, **short circuit** levels, **system control** and **operating** requirements, and **reliability**, **operability**, major **repairs**, **spare** parts availability, and availability of **suitable skills**".				∨	∨
8	2 / 2.1	Check the following points already **considered** "**design reviews** at all key stages, **life-cycle**, the **practicality** of construction, standardization to the maximum **extent practical**, **readily interchangeable** with alternatives, future **extension** and **replacement**, **quality** control, **accelerated** construction, provision for as much **early design**, **off-site manufacture**, **pre-testing** and **pre-commissioning** as possible".				∨	∨
9	2 / 2.2	The concept design should reflect business development and maintenance strategies of the network operator.				∨	∨
10	2 / 2.2	Consider the following points to the **concept design** "network **load development**, **environmental** and **societal** concerns **noise** emission, protection of **ground and water** resources, **safety**, **visual impact**. The availability of **suitable land** and **its cost**. **Actual** and **future loads** define **voltage** levels, transformer **capacities**, nominal **currents** and **shorts circuit** levels. The **number of bays** needed, **bus bars**, bus bar **intersections** and **bus-couplers**. Additional **space for future** extensions.				∨	
11	2 / 2.2	**Financial tools** such as **cash flow** analysis and				∨	∨

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		consideration of **risk management** should be applied **when weighing alternatives**.					
12	2 / 2.2	Check the specifications can cover follows. • Communication **interfaces** • **Local and remote** control • **Bay protection** schemes • Station building **layout** • Working **clearances**, connections for portable earthing equipment etc. • Station **lighting** • **Earth grid** design, lighting protection • **Documentation** requirements				V	
13	2 / 2.2	Check the above specifications to assure **adequate functionality**, **operability** and **maintainability**, to cover all items having a relevant impact on **life-cycle cost** and **standardization**. If detail engineering is given to a contractor the specifications must be more rigid, i.e. **detailed and measurable in quality**.				V	
14	2 / 2.3	Incorporation of standardization, repeatability, and extendibility aims at **reducing the project duration and overall cost**, in order to provide a high operating reliability.				V	V
15	2 / 2.3.1	Challenge the following goals by standardization. • Allows the asset owner's design philosophy to be **rigorously applied to each new asset** • Leads to the use of **a common set of primary and secondary** equipment • Permits the production of **common design templates** • Minimizes **spares** holdings • Minimizes required **skills** • Reduces the **risk** of operator				V	V
16	2 / 2.3.1.1	As for Single Line Diagram, the following point to be				V	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning: Check Required	Planning: Not Necessary	Focus Points, if any.	Result: 1st check	Result: Approval check
		standardized. • Location of the **earth switch** on **disconnectors** • **Current transformer** location, **ratings**, and number of **secondary cores** • The **control**, **metering** & **protection** philosophy to be adopted ".					
17	2 / 2.2.1.2	Check the following for switching scheme. • System **reliability** • System **operation** • Ease of **maintenance** • Limitation of **fault level** • Simplicity of **protection** system • Ease of **extension** and **replacement** • Availability of **land** • **Cost** • Position and **number of cores** of current transformers • Type of **disconnectors** used • **Bay** width • Single level or **multi level** switchyard • Types of equipment **support** structure and **gantry** structure • Shape of **plot** available **for substation and feeder orientation**				∨	
18	2 / 2.2.1.3	Are the following calculations already standardized ? • **Short circuit** forces • **Earthing** design • **Temperature** rise • **Conductor Sag** and **tension** • **Wind force** • **Battery sizing** • **Shielding design** • **Insulation coordination** • **Audible sound** level				∨	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning: Check Required	Planning: Not Necessary	Focus Points, if any.	Result: 1st check	Result: Approval check
18 cont.		• **CT / VT** Application • **Illumination**					
19	2 / 2.3.1.4	Are the following basic factors already specified for structural calculation ? • **Static** loads • **Short-circuit** forces • **Wind velocity** / wind loads • **Seismic** forces • **Snow** and **ice** loading • Bus bar **height**				√	
20	2 / 2.3.1.4	If structures are standardized for the highest wind velocity, cost-effectiveness is adversely affected for **sites in relatively low wind zone areas**.				√	
21	2 / 2.3.1.4	The optimum solution may be to **combine several wind zones** and **create a few variants** of the **structure** design for a given **voltage level** / **bus configuration**.				√	
22	2 / 2.3.2	Is optimization attempted for the following. • **Switch yard** area • **Earthing** • **Layout** • **Cable** philosophy • **Structural** and **civil** quantities				√	
23	2 / 2.3.2	Are the following ideas already checked ? • **Bay Width** Reduction • **Multilevel** Switchyard • Design optimization for **Earthing** • Reduce the value of the **short circuit** forces • Reduction of the effect of **seismic** loading • Reduction of structure and **civil** loading • **Conduits** compared to RCC cable trenches				√	
24 24 cont.	2 / 2.3.3	**Design repeatability** is a crucial issue in achieving a cost reduction through savings in **execution time** (covering engineering, procurement and construction) and is an				√	√

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		extension to **standardization**.					
25	2 / 2.3.4	A comparison of different schemes, the reliability calculation is finished.				V	V
26	2 / 2.3.5	**Extension to an existing** substation needs **a lot of care** to ensure **safety**, because the existing system is **energized**. Many **diverse techniques** may be employed in order to **curtail additional cost** and ensure **reliable supply**.				V	
27	2 / 2.3.6	Check the following points for Interchangeability. • Interchanging equipment with the **same parameters** but from **different manufacturers** • Replacement by upgraded equipment in order to meet **future higher transmission capacity demands** and to **increase** the **short-circuit withstand ability** of AIS elements				V	
28 28	2 / 2.3.7	Check the following points for **constructability**. • **Substation civil** design – foundations of support and towers, cable ducts, earthing grids, and drainage • Substation **technological design** – individual devices and their pre-fabricated units, cable systems, protection and control systems, access for lifting and other mechanisms • Substation **layout design** – location (buildings) of substation components (auxiliary power supply, protection and control systems), location of cable ducts, internal roads and areas for transport, erection and maintenance, location of local lighting, location of lightning protection components, fences and physical protection in general • Optimization of **a method of site work** • Appropriate **foundation construction** • **Underground water level**, drainage of underground, distance from water streams and rivers. • **Climatic** conditions • Permitted **emission limits** at the construction site and other special **environmental protection** requirements				V	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
cont.		• **Seismic** conditions, influence of plants, insects and animals, local air pollution, etc.					
29	2 / 2.4	At the start of each new contract, representatives of the disciplines involved in a project should **perform a review of the specifications and requirements** and determine the level and method of quality planning implementation necessary to meet the specific quality requirements.				V	V
30	2 / 2.5	Check the following requirements for possible accelerated completion. • Pre-**engineering** • Pre-**fabrication** • Pre-**testing** • Pre-**commissioned**				V	
31	3 / 3.1	**Procurement** process is the most obvious **target for** extraction of **cost reductions**. However, to obtain **maximum benefits**, every aspect of this process must be subjected to a **thorough review**, **policies** and **procedures**.				V	V
32	3 / 3.1	There are **two** major approaches. • Tendering the project as a whole package, with the turn-key supplier – **called here "package"** • The utility selects and purchases the major equipment – **called here "free-issue"**. While the **first** approach can result in **lower overall costs**, the **latter** has the advantage of retaining **tighter control over the quality of equipment** supplied, personnel **safety** and **future maintenance costs**.				V	V
33	3 / 3.1	**Prequalification** of suppliers will result in **limiting** the number of **submissions**, thus **cutting** the engineering and contract administration **costs of evaluating** too many tenders.				V	
34	3 / 3.1	A **thorough review** of the technical specifications can result in **significant savings via adopting new technologies** or a **revision of the requirements** to better reflect the **actual conditions at site**.				V	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
35	3 / 3.1	Setting up **long term Blanket Orders** for major equipment **saves the cost of repetitive engineering** and **procurement efforts**.				∨	
36	3 / 3.1	**Streamlining the drawing approval** process will also harvest **significant savings** in **engineering** and **contract administration hours**.				∨	
37	3 / 3.1	**Factory inspection** and **test witnessing** will allow a **reduction of the commissioning effort**, with associated lower costs.				∨	
38	3 / 3.1	A **proper selection of warranty** coverage can **significantly** reduce in-service **expenditure in the event of failure**.				∨	
39	3 / 3.3	**Prequalification** of Suppliers, this activity should be performed **well in advance of the start of the Procurement Process** and involves two distinct steps: **technical** prequalification and **commercial** vetting.				∨	
40	3 / 3.4	The **technical review** should be performed with **particular emphasis to the equipment ratings** required and the **latest information regarding recent field performance of similar equipment** and **new developments**.				∨	
41	3 / 3.5	**Long term contracts** save **Engineering** costs, by **removing the need** for **repeated technical reviews** of the specifications, **evaluation of tenders**, **type tests**, **repeat drawing approval process**.				∨	∨
42	3 / 3.5	**Such contracts** save **tendering costs** to the utility and the supplier, which are then able to **pass such savings back via lower prices**.				∨	∨
43	3 / 3.5	**Long term contracts** intensify **competition** among suppliers and **result in lower costs**.				∨	∨
44	3 / 3.5	**Long term contracts** allow a degree of equipment **standardization**, thus resulting in **reduced** requirements for **spare parts**, **standardized maintenance practices** and ultimately **lower life-cycle costs** for the equipment.				∨	∨
45	3 / 3.5	**These contracts** significantly reduce **the delivery lead time to site**, by allowing the sometimes **lengthy procurement**				∨	∨

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		process to be completed **well ahead of the planning** for **new** substations or the **replacement** programs.					
46	3 / 3.5	The utility's internal planning process should ensure that **new long term** contracts be initiated and placed shortly **prior to expiry of existing** ones.				V	
47	3 / 3.5	The **request for tenders** should also contain the required **validity period for the tender**. As such period should be **sufficient to allow for a thorough tender evaluation**, yet **not exceedingly long**.				V	
48	3 / 3.6	The Form of Tender should be structured in such a way to allow for clear pricing, including if necessary **any escalation over the period of the contract**, and **any foreign exchange variations** as applicable for **major spare parts** and that such prices should be **valid for the life of the contract**.				V	V
49	3 / 3.6	The **Form of Tender** should contain space for **any exceptions** – **commercial** or **technical** – that **suppliers may want to file**, and space for date, seal and signature by authorized company principal.				V	
50	3 / 3.6	A **comprehensive agenda** for the **meeting** should contain both **technical** and **commercial** issue to be discussed, and **key participants notified well in advance**, to prevent no-shows.				V	V
51	3 / 3.6	The **minutes** of the meeting should record **all agenda points discussed** and the required **action/follow up**. The agenda and minutes must become **part of the contract**, for future reference.				V	
52	3 / 3.6	Requests for **extension of tenders' validity** can **result in** revised terms and conditions, **an unwanted complication**.				V	V
53	3 / 3.6	**Terms of delivery** for major equipment are **very important** and all associated conditions must be included. The advantage of **placing the risks** onto the contractor **(who is most knowledgeable about such risks)** must be				V	V

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		considered as part of the evaluation process.					
54	3 / 3.7	**The process of drawing approval** must be thoroughly organized and the **schedule for submissions** and **approval** of drawings **monitored closely**, as they have a direct **impact on the manufacturing**, **delivery** and **completion** of **the project**.				V	V
55	3 / 3.7	Thorough **records of submissions**, **corrections** and **approvals** must be **kept**. The accountable engineer must carefully check that **all previous comments** and **corrections** were **incorporated** into the **final** submission, **before** they are stamped as **approved**.				V	
56	3 / 3.9	The **warranty coverage** must be **clearly stated** in the terms and conditions of the contract. Such issues as **cost of transportation** to and from manufacturer's plant, cost of **dismantling** and **re-installation**, cost of **utility personnel assisting in the process** (switching, grounding, etc.) must be **clearly assigned**.				V	V
57 57 cont.	3 / 3.9	**Manufacturers** will often **offer extended warranty at an additional cost**. Essentially, accepting such extended warranties should be done **on the bases of a risk evaluation**. **The factors** that come into play **in such evaluations** are: • **Manufacturer's reputation** on quality • **Long term performance** track record • **Duty** for which the equipment will be used • **In-house capability** • Availability of **spare parts** • **Duration of the extended** warranty • **Cost** of extended warranty				V	V
58	3 / 3.9	Occasionally, in very competitive situations, **some manufacturers** will negotiate **"free" extended warranties** for a larger slice of the business being tendered. **Another** common offer may involve "free" extended warranties **on condition the equipment is commissioned by the**				V	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		manufacturer. In such case, the **cost of erection supervision** (which often is expensive) must be **factored into the evaluation**.					
59	4 / 4.1	The approach to **cost reduction** of AIS should **concentrate** on minimizing **construction time** and eliminating **mis-sequencing of construction** activities. This could be achieved by **standardization of design** and construction **processes** and **methods**.				∨	
60	4 / 4.1	Are the following points already checked. • **Site preparation** / **Logistics** • Equipment **foundations** • **Control buildings** • Equipment **support structures** • **Delivery** of equipment • **Unloading** and **unpacking** • **Erection** of substation equipment • Installation of the **balance of plant** such as LV systems and connecting cablings				∨	
61	4 / 4.1	As part of the effort to optimize and reduce AIS construction costs, several important factors must be considered as follows. • **Accurate** and **detailed engineering**. • **Availability of material**. • **Experienced** and **well trained** construction **crews**. • **Time available for construction** and **coordination with operation**.				∨	
62	4 / 4.1	An **error in the engineering** will result in construction **delays** and **higher cost** for substation construction. Some of the common engineering **errors are listed below**. • Selecting **complex bus arrangements** • Use a **complex design** • **Miss coordination** between the substation and overhead line design				∨	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning: Check Required	Planning: Not Necessary	Focus Points, if any.	Result: 1st check	Result: Approval check
		• Failure to **verify electrical clearance** requirements • Specifying the **wrong material** for the substation • Designing an **over loaded** relay rack • Specifying the **wrong equipment rating** It is highly recommended that **all required material** be on hand **before the start of construction**. A missing piece of hardware can stop the construction process. **All material** must be **verified**, **organized** and **stored in a proper place for easy access**.					
63	4 / 4.1	It has been found by experience that, when **construction people provide input to engineering** and verify the constructability of the engineering plans during the design process, many errors can be **prevented resulting in reduced construction costs**.				V	
64	4 / 4.1	When the construction is associated with an **existing substation expansion/addition**, **coordination** of work activities with substation operation is **very important** in order to prevent delays due to **inability** of **construction** to work on part of the substation. Construction must be aware of the **additional work** that may require **minimizing the outage time**.				V	
65	4 / 4.3.1	The Utility has several options to **define the delivery of major equipment** for the project such as: • **On time** delivery • **Storage at the Manufacturer's site** • **Storage by the Utility**				V	
66	4 / 4.3.3	The main purpose of the **schedule** is the **coordination** of the progress of **civil** engineering works with the dates of **equipment delivery**. The **task** of the contractor is to **ensure** conditions are appropriate for **temporary storing** of the apparatus. In order to **reduce costs**, deliveries are so **coordinated** with the **progress of works** that the apparatus is **installed directly** after supply.				V	
67	4 / 4.4.1	A project **transportation plan** should include as a minimum,				V	

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		the following components: • **Freight instructions** / **specifications** • **Pro-forma packing lists** • **Nominated** freighting and forwarding **companies** • Procedures for **shipping release** • **Route** of land transportation • **Unloading procedures** • **Heavy lifting plan** for bulky consignments / cargo • **Timing** of freight and delivery					
68	4 / 4.4.1	In addition, transportation **restrictions** may occur due to the **physical size of equipment**. In such a case, utilizing a **standardized design** or a **special design** could overcome transportation restrictions. This is **especially** important for transportation of **large transformers and switchgear**.				∨	
69	4 / 4.5	**Quality** of **construction** is one of the **key areas** where **cost can be reduced** by **minimizing** construction **errors** and **deviations**.				∨	
70	4 / 4.5	Most utilities have a **standard practice** / **procedure** to **evaluate** construction **deviations** from the design. In general, any construction deviation **has to be reported by site inspection teams** and **approved by design engineering teams**. This ensures that **all deviations** are **properly recorded** and **evaluated before the deviation is approved**.				∨	
71	4 / 4.5	A **formal feedback** process is available **in their organization** to learn from the **experience of site** construction. This is normally in the form of working groups or project design review, which is conducted upon completion of the project. In such instances, it is **important to include the site construction staff in the review process**.				∨	∨
72	4 / 4.6	Must try to **minimize the outage** during the construction period.				∨	∨
73	5 / 5.1	Basically, **the tests** on a substation component can be				∨	

<table>
<tr><th rowspan="2">Check Item No.</th><th rowspan="2">Reference Chapter / Clause</th><th rowspan="2">CHECK POINT</th><th colspan="2">Planning</th><th rowspan="2">Focus Points, if any.</th><th colspan="2">Result</th></tr>
<tr><th>Check Required</th><th>Not Necessary</th><th>1st check</th><th>Approval check</th></tr>
<tr><td></td><td></td><td>classified with reference to the materials, subcomponents, or the whole unit, namely:
• Sample Tests
• Design Tests
• Type Tests
• Factory Routine Tests – FATs
• Site Acceptance Tests – SATs (commissioning tests)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>74</td><td>5 / 5.2</td><td>A search for a possible tests optimisation should consider the role of the different tests, to this respect, two approaches can be taken, namely:
(1) Avoiding duplication of the same test in different phases of the life process
(2) Arranging for the on-site tests a tests grouping and planning a tests sequence aimed at optimizing the daily working shift(s) available for the tests (optimization of the testing time).</td><td></td><td></td><td></td><td>∨</td><td>∨</td></tr>
<tr><td>75</td><td>6 / 6.1</td><td>The cost for outstanding issues in a project cannot be ignored. Furthermore, construction staff is normally required in order to clear the outstanding issues. Hence, the outstanding issue must be finalized while construction staff is still on site.</td><td></td><td></td><td></td><td>∨</td><td>∨</td></tr>
<tr><td>76</td><td>6 / 6.2</td><td>Documentation represents the historical account of the project and is the most important aspect of project close out. It is essential that project documents are prepared correctly and compiled in a systematic manner to allow easy retrieval in the future.</td><td></td><td></td><td></td><td>∨</td><td></td></tr>
<tr><td>77</td><td>6 / 6.3</td><td>Planned cleaning up during construction will lead to cost minimization at the project closing out stage.</td><td></td><td></td><td></td><td>∨</td><td></td></tr>
<tr><td>78</td><td>7</td><td>This brochure provides a range of important information which contribute to optimizing the construction cost of AIS substations from the conceptual engineering stage to</td><td></td><td></td><td></td><td>∨</td><td>∨</td></tr>
</table>

Check Item No.	Reference Chapter / Clause	CHECK POINT	Planning		Focus Points, if any.	Result	
			Check Required	Not Necessary		1st check	Approval check
		project close-out as follows. • **Design process** • **Construction process** • **Procurement process** • **Construction process** • **Test and commissioning process** • **Project close out** An engineering checklist that picks up important points from the design process through to project close out, as discussed in the brochure, is included as a practical aid for substation construction projects. A number of **case studies are also included in the brochure**. **The authors** of the brochure **hope** that this brochure will **provide** the reader with a practical **over view** of the issues which **influence the cost of substations** and how these **costs can be controlled**.					

APPENDIX B CASE STUDIES

B.1 OPTIMIZATION IN STRUCTURE DESIGN BY STANDARDIZATION OF WIND ZONE (INDIA)

In India, the entire country is divided geographically into six wind zones. Three designs can be developed for those utilities and industry customers who do not have standardized structure designs and drawings by combining Zone-1 and Zone-2 by considering the Zone-2 velocity. A similar approach can be made for the remaining zones.

Zone	Wind Speed (m/sec)
1	33
2	39
3	44
4	47
5	50
6	55

Most Indian utilities now provide the standardized structure documentation specific to voltage level and bus arrangement. This kind of standardization of structures helps tremendously in the engineering, procurement and installation process. Initially it seems that standardization incurs additional costs; however it aids in reducing the project execution time and the overall project cycle, thereby improving the cash flow.

If the structure drawings and designs are available in standardized form it assists in the following ways:

- Input details are available to commence civil engineering at the project start.
- Weights and member details (detailed bill of materials) for lattice structures are available for procurement of steel.
- The entire documentation required for structure fabrication (including fabrication drawings for individual members) is available to start manufacturing quite early, reducing the total cycle time of the project.
- With the as-built documents available (duly corrected, based on site feedback), construction is quicker and flawless.

If designs and drawings are unavailable there is a series of activities to be undertaken before structural and civil engineering design commences for a substation. These include the following activities (1) - (8):

(1) Preparation of a layout plan drawing
(2) Sag tension calculation

(3) Short circuit calculation
(4) Wind pressure calculation
(5) Approval time for above calculations
(6) Design of the structure
(7) Preparation of fabrication drawings / Commencement of civil works
(8) Approval of structural design and drawings

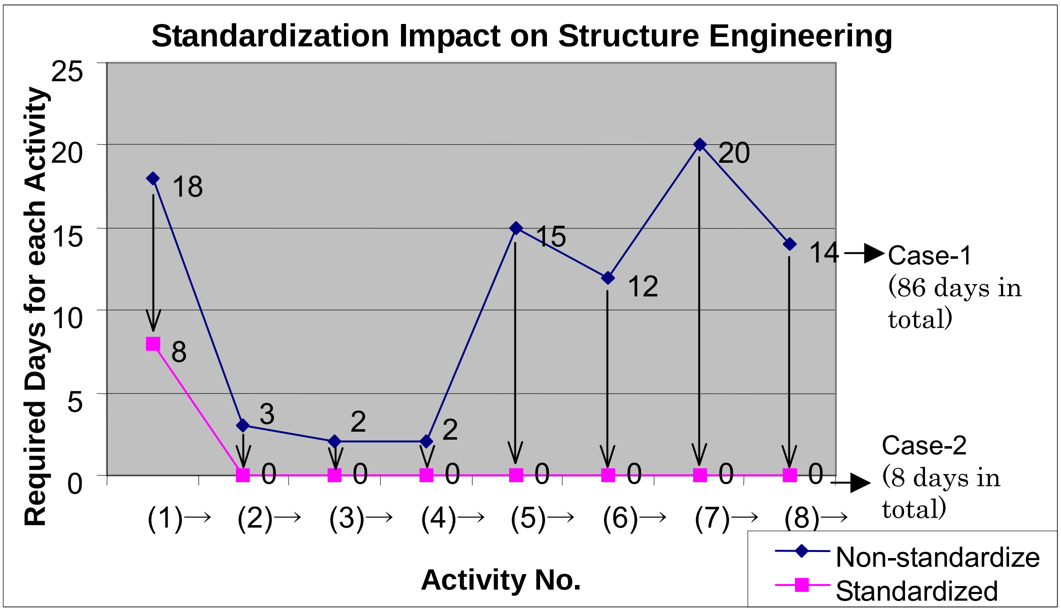


Figure B-1-1: Improvements in Structure Engineering Through Standardization

A typical example showing the advantage of structure standardization is shown in the above graph. The X-axis denotes the Serial No. of the activities while the Y-axis shows a typical time frame taken to complete the activities. It is clear from the above graph that total time taken from preparation of the layout plan drawing to commencing structural fabrication activities is typically 86 days; if the same is standardized then the fabrication activities can start just after finalization of the plan drawing (8 days).

Example: Using the above projection and assuming the man hour cost is $25/hour (approx) and the working day is 8 hours, then:

Case – 1 Cost incurred without standardization

Total Cost = Number of days x Number of hours per day x Cost per hour

= 86 x 8 x $25

= $17,200

Case – 2 Cost incurred with standardization

Total Cost = Number of days x Number of hours per day x Cost per hour

= 8 x 8 x $25

= \$1,600

Many electrical Utilities have standardized their layout and type of gantry structure; in this case fabrication activities can be started as soon as the standardized drawings are received. This greatly assists in expediting fabrication activities and results in flawless fabrication. The resulting shortened project timeline leads to a reduced project cost.

Similarly, as is seen from the above graph, once the structure design is completed the site can be mobilized and civil works can commence. In the case of a standardized structure where no design is required, civil activities can commence as soon as the layout is finalized. This can lead to a substantial saving of time, cost and overall manpower.

B.2 MULTI LEVEL SWITCHYARD TO REDUCE LAYOUT PLAN (INDIA)

As shown below for a low bus profile, the area occupied is 49m x 12m while a high level arrangement occupies 27m x 12m. An example of this is a 132kV substation where the land development cost had to be reduced. A multilevel switchyard was constructed to reduce the substation cost. As can be seen from the given example the required area was reduced from 588 m2 to 300 m2, a reduction of nearly 288 m2 (approx. 49%).

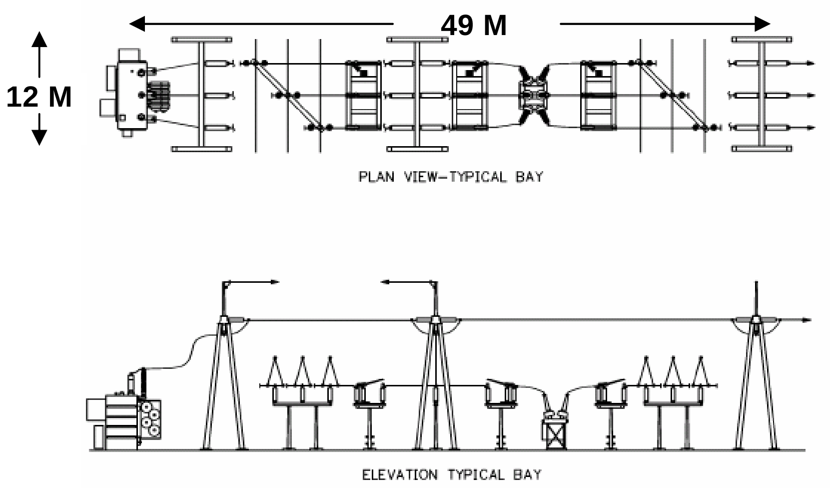


Figure : B-2-1 Low Bus Profile

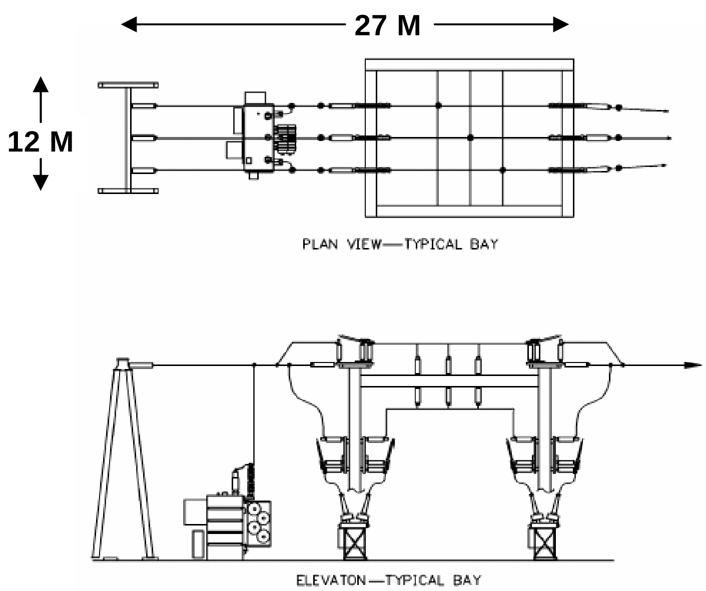
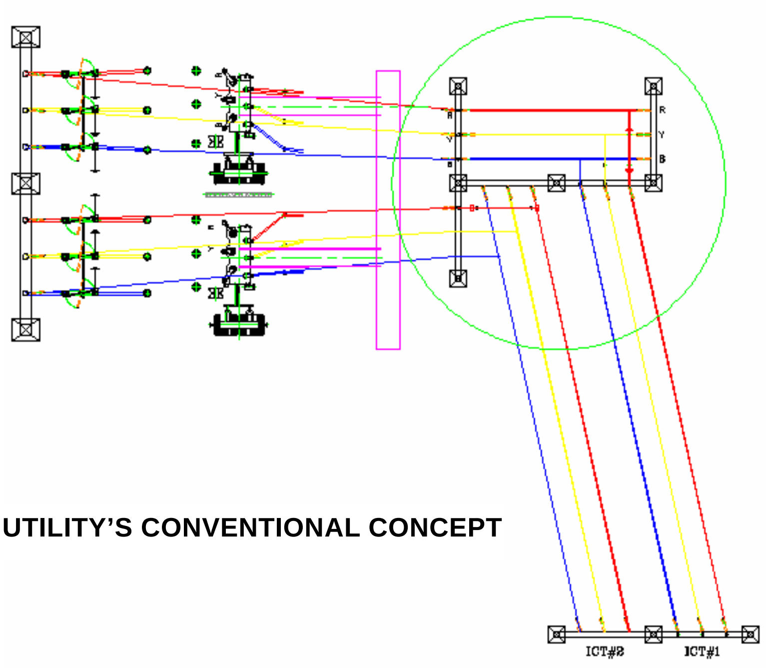


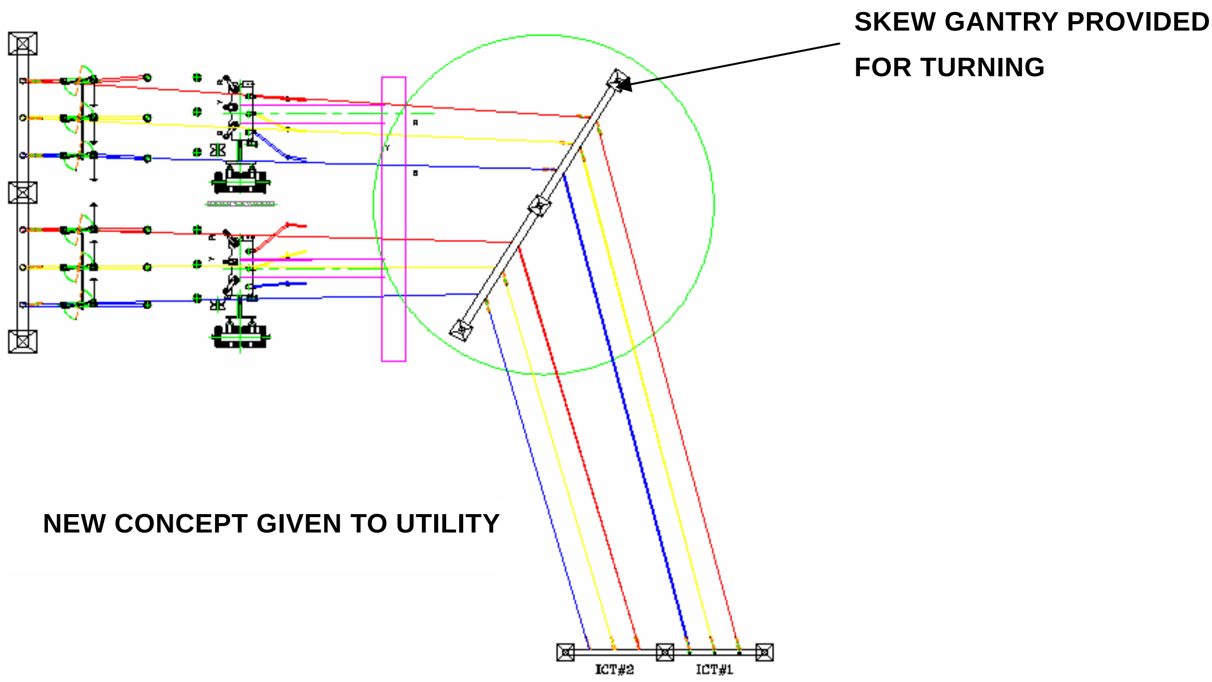
Figure: B-2-2 High Bus Profile

This not only reduced land development costs but also assisted in reducing the cost of earthing, crushed rock surfacing, and lighting. In designing this type of multilevel switchyard, care needs to be taken to ensure that the required electrical clearances are maintained.

B.3 Optimization of Incoming/ Outgoing Structure Design (India)

An example of this is shown below. At one of the 400/220kV projects there was a 90 degree bend in-between one voltage level and another voltage level. The customer's conventional layout required 6 towers and 5 girders for deviation of the LV side of two 400/220kV autotransformers. The same was accomplished by using skew gantries which included 3 columns and 2 beams.





B.4 Use of Automated Computer Aided Engineering Tools for Substation Electrical Installation (Ireland)

B.4.1 Introduction

While examining ways to reduce cost for a large construction program in Ireland the area of optimising design efficiency was examined. Following this analysis it was decided to move to an intelligent software package to complete the entire secondary electrical design for HV substations which would automatically produce wiring details, cable schedules, connection details and materials lists.

This has the effect of significantly reducing design costs and minimizing design time, while retaining in-house design expertise and keeping full control of systems and materials used on the HV network.

B.4.2 Initial Preparation

For this transformation to be successful several preparatory steps were required:

- A complete set of generic design standards were created with common structures and layouts.
- Creation of elementary design drawings detailing requirements for protection/interlocking schemes etc.
- A training program was required for designers on new software.
- A training program for clients on the change in design format
- Implementation of a trial project.

B.4.3 Decisions Taken

The following approach was adopted as standard for electrical substation designs:

- One file was created for a complete substation, fully integrated production of wiring tables, cable schedules, materials lists etc for the entire station.
- The structure of design was based on the physical location of devices i.e. schematic drawing reflected physical location (e.g. 110kV CB to have its own section in drawing) to facilitate changes of equipment, modifications to devices without impacting on other areas of the scheme.

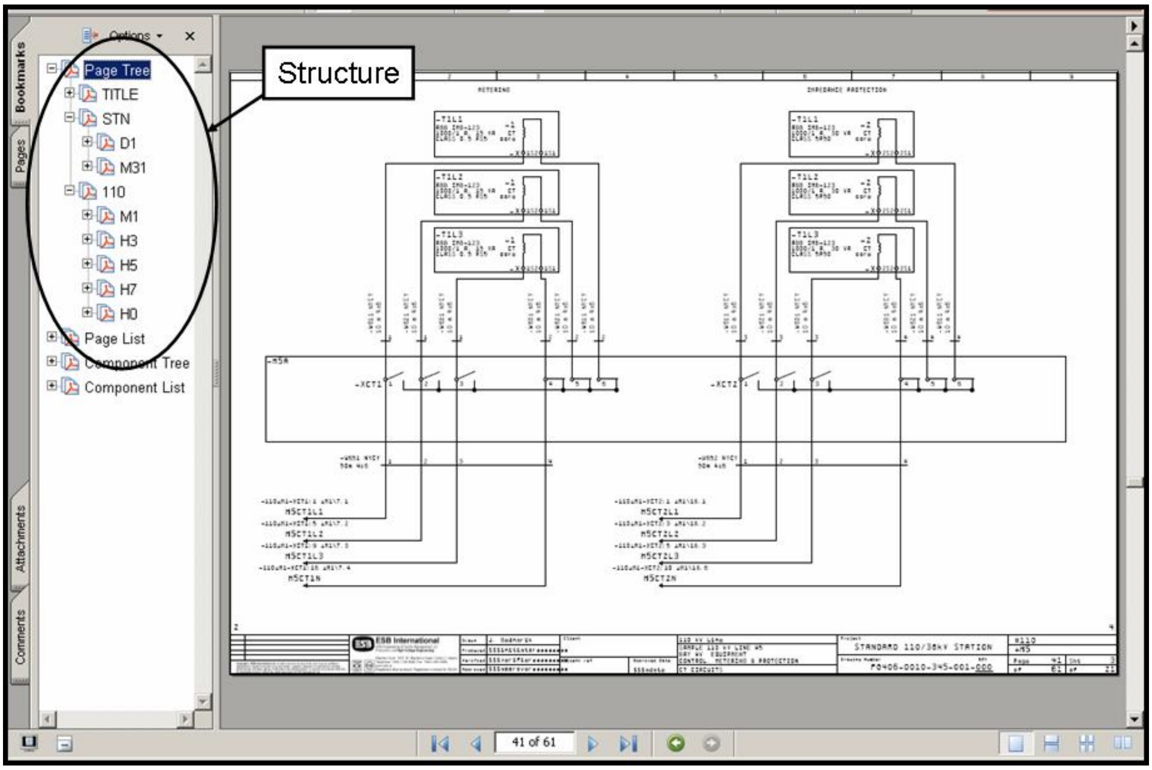


Figure B-4-1: Screenshot Highlighting Structure of Design

Figure B-4-1 shows a typical example of the structure for 110kV substation design in pdf format. This example represents the bay schematic drawing element of the project. The sheet shown has CT wiring details for 2 cores and shows the cables to the protection cabinet.

B.4.4 Advantages

The primary advantage of using an intelligent design tool is a dramatic reduction in design time when compared to traditional approaches using 'manual' CAD tools (~ 70%).

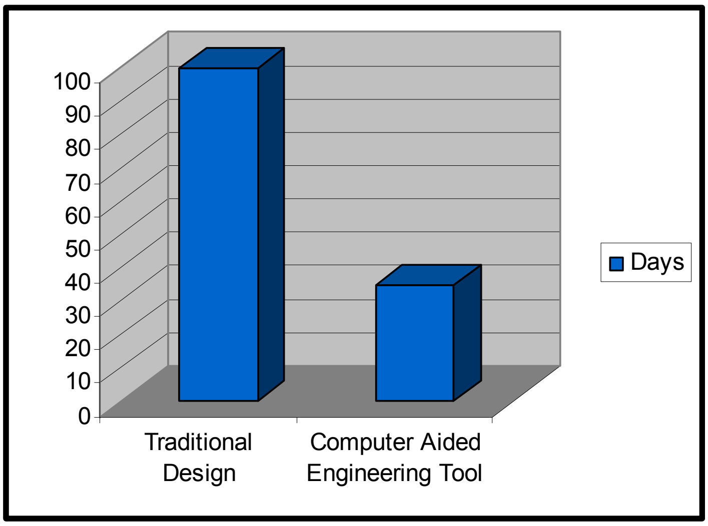


Figure B-4-2: Estimation of Time Saving for Full Electrical Design of HV Station

Figure B-4-2 shows the estimated design time saving when the automated design tool is used with standard design templates for a large HV station.

This system also minimises / eliminates cross referencing ‘human’ errors when compiling wiring tables, cable schedules, material lists etc. The following items are generated automatically from the schematic diagrams:

- Cable Schedules
- Wiring Details
- Materials Lists
- Bill of Material

The format of cable schedules and wiring tables may be designed to optimise efficiency during installation.
The system allows for full integration of design into one structured file containing all secondary system information for the entire substation.
The system also allows for ease of integration of new equipment in to designs (e.g. integration of new HV CB into standard design templates can be done very quickly)

B.4.5 Disadvantages

There is a high initial overhead to produce generic templates and train staff for proficient use of the software package.

There can also be some hesitance from other stakeholders (such as contractors, commissioners etc) to accept new structure of designs. The ‘paper’ size of the designs required for large substations can be difficult to manage, this can run in to thousands of sheets of generated wiring details.

There is increased complexity with one file containing the total electrical design package for the substation. Issues such as design revision management, must be carefully managed, particularly if there are several designers working on the project.

In order to maximize benefit of this tool a rigid set of standards must be used to ensure transparency and inter-compatibility across designs. Conversely this can be regarded as an advantage ,driving a single design standard to be used throughout all projects

There may also be possible compatibility issues, a dependence on the software manufacturer due to the high cost of switching to another package. However it is possible, in some cases, to convert a file from one package to another.

B.4.6 Cost

The cost of implementation of this tool is dependant on the following:

- Structure of design department (number of designers who will use software)
- Software itself (initial and yearly licensing costs)
- Training requirements (for both designers and consumers)
- Development/Conversion of generic templates
- Introduction of a requirement for location of permanent PCs in substations

These factors must be analysed against the quantity of similar substations to be constructed in the near future and the strategic direction of the utility in question with regard to in-house design capability.

B.4.7 Conclusion

The use of an automated electrical design tool has been successful in Ireland. It has resulted in an estimated 70% saving in design time for the substation secondary electrical systems (when compared to manual CAD methods), a reduction in design errors and increased control of design standards used. It has also reduced the time required to introduce a new element of plant in to generic designs following changes in purchasing agreements.

This approach is recommended for any utility with a dedicated design section and a non-Turn Key substation construction program.

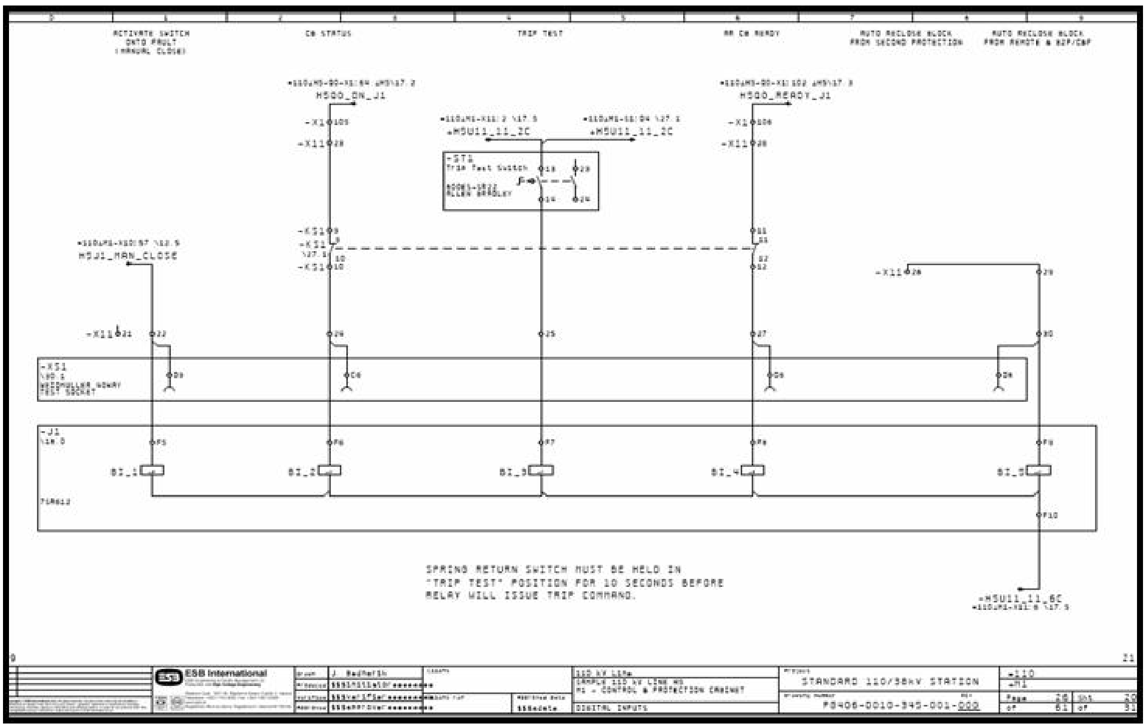


Figure B-4-3: Screenshot Example of Design

B.5 Lowering LIWV by Applying a High Performance Zinc Oxide Surge Arrester (Japan)

In Japan, "Guide to Lighting Protection Design of Power Stations, Substations and Underground Transmission Lines" was published, and this guide summarized various studies and methods to conduct precise analysis by using EMTP (Electro Magnetic Transients Program).

B.5.1 Application of High Performance Surge arrester

These days, the development of a new type of ZnO Surge Arrester (SA) for GIS achieves a lower discharge voltage than that of the former type of SA. Thus, the introduction of this high performance SA can suppress lightning overvoltage, resulting in a situation where lower LIWV (Lightning Impulse Withstand Voltage) equipment can be installed. In this way, in Japan the LIWV of 550kV GIS was reduced from 1800kV to 1550kV, 1425kV or 1300kV.

Recently, a porcelain high performance SA was developed, so the LIWV of AIS can also be reduced.

B.5.2 550kV AIS Configuration

Figure B-5-1 shows the AIS model. For easy analysis, the model configuration is generally one-line-one-bank. Figure B-5-2 shows the result at the power transformer. On the one hand, when the SA discharge voltage (V10kA) is 1220kV, the lightning over voltage is 1500kV. Thus the preferable LIWV of a power transformer is 1550kV. On the other hand, when V10kA of the SA is 870kV, the lightning over voltage is 1250kV; thus the LIWV of a power transformer can be reduced from 1550kV to 1300kV.

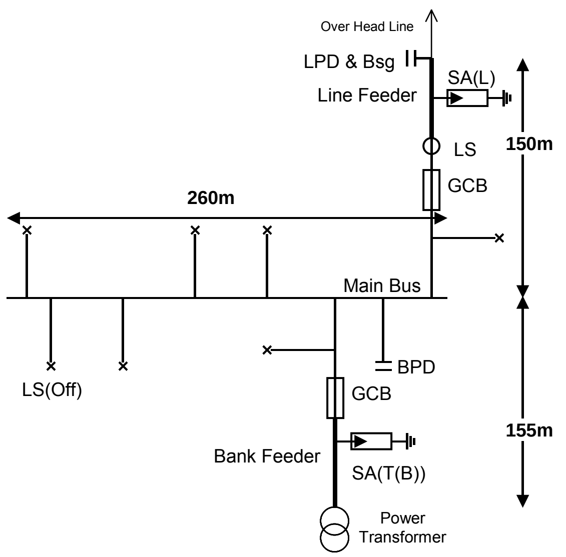


Figure B-5-1: 550kV AIS model

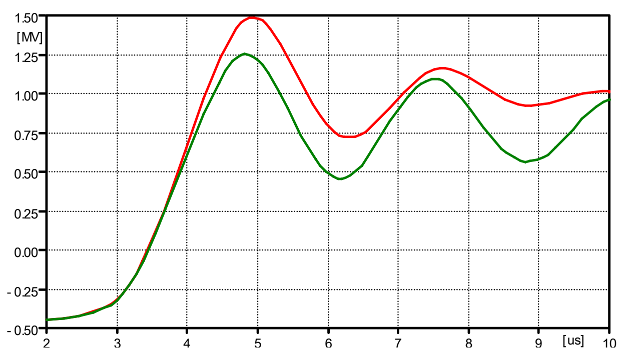


Figure B-5-2: Lightning over voltage at Power Transformer

B.5.3 SUMMARY

The installation of a high performance SA and optimizing the SA location can reduce the LIWV, even if the substation is AIS.

B.6 REPLACEMENT OF 245-KV CIRCUIT BREAKERS (GERMANY)

The substation existing 245kV circuit breakers were approaching the end of their useful life and maintenance costs were high, being above average for their class of equipment. Conversion of the 245kV section of the substation to 400kV was anticipated within the next 12 years according to long-term network development planning. Consequently an intermediate solution was needed.

B.6.1 CONDITION ASSESSMENT

The existing circuit breakers still had sufficient breaking capacity and were of the two pressure-type with separate 15 bar SF_6 tanks. Operating and Maintenance records showed that the old circuit breakers had a normal reliability, but a relatively high maintenance effort was needed due to short overhaul intervals and frequent exchange of expensive high pressure gas circuit parts.

B.6.2 ALTERNATIVES CONSIDERED

The alternatives were to replace the circuit breakers with either new units or ones that were in adequate condition. Evaluation showed that the most favorable solution for the required 12 year lifespan was to use 25 year old puffer-type circuit breakers with the same electrical characteristics, which were available from previous conversions. As part of the installation the circuit breakers were overhauled to ensure they would not require major maintenance during their operating life.

B.6.3 SUMMARY

Replacement was performed at about 40% of the cost of installing new circuit breakers. The solution provides equal life-time expectancy for all 245-kV switch bay components prior to their conversion to 400 kV in about 2017. The photos below in Figure B-6-1 show the installation before and after replacement of the circuit breakers.

Before Replacement

After Replacement

Figure B-6-1: 245-kV Switch Yard Circuit Breaker Replacement

B.7 CONVERSION OF 500KV CIRCUIT SWITCHERS TO DISCONNECT SWITCHES (CANADA)

British Columbia Transmission System extends over a very large territory and includes over 5700 km of 500kV lines. To facilitate voltage control, one transmission company has over 100 units of 500kV shunt reactors installed in various substations on the system. When these shunt reactors were installed, in the early 1980's, to minimize costs S&C circuit switchers were chosen and installed as the switching devices.

An advantage of these circuit switchers over circuit breakers, in addition to the relatively low installed cost, was that they included a built-in, good quality disconnect switch.

The disadvantages were not all known at the time. As time passed, the disadvantages intrinsic to using these devices to switch 500kV shunt reactors became obvious:

- circuit switchers are prone to re-strikes that over time can lead to severe damage of the shunt reactor windings
- circuit switchers can fail spectacularly – as illustrated in a well known movie circulated on the Internet – with potentially heavy damage to other equipment in the substation.
- circuit switchers used for shunt reactor switching can sustain a very limited number of operations – usually no more than 2000 operations before the interrupters must be replaced.
- The interrupters are sealed units that do not allow replacement of worn-out contacts or shorted closing resistors, thus increasing the maintenance costs.
- For the same reason SF_6 gas leaks cannot be fixed.
- Recently the OEM has discontinued support for the 500kV range (and is no longer offering switchers in this voltage range), thus leaving these devices orphaned.

After almost a quarter century of operating these devices company has adopted a program to replace over a number of years most shunt reactor-switching 500kV circuit switchers in their system with Live Tank circuit breakers equipped with surge arresters and point-on-wave relays that minimize transients and facilitate re-strike-free switching of reactors.

Normally that process would have required removal of the existing circuit switchers and installation of the new circuit breakers, arresters and new disconnect switches.

The innovative aspect of this program consists of re-using the disconnect switch of the existing circuit switchers, thus realizing savings of approx. CAD$250,000 per position.

The conversion of the circuit switchers consists of the removal of the 2 interrupters and 2 of the porcelain columns supporting them, and connecting the new circuit breaker directly to the circuit switcher disconnect switch. Some additional modifications are performed in the circuit switcher control box (installed on the middle phase) and P&C modification in the control room.

Two pictures, illustrating a circuit switcher before the conversion, and a converted position that includes the modified switcher, new circuit breaker and surge arresters, are included below.

Figure B-7-1: Arrangement prior to conversion

Figure B-7-2: After conversion

B.8 New solution for three-phase power transformer transportation and its installation in AIS substations (Portugal)

B.8.1 Introduction

The evolution of power transformers and auto transformers in Portugal since the 1950s ‘till today was summarized firstly by the installation, in the substations, of single phase bank transformers and then by three-phase transformers. Due to the higher masses and dimensions caused by the growth of power transformer ratings and the increased legal and technical restrictions on transportation, new solutions were imposed on the Portuguese National Transmission Utility, which were technically and economically evaluated. As a result, a new solution was retained to produce three-phase transformers combining the transport advantages of single-phase transformers with the on-site installation advantages of three-phase units.

B.8.2 Construction Details of the New solution

The new solution for three-phase transformers began to be developed by the National Electricity Transmission Utility and a Transformer Manufacturer working in cooperation.

The main constructive aspects of this solution are:

- 3 identical single-phase units, each one inside its own tank with provisional cover for transportation only, allowing each one as being a phase of a three-phase transformer (Dissociate Phase Transformer);
- Common cover to be installed on-site over the 3 tanks, after removal of the 3 provisional covers;
- Arrangement of bushings, on-load tap changers and de-energised tap changers identical to the one of a conventional three-phase transformer;
- Identical cooling system assembled in each single-phase unit;
- Each single-phase is interchangeable with all the others. The figure below shows a replacement of any phase on-site with the innovative solution;
- Upper and lower mechanical immobilization between adjacent tanks;
- Easy connection of all cables coming out from each single-phase unit to the cables inside the common cover;
- Overall dimensions similar to the ones of the identical conventional three-phase transformer.

Figure B-8-1: On-site replacement of any phase

The photos below show the on-site installation between conventional three-phase solution, new three-phase solution and conventional three-phase bank solution.

Figure B-8-2: Conventional three-phase solution

Figure B-8-3: Conventional three-phase bank solution

Figure B-8-4: New three-phase solution

B.8.3 Advantages of the New Solution

Assure in the future:

- Easy transportation - minimum weight and dimensions;
- Minimum transport price.

The main technical advantages are:

- The legal and technical restrictions imposed on transportation are solved;
- No need to reinforce bridges;
- On-site installation area is identical to the one dedicated to a conventional three-phase transformer;
- Does not increase the civil work cost;
- Does not change the current layout of the bays;
- Reduces transport cost;
- Reduces the outage times caused by faults in power transformers;
- Interchangeable with an identical conventional three-phase transformer;
- Limited consequences of an internal fault;
- Only one single-phase unit as spare for all three-phase power transformers with this solution;
- Adoption of a solution which will be standardized in the utility in the very near future;

The main economic advantages are:

- Always lower global cost for acquisition, transport and on-site erection than the solution with conventional single-phase transformers to be installed as one three-phase bank;
- Lower global cost or slightly higher (in few cases, for lower transformer ratings) for acquisition, transport and on-site erection than the solution with conventional three-phase transformers, assuming that it's possible to transport such a heavy unit.

The following table shows the Total Price Evaluation for Conventional and New Solutions.

Table 8-8-1 Total Price Evaluation for Conventional and New Solutions

Three-Phase Transformers		**Transformer 170MVA 400/60/20kV**	**Autotransformer 250MVA 400/150/20kV**	**Autotransformer 450MVA 400/220/20kV**	**Autotransformer 450MVA 400/150/20kV**
Conventional Solution	Ex-Works Price including Losses Evaluation (Reference Value [A])	100	100	100	100
	Transport Price (% of [A])	15.7	16.2	17.7	17.4
	Total Price (% of [A])	**115.7**	**116.2**	**117.7**	**117.4**
New Solution	Ex-Works Price including Losses Evaluation (% of A])	111.8	106.9	109.8	107.5
	Transport Price (% of [A])	5.5	6.1	5.8	6.4
	Total Price (% of [A])	**117.3**	**113.0**	**115.6**	**113.9**
Total Price Variation (New/Conventional) (% de [A])		**+1.6**	**-3.2**	**-2.1**	**-3.5**

B.9 Modernization Without Disconnection - Outage management (Poland)

The presented 220/110kV substation supplies the capital of Poland, Warsaw, with electricity. It was built in the early 1950s, and after 45 years of intensive utilization it had to be modernized; all of the equipment had to be replaced. Because of the territorial limit the substation had to remain in exactly the same place. It was unacceptable to de-energize the substation during modernization because 40% of the electricity supply to the city of Warsaw flows through the substation.

The modernization approach adopted was to do everything in stages. The first stage was to build components of the new 220kV and 110kV switchgear and to link them with the existing switchgear. The next stages were in turn removing components of the existing switchgear and building components of the new switchgear. During all of these stages there were two substations joined with a temporary connection. The whole modernization took 5 years, resulting in a new substation that was constructed with no noticeable impact on consumers.

The process and effects of the modernization are shown in the drawings and photos below.

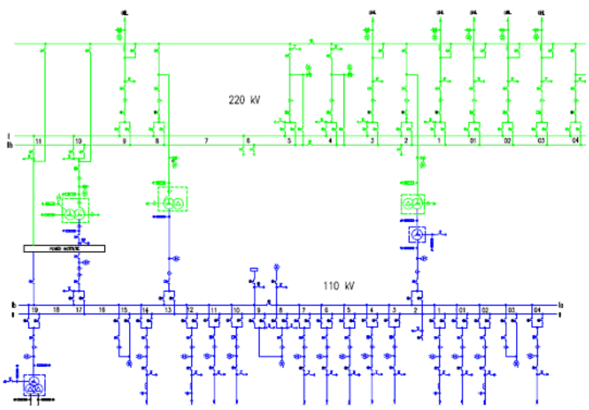


Figure B-9-1: Old substation – single line diagram

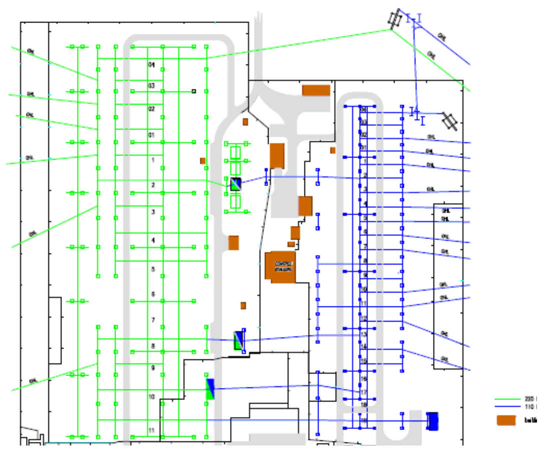


Figure B-9-2: Old substation – layout

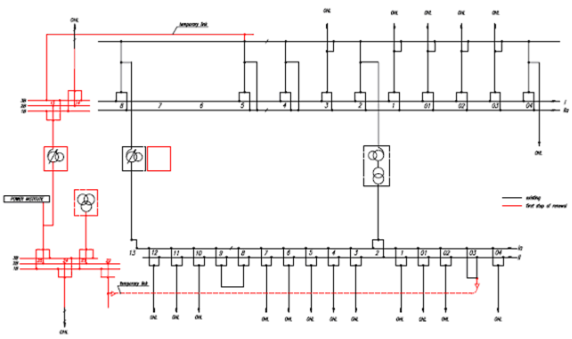


Figure B-9-3: First stage of renewal – single line diagram

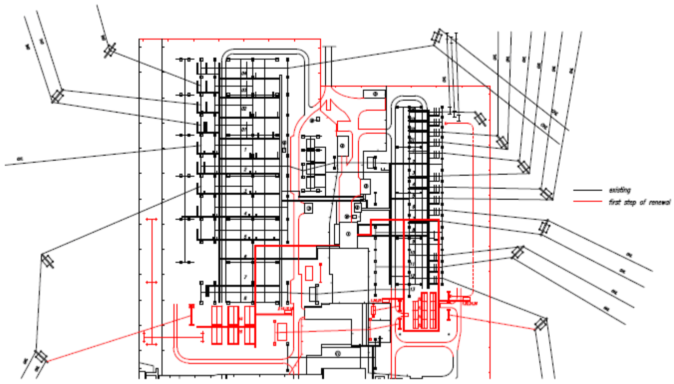


Figure B-9-4: First stage of renewal – layout

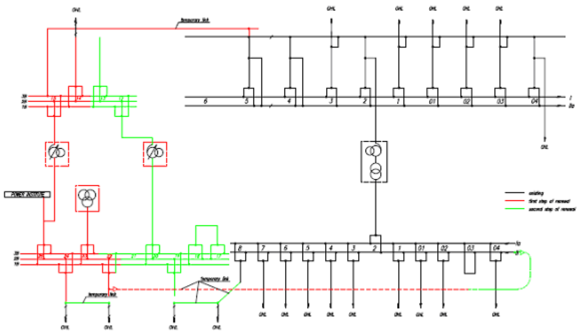


Figure B-9-5: Second stage of renewal – single line diagram

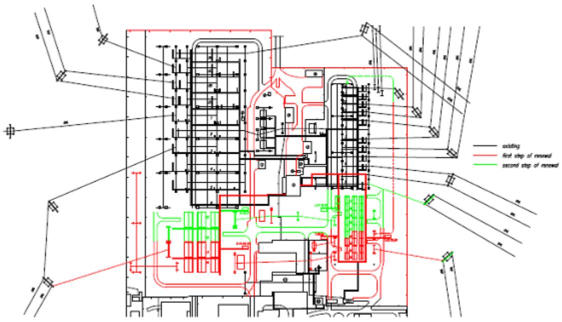


Figure B-9-6: Second stage of renewal – layout

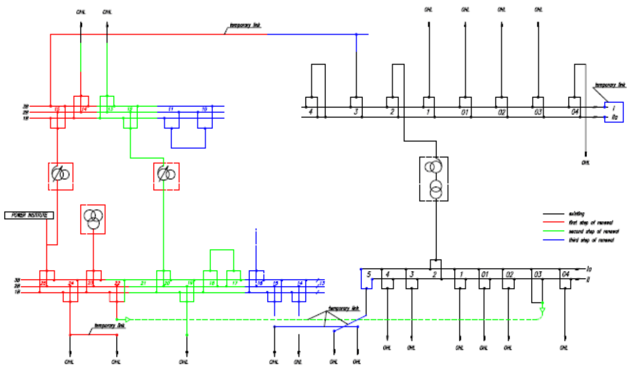


Figure B-9-7: Third stage of renewal – single line diagram

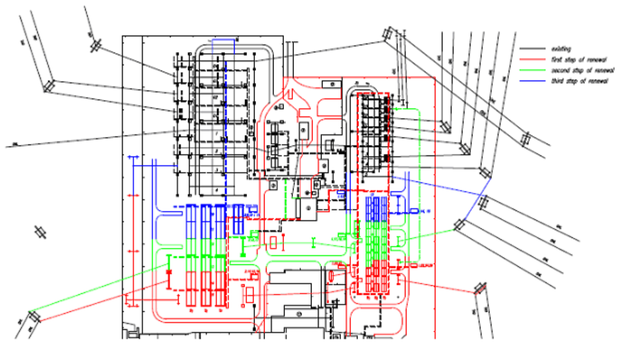


Figure B-9-8: Third stage of renewal – layout

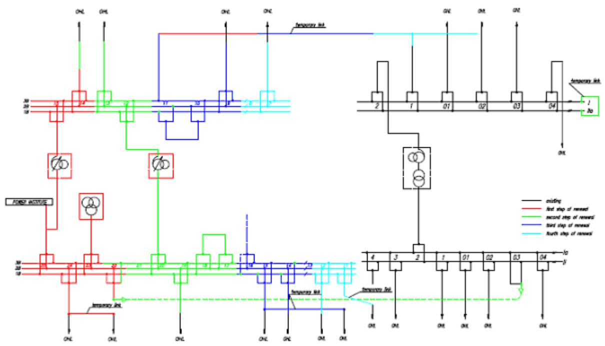


Figure B-9-9: Fourth stage of renewal – single line diagram

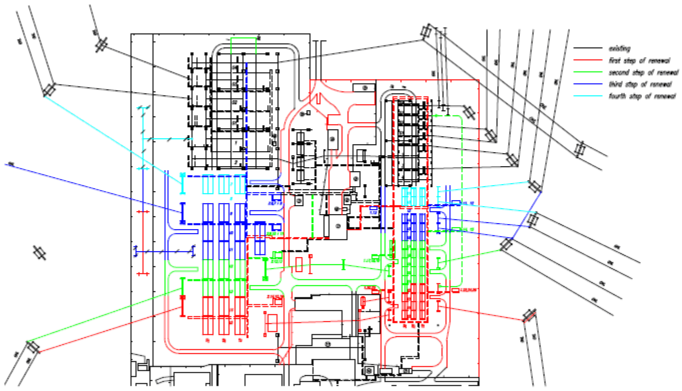


Figure B-9-10: Fourth stage of renewal – layout

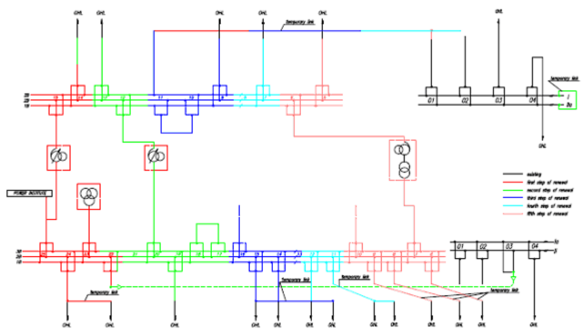


Figure B-9-11: Fifth stage of renewal – single line diagram

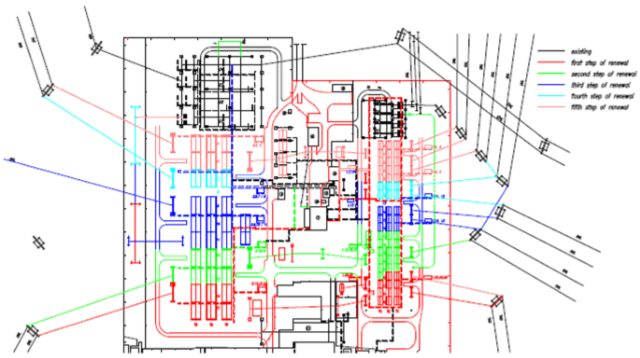


Figure B-9-12: Fifth stage of renewal – layout

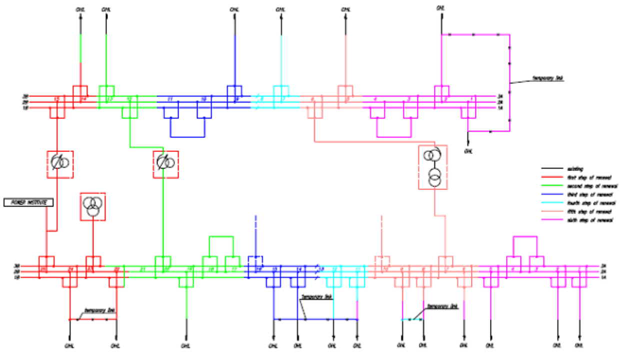


Figure B-9-13: Sixth stage of renewal – single line diagram

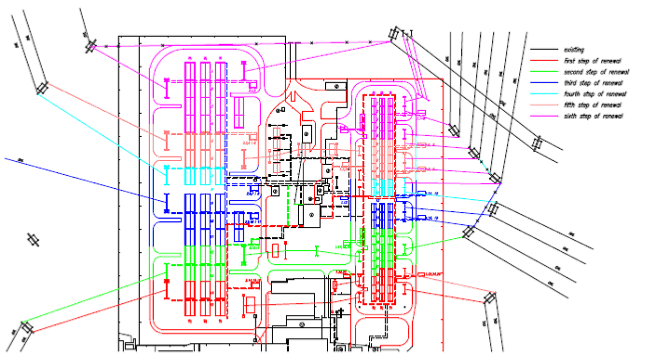


Figure B-9-14: Sixth stage of renewal – layout

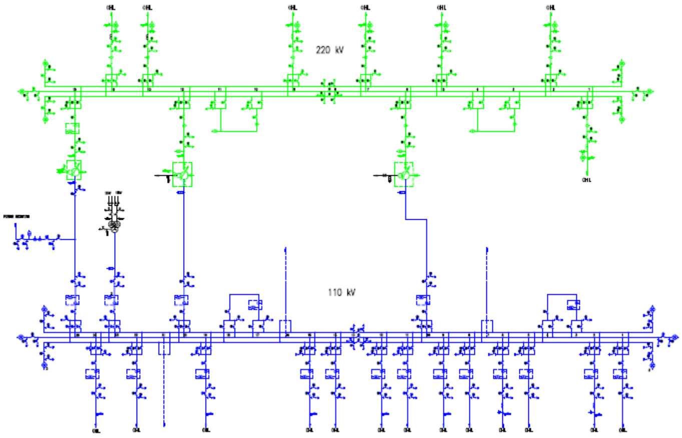


Figure B-9-15: New substation – single line diagram

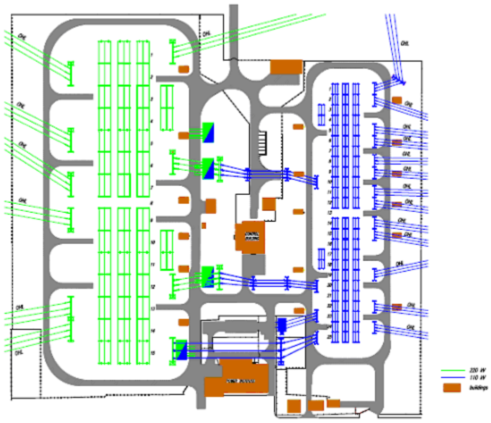


Figure B-9-16: New substation – layout

Photo 1: Old 220 kV switchgear

Photo 2: New 220 kV switchgear

Photo 3: Old 220 kV switchgear

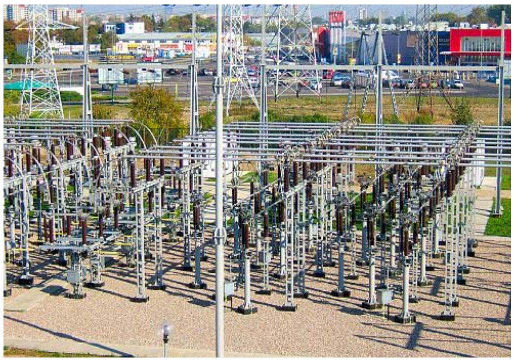


Photo 4: New 220 kV switchgear

APPENDIX C SUMMARY OF ANSWERS TO QUESTIONNAIRE

WG B3.15 issued a questionnaire at the beginning stage of our study. The main objective of this survey was to identify what interested groups engaged in the substation field consider, concern and expect about optimization of engineering and construction cost of Air Insulated Substations (AIS) such as following items

- Design and engineering
- Construction
- Test and commissioning
- Procurement
- Project closeout

The responses to this questionnaire are reflected in the main body of the brochure and are the supporting items for the review of substation construction project for all reader.

Followings are summary of the questionnaire.

C.1 CHARACTERISTICS OF SURVEY GROUP

Worldwide 24 companies from 18 countries and 5 continents participated in this survey. Of these, 16 were utility groups (Government/ Private utility, Generation/ Transmission/ Distribution company) and 8 were Engineering and Manufacturing groups.

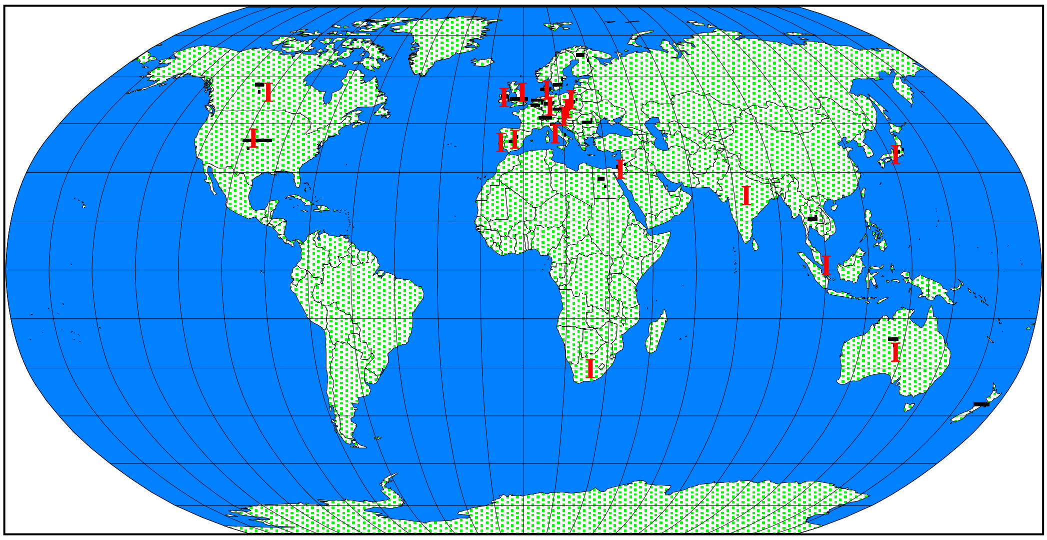


Figure C-1: Participating

Figure C-1 shows the geographic distribution of the participating companies. The majority of respondents (11 of 24) were from Europe. Japan was well represented with 4 respondents.

C.2 Design Process

C.2.1 Standardization (Q2.1)

At the basic design/decision of equipment stage, the application of the international standards (i.e. IEC/IEEE) contributes in providing quality to the components and shorting their construction period.

WG asked if present international standards are satisfactory or not, and received comments.

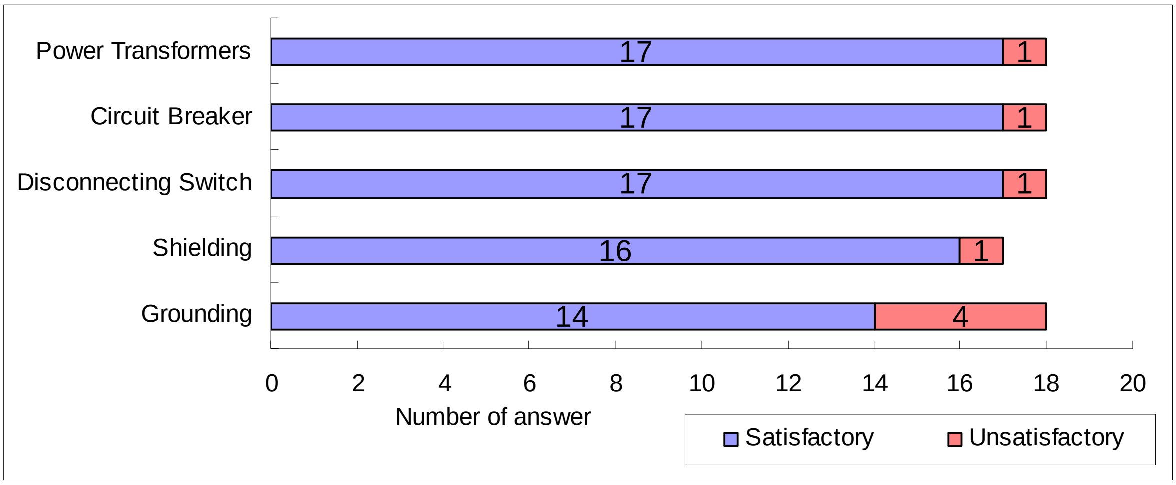


Figure C-2: International Standards Satisfaction

Figure C-2 shows most of respondents answered "Satisfactory". Satisfactory comments are following.

- The combination of ANSI/CSA/IEC standards provides sufficient guidance for various aspects of transformer performance and coordination.
- As long as local standards catering for local conditions using international standards as a base forms part of overall strategy.

International standards are specified to meet with general requirements and condition all over the world. Therefore, it is effective to reduce design time and cost as well as to keep proper reliability on substation design stage.

Besides, some respondents answered "Unsatisfactory" as follows.

- There is limited information for switching ungrounded capacitor banks, reactor switching and synchronizing duty.
- The requirements for induced current switching by earthing switches in IEC 62271-102, in particular the levels for magnetically induced currents, are lower than the actual levels that can arise in service. It is therefore necessary for the user to request additional testing beyond the standard requirements.
- Standards for shielding do not protect the most sensitive equipment in a satisfactory degree.
- International Standard is too strict to meet with out company soil.
-

International standards do not cover all aspects especially such as above mentioned special duties. Therefore, It is important to study and create our own standards to meet with special duties and conditions based on an international standards applied worldwide.

C.2.2 CONFIGURATION (Q2.2)

WG asked what specification /standard configuration apply to AIS substations.

(1) WG asked what kind of bus configuration do you apply substations.

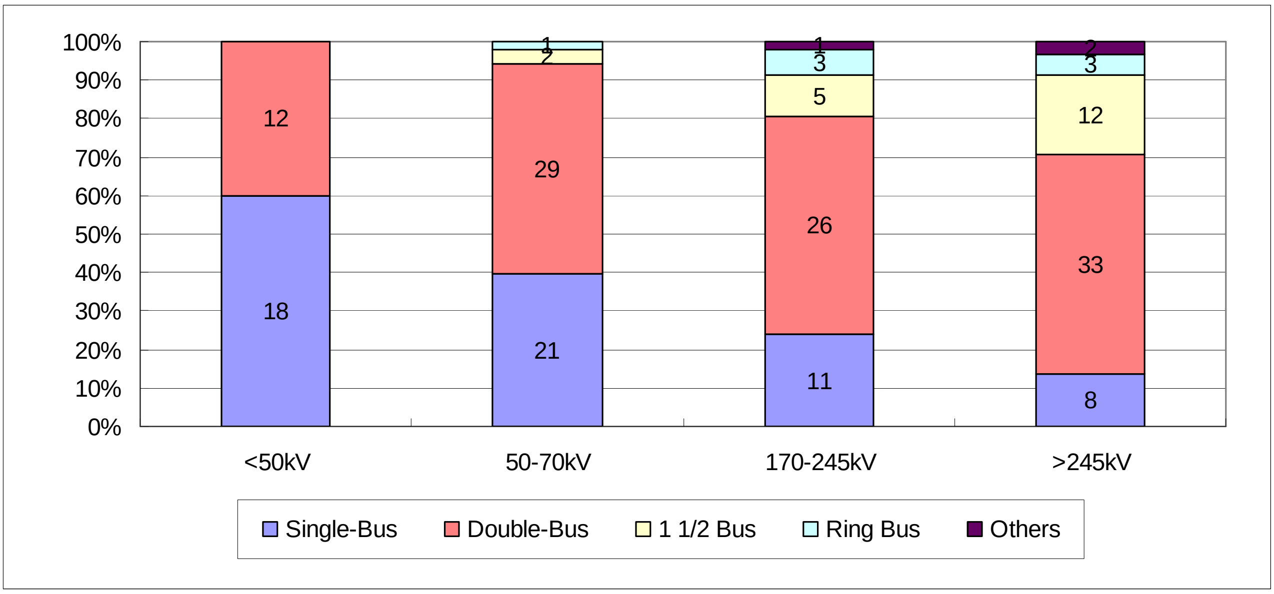


Figure C-3: Bus configuration depends on bus voltage

Figure C-3 shows that the bus configuration depends on the bus voltage. “Double-Bus” is a common bus configuration of substation for all voltage levels. “1½ Bus” and “Ring Bus” are applied to high voltage busbar to secure high bus reliability.

Bus configuration is the key aspect in establishing substation reliability and substation construction cost.

(2) WG asked how to optimize insulation coordination to meet with your design condition? A various kind of comments are obtained as follows.

- We generally do not change from standard insulation requirements, other than in some high pollution areas where we require higher levels.
- Insulation coordination is designed in order that flashovers are not occurred for the assumed voltages even under bad situation or climate, like strong wind and high humidity.
- The assumed maximum overvoltage should be based on both the maximum lightning voltages which we have been experienced and the maximum switching impulse voltages which are assumed.
- Design of our AIS substations is based on EN/IEC recommendations. We use

1425/1050kV and expect less than 10kA lightning current in direct stroke to the phase conductors in the substation.

- Reduced BIL of transformer is being used after coordinating it, suitably with LA.
- We measured parameter of actual transmission line and substation equipment. Then we carried out EMTP analysis and decided necessary insulation level.
- EMTP analysis to determine appropriate requirements. Also we consider the impact of maintenance activities on insulation coordination to eliminate ongoing constraints that impact ongoing operating and maintenance costs.

An optimized insulation level depends on climate condition such as wind, snow and pollution level as well as differences on substation grounding systems and switching/ impulse surge level.

In addition, WG asked allowable minimum clearance which is relate to insulation level.

Table C-1: Allowable Minimum Clearance

Case	Distance	System voltage	Case	Distance	System voltage	Case	Distance	System voltage	Case	Distance	System voltage
(1)	1.5m	66kV	(1)	5m	275kV	(1)	-	253kV	(1)	-	550kV
(2)	0.85m		(2)	3.3m		(2)	4.55m		(2)	6.75m	
(3)	--		(3)	--		(3)	8.25m		(3)	10m	
(4)	2.3m		(4)	2.3m		(4)	2.1m		(4)	3.7m	
(1)	1.05m	72kV	(1)	1.65m	145kV	(1)	4.5m	230kV	(1)	7.6m	500kV
(2)	0.77m		(2)	1.2m		(2)	1.8m		(2)	4m	
(3)	3.2m		(3)	3.7m		(3)	5.8m		(3)	8m	
(4)	0.9m		(4)	1.2m		(4)	-		(4)	-	
(1)	0.35m	33kV	(1)	1.55m	170kV	(1)	0.9m	110kV	(1)	2.9m	400kV
(2)	0.35m		(2)	1.55m		(2)	0.9m		(2)	3.6m	
(3)	3m		(3)	3.8m		(3)	1m		(3)	3m	
(4)	3m		(4)	3.8m		(4)	2.1m		(4)	5.4m	
(1)	4m	220kV	(1)	5m	400kV	(1)	0.47m	42kV	(1)	1.1m	123kV
(2)	6m		(2)	7.5m		(2)	0.47m		(2)	1.1m	
(3)	6m		(3)	7.5m		(3)	-		(3)	-	
(4)	5m		(4)	7m		(4)	-		(4)	-	
(1)	1m	84kV	(1)	4.2m	300kV	(1)	0.76m	72.5kV	(1)	4m	420kV
(2)	0.76m		(2)	2.7m		(2)	0.76m		(2)	3.5m	
(3)	-		(3)	-		(3)	3m		(3)	5.75m	
(4)	1.1m		(4)	2.2m		(4)	3m		(4)	5.25m	
(1)	1m	84kV	(1)	2.7m	300kV	(1)	2m	110kV	(1)	3.6m	380kV
(2)	1.7m		(2)	4.2m		(2)	1.2m		(2)	3.4m	
(3)	1.4m		(3)	4m		(3)	5.2m		(3)	7m	
(4)	-		(4)	-		(4)	-		(4)	-	
(1)	5m	400kV	(1)	1.3m	150kV	(1)	0.35m	33kV	(1)	1.55m	170kV
(2)	2.9m		(2)	1.3m		(2)	0.35m		(2)	1.55m	
(3)	4m		(3)	3.35m		(3)	3m		(3)	3.8m	
(4)	2.5 - 4m		(4)	-		(4)	-		(4)	-	
(1)	-	220kV	(1)	-	400kV	(1)	3.66m	230kV	(1)	6m	525kV
(2)	2.1m		(2)	3.5m		(2)	2.03m		(2)	3.6m	
(3)	7m		(3)	8m		(3)	4.52m		(3)	6.55m	
(4)	-		(4)	-		(4)	-		(4)	-	
(1)	1.59m	145kV	(1)	3.1m	362kV	(1)	0.32m	33kV	(1)	4.2m	420kV
(2)	3.6m		(2)	5.3m		(2)	0.32m		(2)	3.6m	
(3)	-		(3)	-		(3)	-		(3)	-	
(4)	-		(4)	-		(4)	-		(4)	-	
(1)	3.7m	145kV	(1)	2.4m	300kV	(1)	3.7m	145kV	(1)	3.6m	420kV
(2)	-		(2)	2.1m		(2)	-		(2)	2.8m	
(3)	-		(3)			(3)	-		(3)		
(4)	-		(4)			(4)	-		(4)		

[Case]

(1) For the receiving steel structure: Distance between live conductors phase to phase in air insulation

(2) For the equipment: Distance from live conductor to earthing ground

(3) For safety: Distance from live conductors to maintenance road on which traveling vehicles runs when patrol, inspection and maintenance

(4) For live work: Distance from live work position and live conductors

Variety kinds of answers were obtained although in the same system voltage class. These results may come from differences of insulation design level, safety code, electrical regulation, etc.

C.2.3 CONSTRUCTABILITY (Q2.3)

On the design and engineering stage, it is the key point how much engineer cooperate constructor and how to feed back their practice to design and engineering stage to avoid re-designs and re-works which strong related to construction cost.

WG asked 3 questions with regards to constructability as follows.

(1) Do you control construction deviations from design?

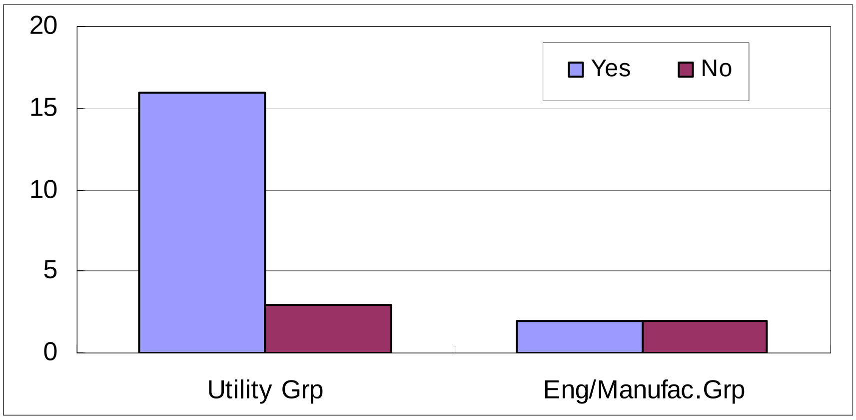


Figure C-4: Construction deviation control from design

Most of utility group recognize the importance of construction deviation control to avoid re-design and re-works, and have responsible for that. Major comments are follows.

- After each construction is designed, owners review its design and deviations. If its deviations are reasonable, owners approve its design and deviations by issuing approval.
- All construction activities at site are in line with drawings issued. Any change from design has to be approved by design engineer and then only construction work is carried out at project site.
- Any deviation from company standards are reviewed in detail at a formal Design Review stage of the project. Any deviation from the design at the construction stage requires

approval as part of the site inspection process. This requirement is in the contract.

- Approval of design/ drawing approving authority is required for any deviation in construction from approved "Released for Construction" drawing.

(2) Do you have a formal feedback process from construction to design standards to modify engineering standards?

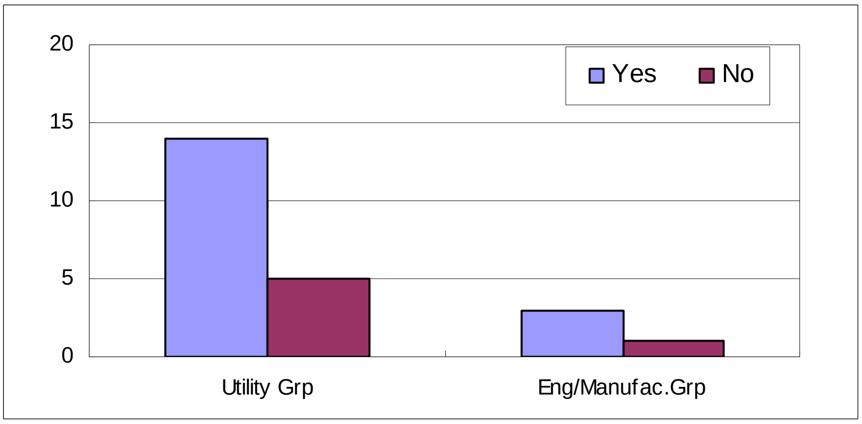


Figure C-5: Formal feedback process from construction to design

Most of utility group apply formal feedback process from construction to engineering standards to modify and to update their own design standards. Major comments are follows.

- The project department is responsible for the engineering standards applied to all substations. The engineering standards are revised periodically. But whenever the construction department considers useful to change some standards it will ask officially the project department to study such a modification on the engineering standards.
- Working groups are periodically held. They discuss engineering standards considering latest technical trend and they draft amendments to engineering standards. After amendments are approved by the appropriate procedure, they are modified.
- Project managers are involved in design and standardisation, so they could directly influence with past experience.

(3) Is constructor involved in the conceptual stage of a substation project?

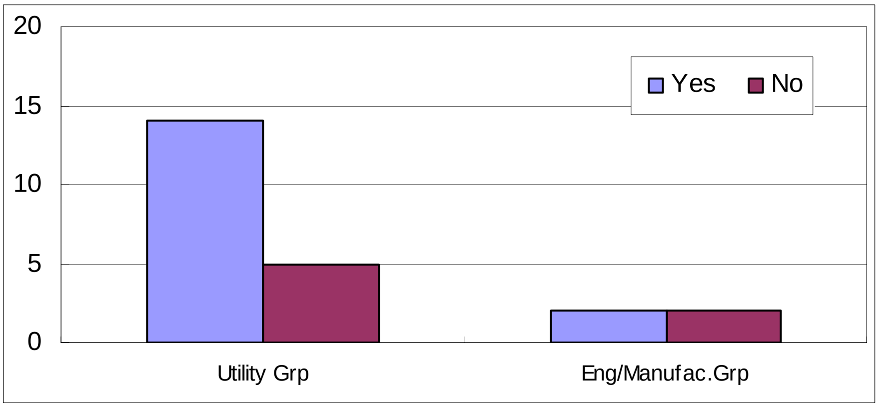


Figure C-6: Constructor involvement in the conceptual stage

Many utility groups involve constructor in the conceptual stage. Some respondents answered they have not been involved constructor yet, but they also consider that. Major comments are follows.

- Constructors are highly concerned with each substation project from its conceptual phase stage. They are involved in system planning, engineering, construction maintenance and operations.
- Project-team incorporates system planning. engineering, construction, maintenance and operations. Major equipment layout in the design stage is highly related to constructor.
- The constructor has been increasingly involved at the conceptual stage of the substation project through previous 'Joint Activity Solutions' and the present 'Alliance' system.
- Generally we don't involve the constructor. Nevertheless when there is a new product like, for example, a new Mixed Technology Switchgear that will be designed for the first time to work in our network we involve the constructor or the usual furnisher of that equipment.

C.2.4 DEPENDABILITY （MAINTAINABILITY) (Q2.4)

Once after substation construction is completed, electric company has responsibility to supply electricity with stable and reliable. Therefore, it is essential to consider maintenance issue in design and engineering stage in order to reduce maintenance cost. Maintenance person has an importance role in this viewpoint.

WG asked 3 questions with regards to constructability as follows.

(1) Do you consider maintenance aspects from design?

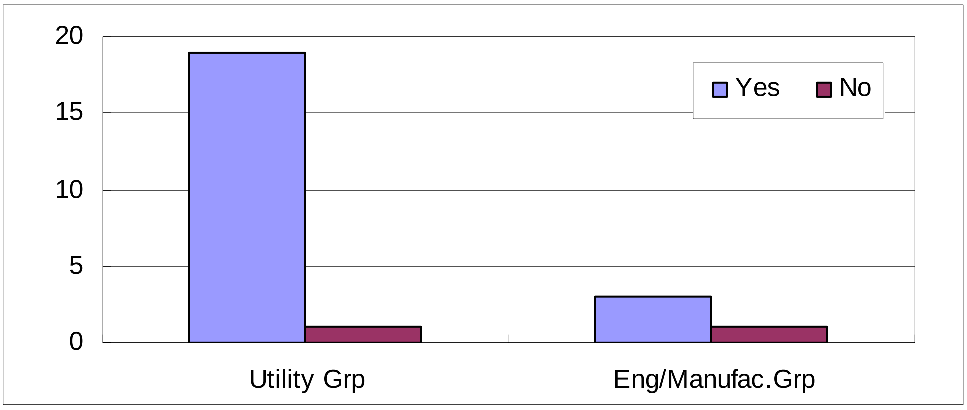


Figure C-7: Consideration of maintenance aspect in the design stage

Most of utility and engineering group consider maintenance aspects from design stage. Major comments are follows.

- We design equipment layout to keep appropriate machinery setting space in case of repair, overhaul and failure.
- Substation design follows engineering standards that provide maintenance

requirements. Equipment selection is conditional on meeting existing engineering standards that cover clearances and maintenance requirements covered by maintenance standards.

- Before finalization of substation layout, aspects like Isolator, Circuit breaker maintenance; Power Transformer removal etc are being considered. Equipment layout (Indoor) is prepared based on the maintenance requirement i.e. section clearance specified in local statutory standards.

(2) Do you have a formal feedback process of maintenance to modify engineering standards?

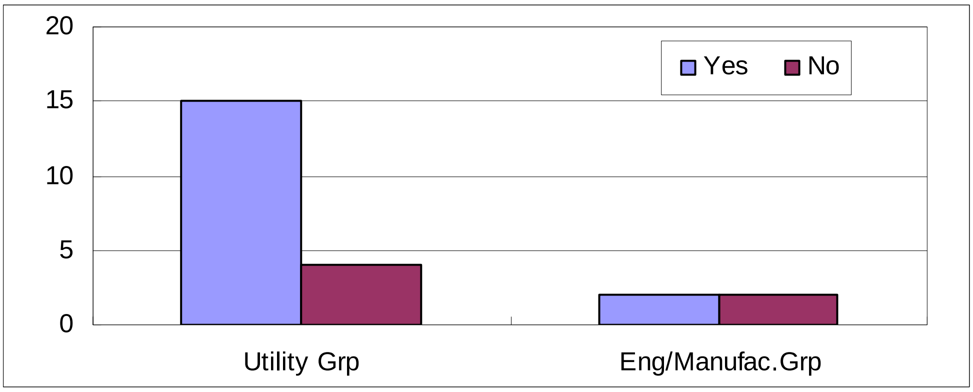


Figure C-8: Formal feedback process of maintenance

Most of utility group have formal feedback process from maintenance to engineering standards to modify and to update their own design standards. Major comments are follows.

- Asset Maintenance has a representative on the project evaluation team. Asset Maintenance provides the main site inspection service during construction, and is represented at the project review where future changes are recommended.
- A substation working group which consists of construction, maintenance, operation and engineering meet monthly to discuss any required changes.
- Engineering standards are revised periodically to meet with revised maintenance policies.
- People from maintenance are involved in designing and construction of substation.
- These type of feedback are often conveyed by the customers, once the substations handed over to them. Basic customer specifications are updated by feedback from their maintenance group.

(3) Is maintenance involved in the conceptual stage of a substation project?

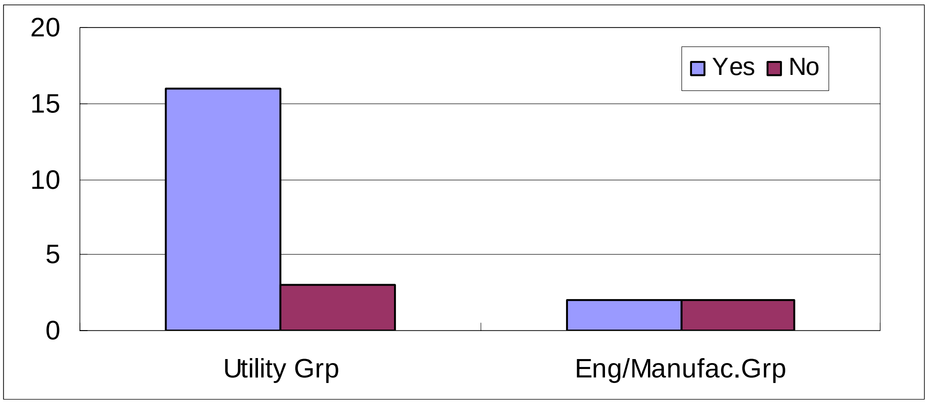


Figure C-9: Maintenance involvement in the conceptual stage

Most of utility group involve maintenance in the conceptual stage. Major comments are follows.

- Design principles are coordinated with maintenance staff.
- Project-team incorporates system planning, engineering, construction, maintenance and operation.
- Yes they have the opportunity to comment on the conceptual report.
- Only to a limited extent. Asset Program Definition has a mandate over Sustainment - includes maintenance and capital program in existing stations. System Planning oversees new substations and has a consultation process with Asset Program Definition.

C.2.5 REPEATABLE DESIGN SPECIFICATION (REPEATABILITY) (Q2.5)

Repeatability is a crucial issue in achieving a cost reduction through savings in execution time (engineering, procurement and construction) and is an extension to standardization. Repeatability is also able to contribute to secure quality of design and equipment.

WG asked respondents that "Does your company apply following repeatable designs and specifications per voltage level?"

Table C-2: Adoption rate of Repeatability per voltage level

	<50kV	50-70kV	170-245kV	>245kV	Average
1.Template Design	87%	75%	60%	70%	73%
2.Bus Layout	53%	65%	60%	60%	60%
3.Switchgear Layout	80%	65%	60%	65%	68%
4.Main Transformer Design/Specification	60%	65%	60%	70%	64%
5.Switchgear Design/Specification	53%	55%	60%	60%	57%
6.Insulator Design/Specification	40%	45%	47%	50%	45%
7.Bus current Specification	53%	65%	67%	65%	63%
8.CT / PT / PD Design/Specification	53%	65%	60%	60%	60%
9.Power Cable Design/Specification	47%	45%	47%	60%	50%
10.Reactive Power Compensator Design/Specification	53%	50%	53%	55%	53%
11.Protection Relay Design/Specification	60%	60%	60%	60%	60%
12.Station Power Supply Circuit	47%	50%	60%	55%	53%
13.Building Layout/Room Space	67%	80%	73%	80%	75%
14.Seismic Specification	53%	50%	33%	55%	48%
15.Lightning Specification	53%	55%	40%	55%	51%
16.Contamination e.g. Salt, Sand and Dust Specification	60%	60%	40%	55%	54%
Number of Respondents	15	20	15	20	

Green column: More than 70% answered "YES". Pink column: Less than 50 % answered "YES"

"Adoption rate" = "number of answer" / "number of respondents" *100

Table C-2 shows the adoption rate of each repeatable design and specifications per voltage level. "Template" and "Building layout/ room space" are widely applied repeatable design. Meanwhile, "Insulator", "Power cable" and "Seismic" are less applied repeatable design, and they are designed and specified per construction.

One respondent answered "Greenfield sites (new substations) tend to be constructed from standard designs however refurbishments and extensions tend to be more varied designs (to keep an original layout and design concept).

Generally, equipment installed outdoor is easy to layout to fit substation land shape and must design to meet with an environmental condition such as wind/ snow, lightning, contamination and seismic aspects even if in case of new substations. Construction cost could be reduced if repeatable design and specification are widely applied to outdoor equipment.

C.2.6 Engineering Quality Control (Q2.6)

Substation construction cost can be minimized by a high level of quality control. To support this, documentation control includes document standardization shall be conducted. In addition, engineer education system and internal licence system shall be established as a part of quality control.

WG asked 4 questions with regards to quality control as follows.

(1) Does your company have any in-house design standard for AIS substation? (Q2.6.1)

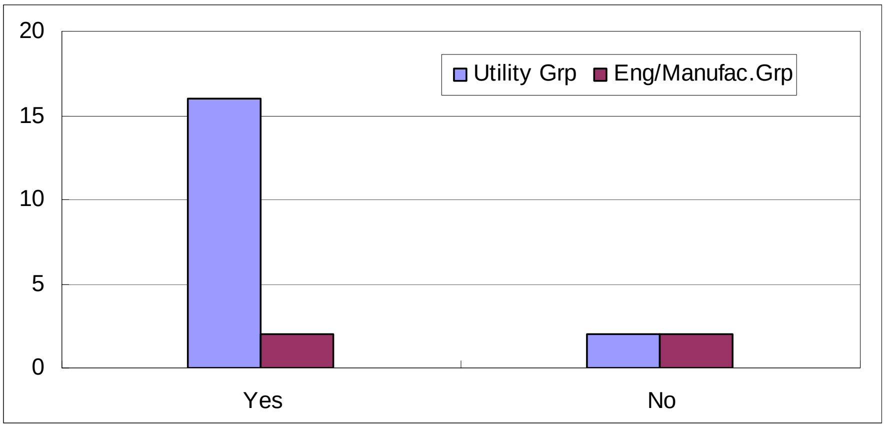


Figure C-10: In-house design standard for AIS

Most of respondents answered they have their own design standards such as follows.

- Design standards for substation, salt contamination countermeasures, lightning measures etc.
- Design guidelines, detailed engineering standards, procurement standards (major equipment limiting dimension drawings).
- Everything from clearance, through equipment, fire protection, seismic.
- Template layout, primary and secondary equipment standards.
- Standard designs for all control/protection and physical designs associated with 38kV, 110kV and 220kV stations.
- Standard in house switchyard engineering calculation package has been developed. This has different modules covering earthing, shielding short circuit for rigid and bundled conductor, temperature rise, CT application relay and relay setting calculation. Utility wise standard layouts, general guidelines / check list for designing AIS substation are used.

(2) Does your company have design engineers education system? (Q2.6.2)

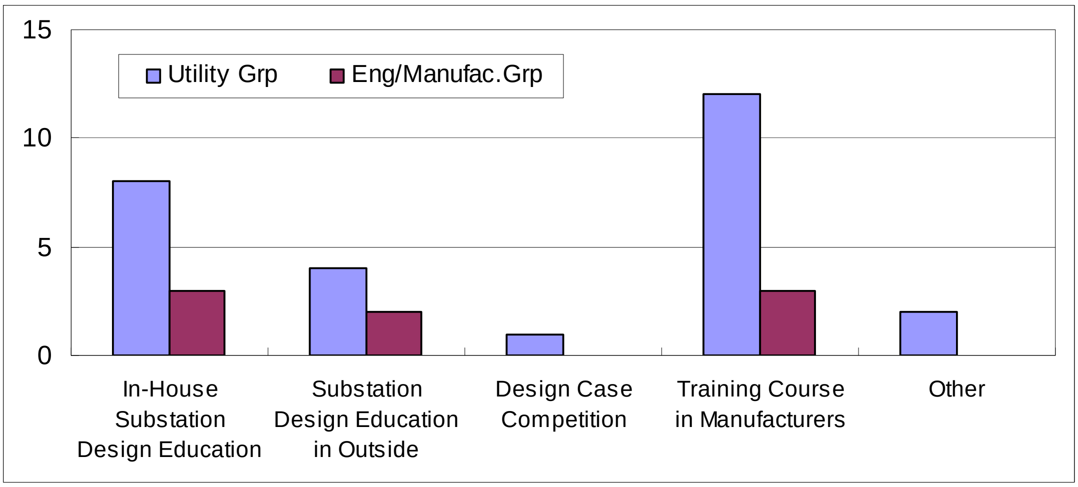


Figure C-11: Education system for design engineers

As figure C-11 shows, company provides an education system for design engineers not only design wise education program but also training course in manufactures which cover extensive subject to educate engineers with high comprehensive knowledge.

(3) Does your company have following internal licensing system /restriction imposed on design engineers? (Q2.6.3)

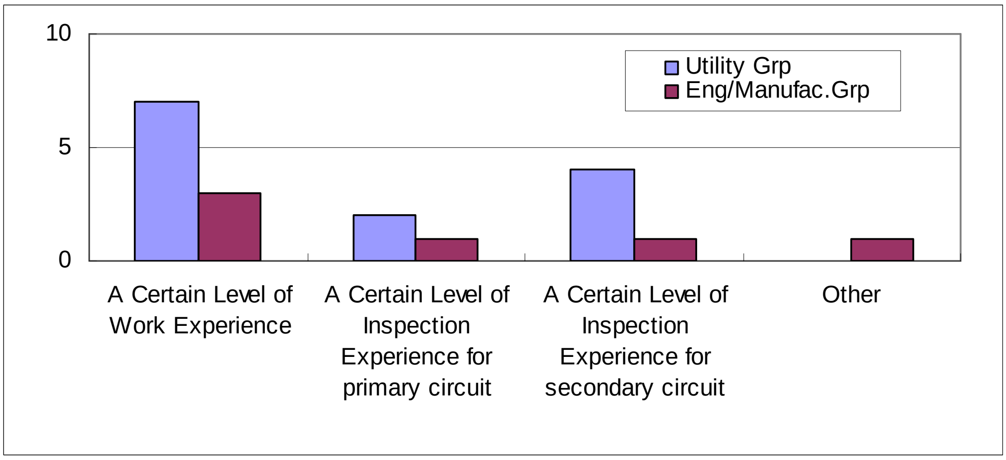


Figure C-12: Internal licensing system /restriction for design engineers

According to figure C-12, no companies have any internal licensing system for design engineers. Besides, many companies require a certain level of work and inspection experiences to them. Companies consider that work experience which covers general field work is the first priority to all design engineers, and inspection experience for secondary circuit is more important than that for primary circuit.

(4) Does your company have internal quality control system other than manufacturers and constructors at the construction? (Q2.6.4)

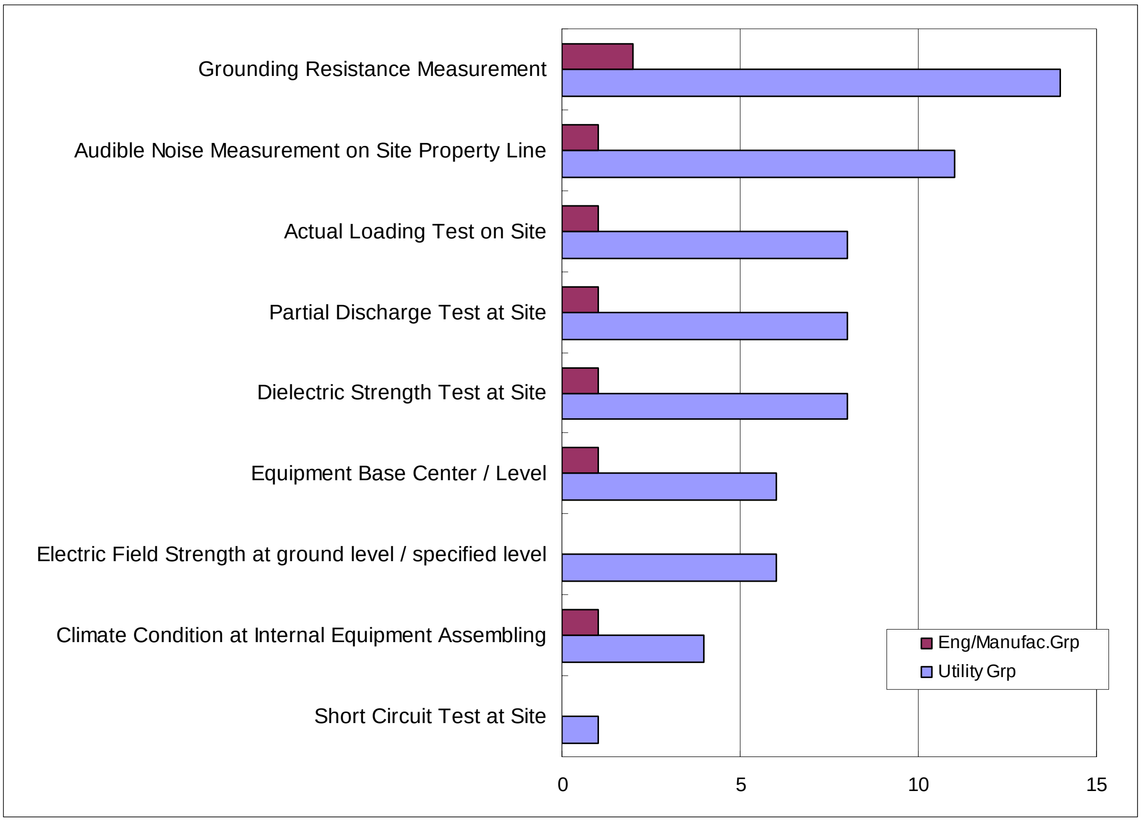


Figure C-13: Internal quality control system

Many companies have internal quality control system on "Ground resistance measurement" and "Audible noise measurement on site property line" which are only available on site.
In addition, companies must control quality on "Ground resistance measurement", "Audible noise measurement on site property line" and "Electric field strength at ground level" to meet with national/ local regulations and safety codes except for quality control.
Besides, "Short circuit test", "Climate condition at internal equipment assembles" and "Equipment base center level" are depended on manufacture quality control rather than internal quality control.

C.2.7 ACCELERATED COMPLETION CONCEPT (Q2.7)

In order to minimize the time required to finish the construction project, all the tasks needed in each stage must be improved, the aim being to facilitate and minimize the tasks in the next stage. As a consequence, the necessary work on site is considerably reduced by applying accelerated completion concept.
WG asked which of the following pre-engineering/ -fabricated/ -tested/ -commissioned/ -module items does your company use per voltage level.

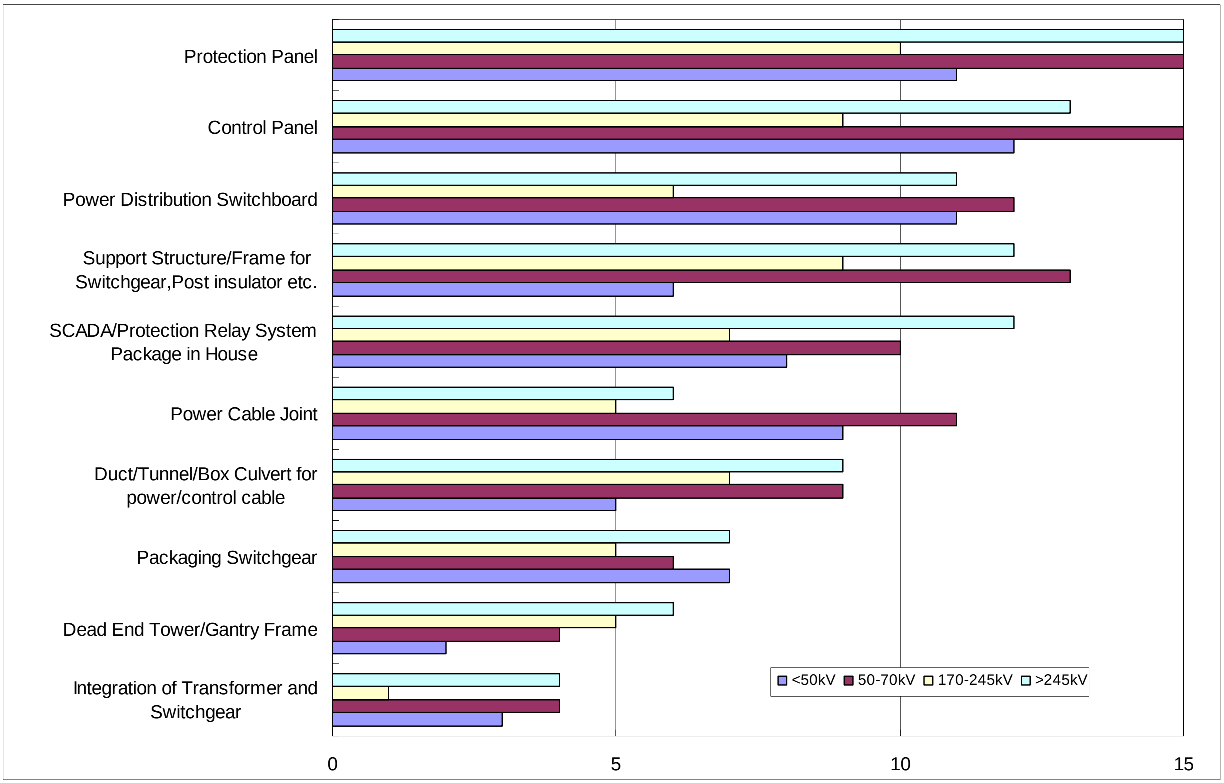


Figure C-14: Use of pre-engineering/ -fabricated/ -tested/ -commissioned/ -module items

Accelerated completion concept is commonly applied to secondary equipment such as "Protection panel", "Control panel", "Power distribution switchboard" and "SCADA system" and achieved to minimize the time required to finish the construction as well as to secure quality of construction.

On the other hand, accelerated completion concept is not common to primary equipment at the present. This concept also could be common to primary equipment if integrated technologies such as GIS (Gas Insulated Switchgear) and MTS (Mixed Technology Switchgear) become popular in the future. Then further minimization of the time reduction on the construction will be achieved.

C.3 Construction Process (Q3)

Construction process is the process of using the engineering drawings and the specified material to construct a new substation or add to an existing substation as required. The construction process involves also the physical transformation of a piece of land into a substation plot. Construction process is affected by variable and differing conditions for each project, under limited circumstances depending on the real condition of the substation site. WG asked some questions how to optimize construction process in a substation project.

C.3.1 Construction Methods for new AIS substaitons (Q3.1.1)

WG asked what kind of construction method do you apply to construct new AIS.

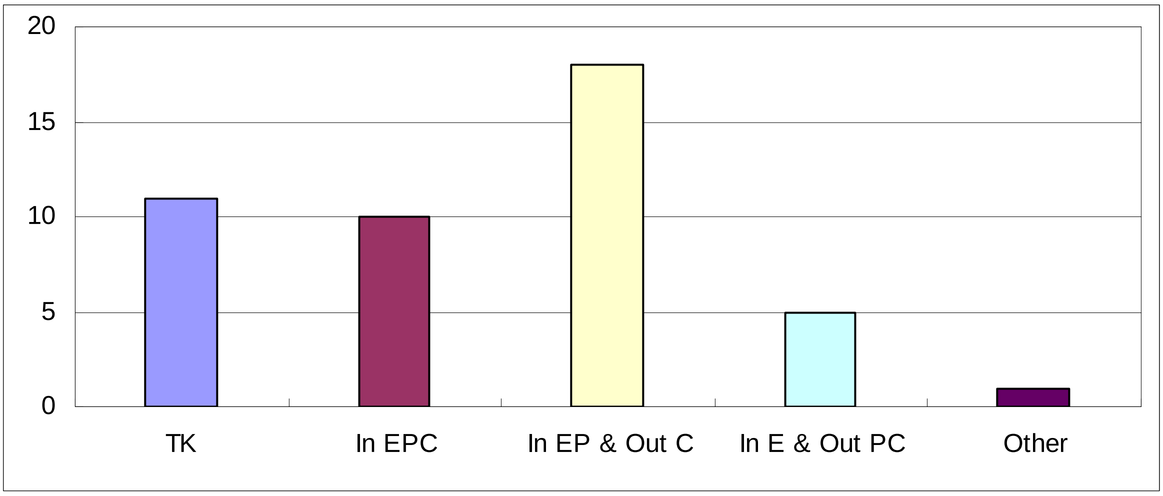


Figure C-15: Construction method for new AIS

TK: Turnkey
In EPC: In-house Engineering/ Procurement/ Construction
In EP & Out C: In-house Engineering/ Procurement and giving out Construction to contractor
In E & Out PC: n-house Engineering and giving out Procurement/ Construction to contractor

Couples of construction methods are applied to new AIS projects depend on nature of projects. “In EP & Out C” is major option and “FK” is also applied to new AIS construction projects.

C.3.2 Construction Methods for Existing AIS substations (Q3.1.2, Q3.1.3)

WG asked what kind of construction method you apply to construction on existing substation according to following cases.

- Type of construction: “Expansion”, “Replacement/ upgrading”
- Type of equipment: “Power transformer”, “Feeder”, “Bus coupler/ Bus section”
- Voltage: “Less than 50kV”, “50kV to 170kV”, “170kV to 245kV”, “More than 245kV”

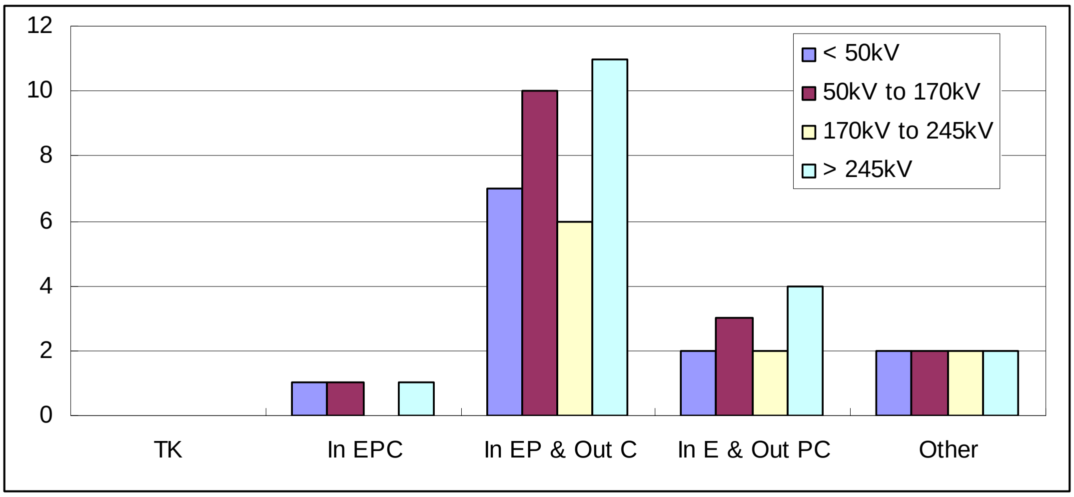


Figure C-16: Construction method for existing AIS (Power transformer expansion)

Figure C-16 shows answer in case of power transformer expansion. “In EP & Out C” is major construction method for power transformer expansion to all voltage class. And respondents

answered “TK” method is not applied to their existing substation construction.
This trend is almost the same as other cases (type of construction, type of equipment and voltage class).

C.3.3 Site Logistics (Q3.2)

During the substation project, delivery and storage of materials and equipment require coordination to ensure that the materials are delivered on time and stored properly in order to minimize the cost caused by delivery waiting time and transportation strategy.
WG asked what kind of logistics strategy do you mainly use the assets under construction.

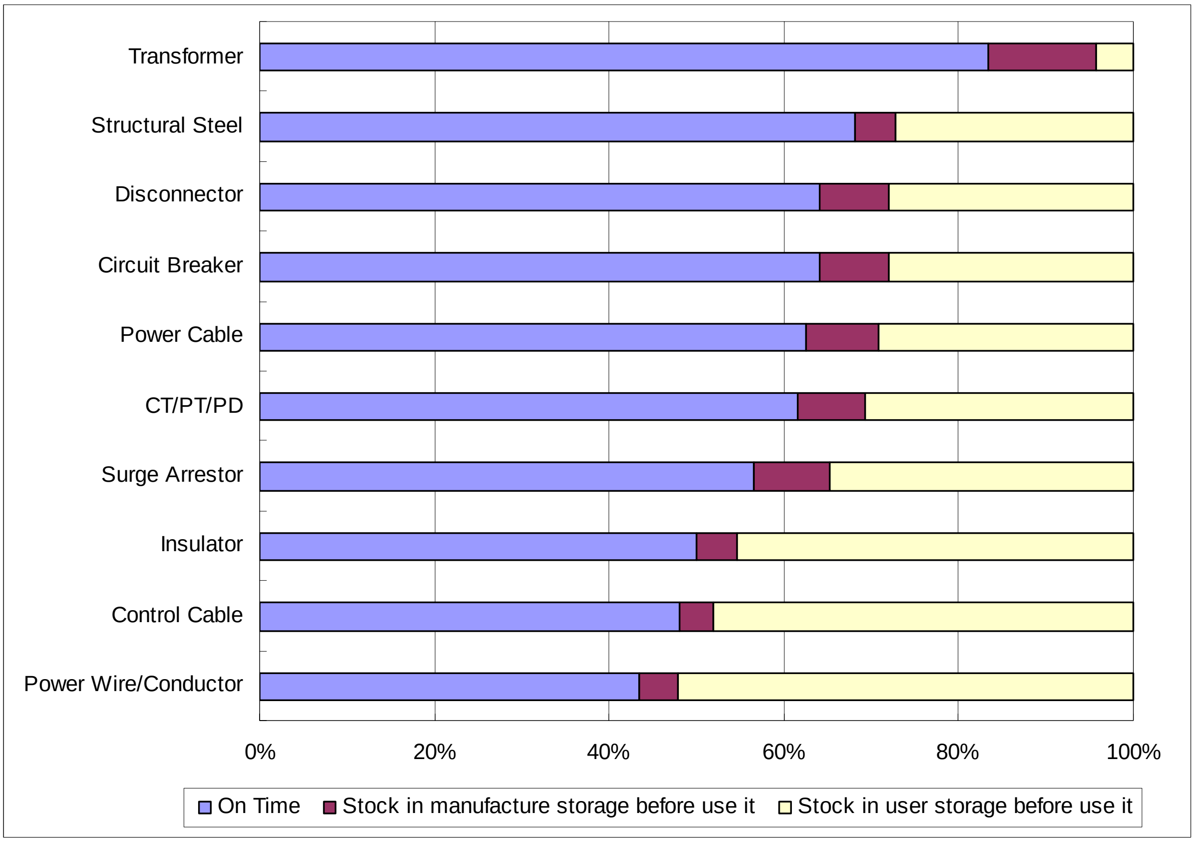


Figure C-17: Site logistic strategy

Figure C-17 shows that primary equipment such as “Transformer”, “Disconnector” and “Circuit breaker” is generally delivered to site on time to save storage space. On the other hand, construction material such as “Insulator”, “Control cable” and Power wire/ Conductor” is delivered to site in batches and stocked in user storage before use it. This option is easy to adjust minor changes of construction progress. “Stock equipment in manufacture storage before use it” is minor option to avoid an additional stock cost to manufacture.

C.3.4 Transportation (Q3.3, Q3.4)

In a substation project, transportation is the key process which ensures that the equipment is delivered to the construction site safely and on time. In addition, transportation quality control is another concern issue to avoid unnecessary defect during transportation and to save cost for re-production.

WG asked two questions with regard to transportation quality control as follows.

(1) What kind of design to deal with transportation restriction does your company adopt per voltage level?

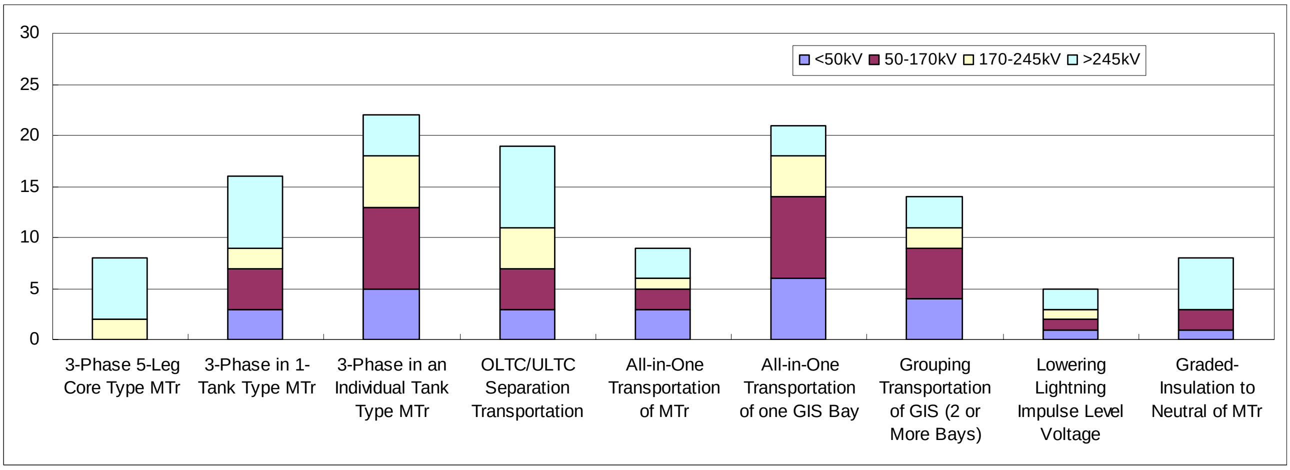


Figure C-18: Transportation restriction strategy

Huge mass transformer designed to split some segments and to deliver on site to deal with transportation restriction. Relatively small mass equipment delivers as “All in one” or “Grouping” to save transportation cost.

(2) What kind of transportation quality control does your company adopt per voltage level?

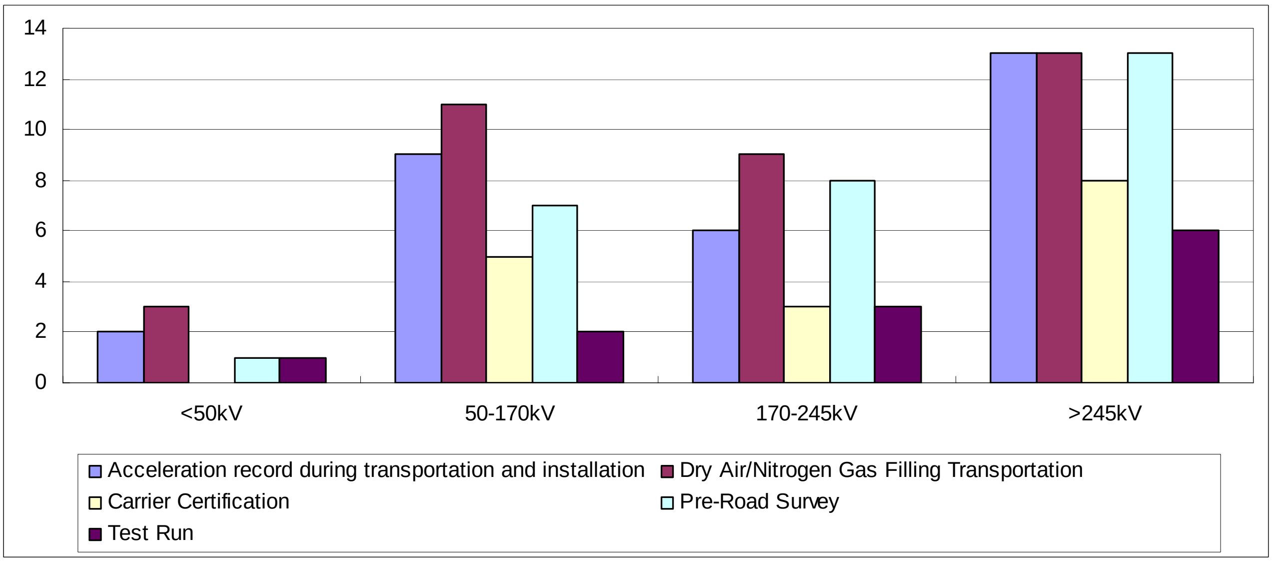


Figure C-19: Transportation quality control

“Acceleration record” and “Dry air/ Nitrogen gas filling” are widely applied to transportation quality control. In addition, more strict measure such as “Pre-road survey” and “Test run” are taken to high voltage equipment. Besides, equipment less than 50kV is rarely taken any measure for quality control. This may comes from differences of required quality and cost.

C.3.5 OUTAGE MANAGEMENT FOR EXISTING AIS SUBSTATIONS CONSTRUCTION (Q3.5, Q3.6)

Outages are a definite requirement at existing substations construction such as the extension, upgrading and replacement. Normally, utility will try to minimize the outage during the construction period. Outage schedules are usually coordinated with transmission/grid regulators to minimize the period of outage.

WG asked some questions to recognize the trend of outage management according to following cases.

- Type of construction: “Expansion”, “Replacement/ upgrading”
- Type of equipment: “Power transformer”, “Feeder”, “Bus coupler/ Bus section”
- Voltage: “Less than 50kV”, “50kV to 170kV”, “170kV to 245kV”, “More than 245kV”

(1) How do you mainly manage substation outage? (Q3.5.1, Q3.6.1)

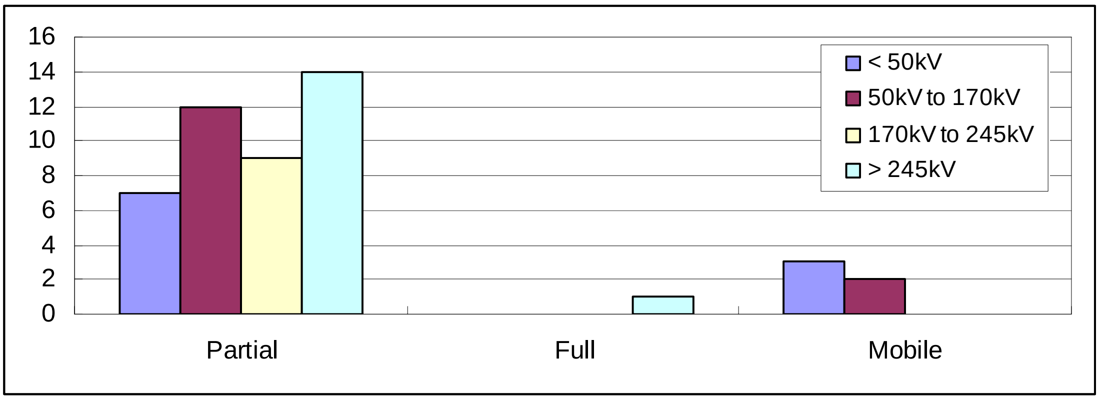


Figure C-20: Outage management (Power transformer replacement/ upgrading)

Figure C-20 shows answer in case of power transformer replacement/ upgrading. “Partial shutdown” is major outage option for power transformer replacement to all voltage class. This trend is almost the same as other cases (type of construction, type of equipment and voltage class). “Mobile” option is also used to less than 170kV transformer replacement.

(2) How long is the typical shutdown period on a daily basis? (Q3.5.2, Q3.6.2)

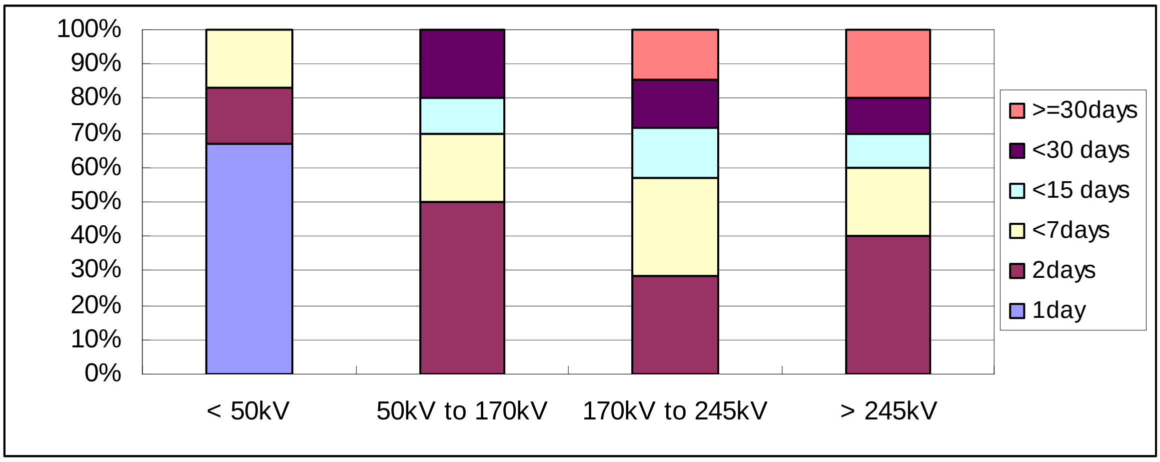


Figure C-21: Typical shutdown period (Feeder expansion)

Figure C-21 shows answer in case of feeder expansion. Approx. 80% of feeder expansion shutdown for less than 50kV is carried out within 2days. In case of feeder expansion shutdown for more than 170kV, more than 40% of shutdown is carried out more than 15days. This trend is almost the same as other cases (type of construction, type of equipment).

(3) How long is the typical construction period from the engineering design to the completion on a monthly basis? (Q3.5.3, Q3.6.3)

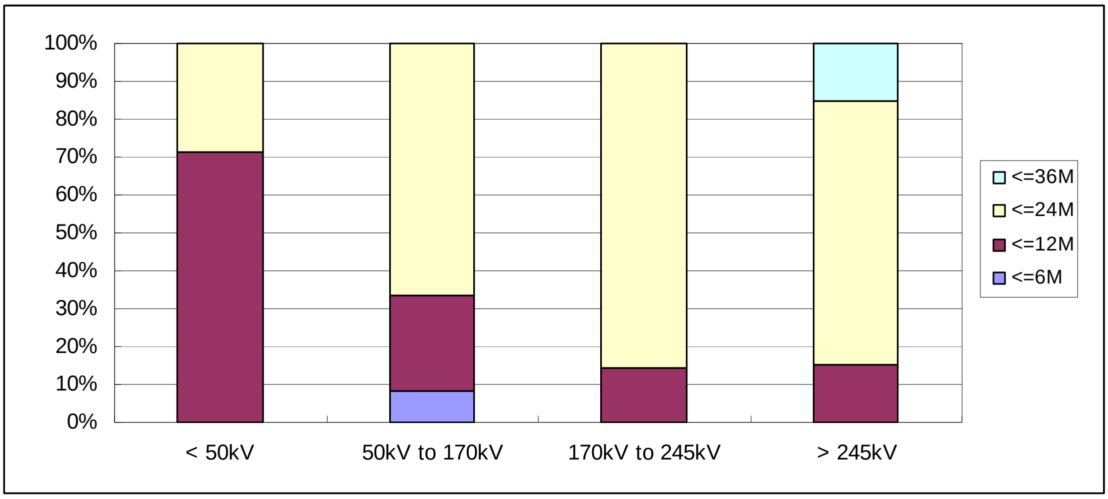


Figure C-22: Typical construction period (Power transformer replacement/ upgrading)

Figure C-22 shows answer in case of power transformer replacement/ upgrading. Approx. 70% of power transformer replacement/ upgrading construction period for less than 50kV is within 12months. In case of power transformer replacement/ upgrading construction for more than 170kV, more than 80% of construction period is more than 12 months. This trend is almost the same as other type of equipment and voltage class.

C.4 Test and Commissioning Process (Q4)

C.4.1 Test Items (Q4.1.1, Q4.1.2)

A set of tests along the different phases of their production and construction stage is identified by IEC/IEEE and other standards and is conducted to evaluate the performance and condition of equipment at each of production and construction stage.
WG asked type of tests required in practice as follows.

(1) What kind of tests do you require for Main Transformer? (Q4.1.1)

Table C-3: Requirement of test items for transformer on each test

#	Test Item	TYT	FAT	SAT	CMT
1	Visual and dimensional inspection	8	18	8	6
2	Oil tightness test	7	17	9	4
3	Vacuum test	8	16	3	3
4	Winding resistance	8	18	7	5
5	Voltage ratio	8	17	8	5
6	Polarity and phase relationship	8	16	9	5
7	Excitation current and no load loss	8	17	0	2
8	Impedance voltage and load loss (3 phase test)	8	17	0	1
9	Impedance voltage (single phase test)	6	18	0	1
10	Measurement of zero sequence impedance	12	9	1	1
11	Impulse voltage withstand test	12	15	0	0
12	Power frequency voltage withstand test	9	16	2	1
13	Switching impulse test	12	9	0	0
14	Separate-source over voltage withstand test	10	10	0	0
15	Induced over voltage withstand test and partial discharge test	9	14	0	0
16	Insulation resistance	8	15	8	6
17	Insulation power factor and capacitance	8	16	6	6
18	Noise level	9	12	1	5
19	Vibration test	9	4	0	3
20	Test on On load tap changer	11	17	3	6
21	Temperature rise test	14	7	0	1
22	Over load temperature rise test	8	7	0	1
23	Short circuit impedance at low voltage	8	10	0	1
24	No load current at low voltage	4	10	1	1
25	Auxiliary power measurement	6	12	2	3
26	Gas analysis test and oil test	7	14	8	7
27	Harmonics of the no load current	6	9	0	3
28	Core insulation resistance	3	11	5	3
29	Function test for protective accessory	6	13	11	7
30	Inspection of BCT	5	10	8	4
31	Inspection of On load tap changer	5	13	11	7
32	Inspection of Bushing	7	12	10	6
33	Inspection of cooling fans	7	12	12	6

TYT: Type Test
FAT: Factory Acceptance Test
SAT: Site Acceptance Test
CMT: Commissioning Test

Table C-3 shows the number of answers for transformer on each test items and yellow column indicates frequent answer among them. A lot of test items are duplicated and are possible to eliminate unnecessary to optimized test process.

(2) What kind of tests do you require for Circuit Breaker? (Q4.1.2)

Table C-4: Requirement of test items for circuit breaker on each test

#	Test Item	TYT	FAT	SAT	CMT
1	Visual inspection	10	14	11	9
2	Resistance of main circuit	11	16	8	3
3	Tests to verify the resistance of tripping and closing coil	9	12	6	4
4	Test to verify insulation resistance	7	9	5	6
5	Power frequency voltage test	15	14	2	3
6	Partial discharge test	13	9	2	4
7	Dielectric tests on auxiliary circuit	10	13	2	3
8	Gas tightness test	11	14	3	6
9	Test for gas density detectors	9	11	7	7
10	Mechanical operating test	13	15	5	9
11	Pressure test of enclosure	11	5	0	0
12	Seismic Test	11	0	0	0
13	Flashover Test	11	0	0	0
14	Impulse voltage withstand test	16	5	0	0
15	Short Circuit Breaking Current Test	16	3	0	0

TYT: Type Test
FAT: Factory Acceptance Test
SAT: Site Acceptance Test
CMT: Commissioning Test

Table C-4 shows the number of answers for circuit breaker on each test items and yellow column indicates frequent answer among them. A lot of test items are duplicated and are possible to eliminate unnecessary to optimized test process.

C.4.2 TRAINING (Q4.2)

WG asked if utility group (Government/ Private utility, Generation/ Transmission/ Distribution company) require following kind of training conducted by contractor/ supplier.

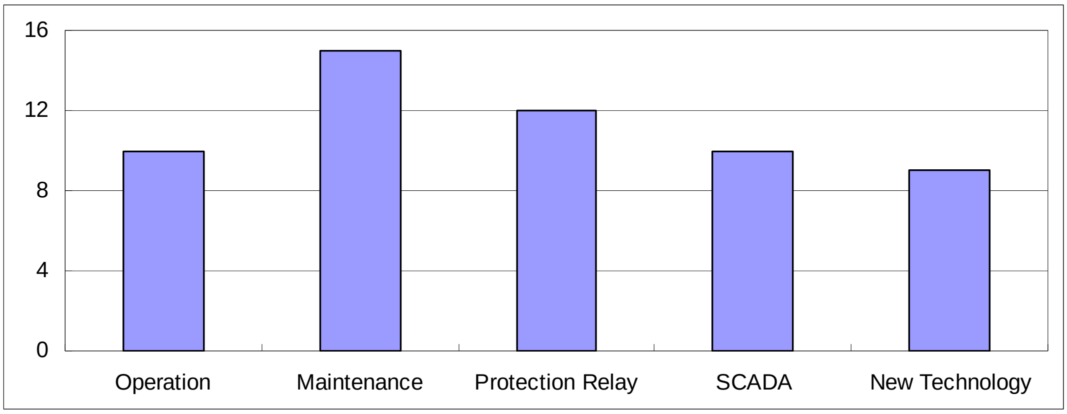


Figure C-23: Training course requirement

“Maintenance” is top training requirement followed by “Protection relay”, “SCADA”, “New technology” and “Operation. Operation is a unique technique for utility group.

C.4.3 Capital Spending (Q4.3)

WG asked the total yearly capital proportion for new substations construction and existing substations construction.

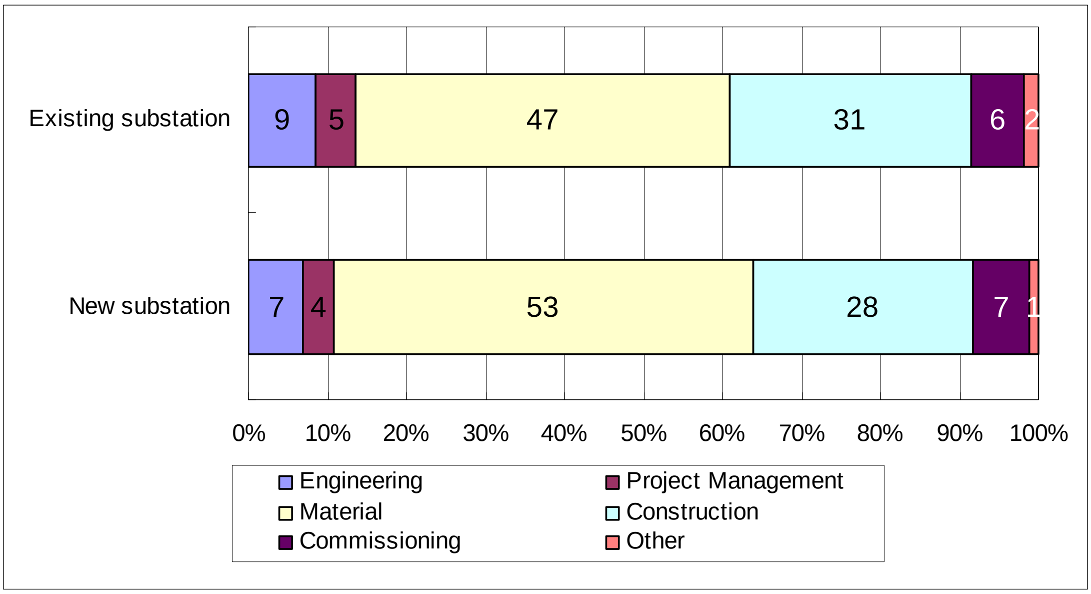


Figure C-24: Proportion of capital spending substation construction

Figure C-24 shows that approx. 50% of capital spending is “Material cost”.
“Engineering” and “Construction” in existing substation construction occupy more than in new substation construction. Optimization of “Engineering” and “Construction” is the key to optimize construction cost for existing construction project.

C.5 Procurement Process (Q5)

As part of the effort to reduce the construction cost of new and renovating existing AIS, the procurement process is the most obvious target for extraction of cost reductions. However, to obtain maximum benefits, every aspect of this process must be subjected to a thorough review, and all associated practices examined, no matter how deeply ingrained they are in the utility policies and procedures.
WG asked some questions about procurement strategies with regards to cost reduction as follows.

(1) Do you have any alliance with supplier? (Q5.1)

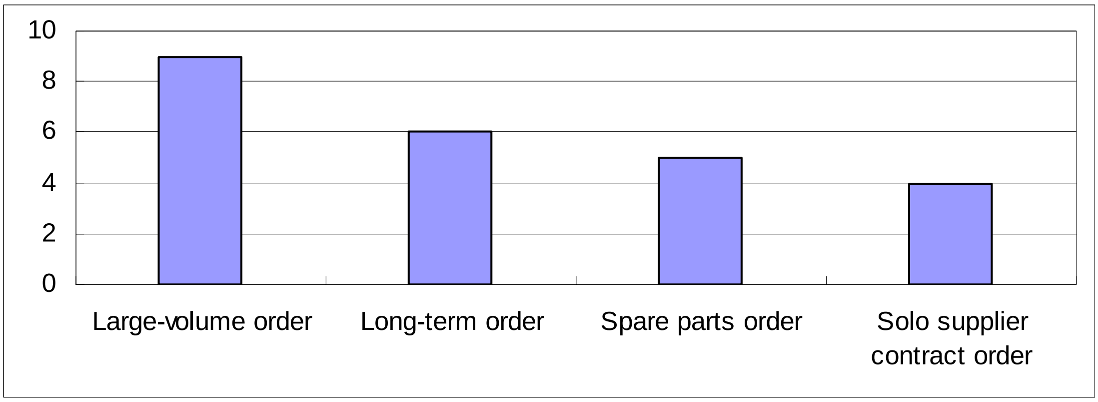


Figure C-25: Alliance strategies with supplier

Figure C-25 shows that “Large volume order” is the major strategy followed by “Long-term order” with regard to cost reduction. These strategies can lead to “Win-Win” partnerships between the Utility groups and manufacturer and supplier groups. The Utility group expects procurement cost reduction as well as a stable supply of equipment. In the meantime, the manufacturer and supplier group can set up long-term production plans as well as long-term sales prospects, and can adjust the Utility group procurement requirements.

(2) Do you have following Strategic Sourcing? (Q5.2)

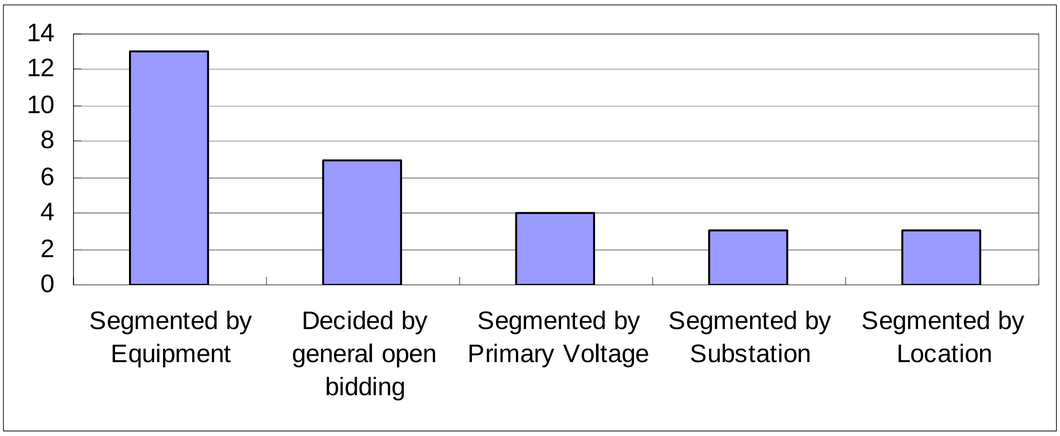


Figure C-26: Procurement strategies

“Segmented by equipment” is major strategy. It provides utility group cost reduction benefit as well as integration of maintenance skill and spare parts. “General open bidding” is also effective strategy for cost reduction. But utility group must consider carefully before taking this option because this might cause decline of equipment quality and inefficient maintainability.

(3) Do you have pre-approved system (technical e.g. type tests, quality assessment) (Q5.3)

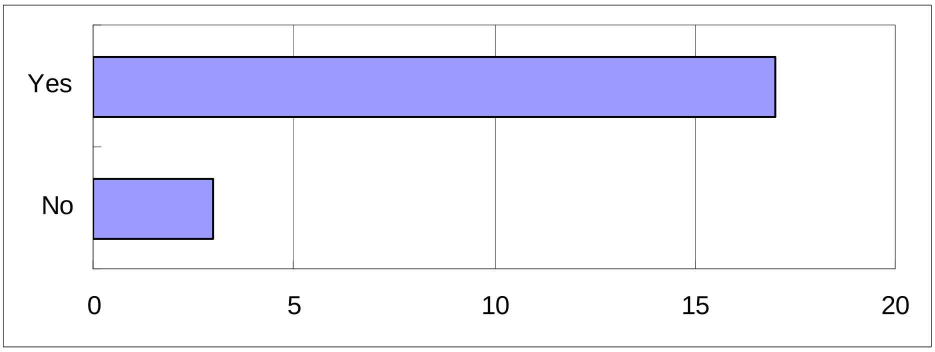


Figure C-27: Pre-approved system strategy

Most of respondents answered they have pre-approved system for primary equipment such as transformer, circuit breaker, switchgear, power cable, surge arrester. Pre-approved system provide utility group saving of engineering time and quality assurance of equipment.

(4) Have you ever employed following innovative technology to AIS for cost reduction in case of refurbishment, new construction? (Q5.4)

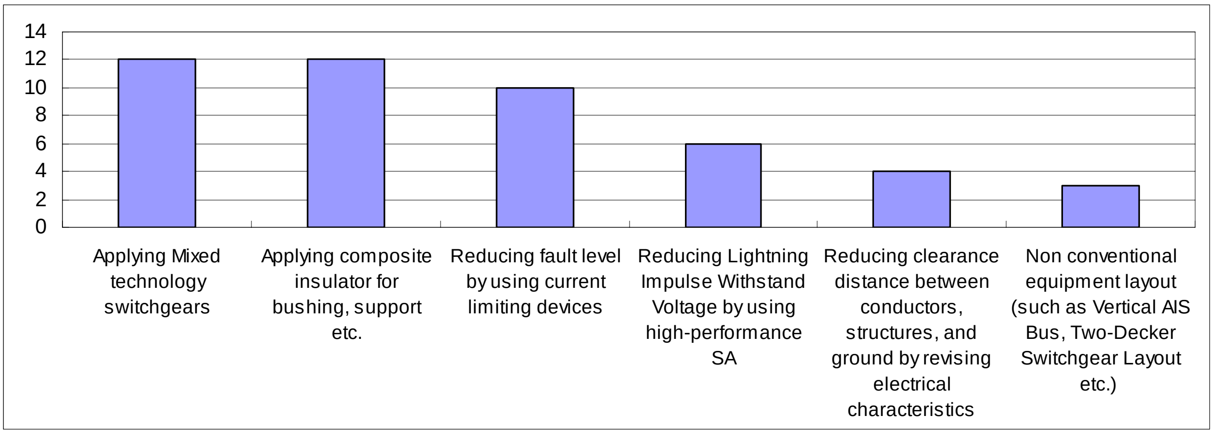


Figure C-28: Innovative technology employment

"Mixed technology" become possible solution for cost reduction as well as "Composite insulator and bushing. Revising engineering such as "Reducing LIVW", "Reducing clearance" and "Non conventional layout" are not major solution at the moment but could become effective solution in the future.

C.6 Project Closeout (Q6)

At the end of the project, after the successful commissioning of the substation, the substation installation is finally handed over to the customer / user.

Some of the requirements to close out the project include the compilation of project documentation such as drawings, manuals and so on. Other activities would include cleaning up of the construction site.

WG asked if following documents required as completion drawings. (Q6.1)

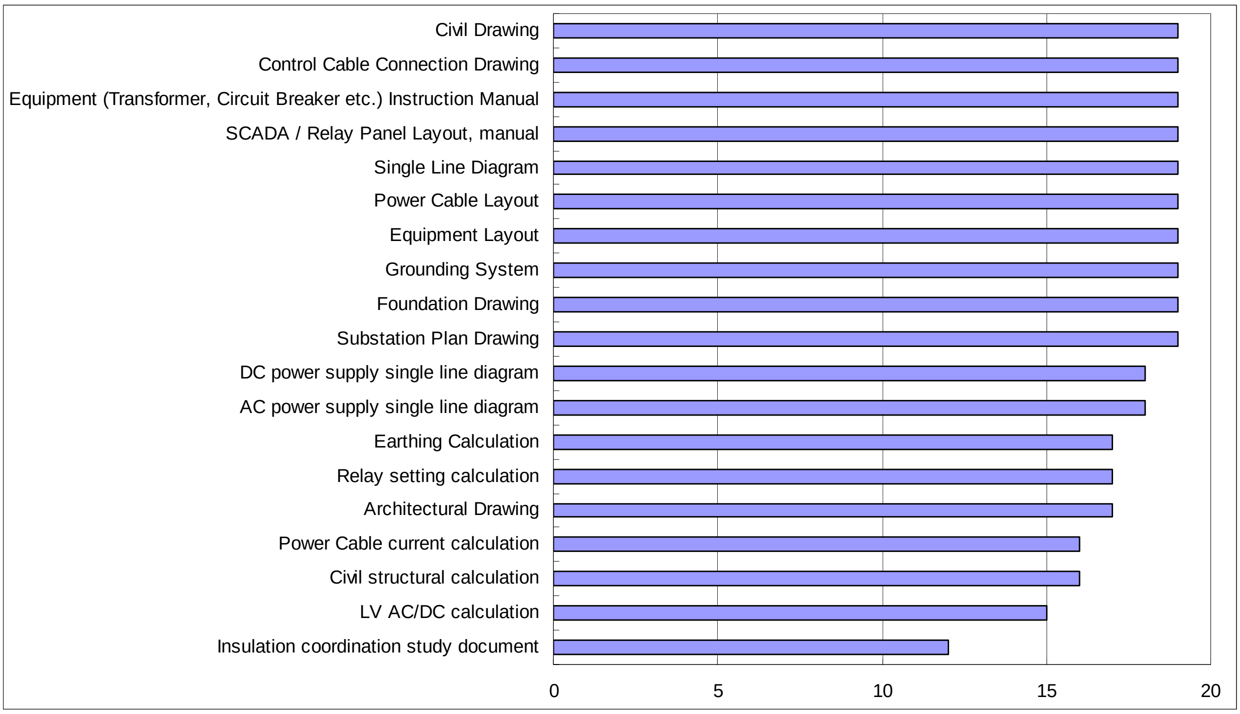


Figure C-29: Requirement of project completion documentation

Figure C-29 shows that utility group require all kinds of drawing and documents at the end of project. Completion of substation project is also starting point on operation & maintenance of substation for utility group. In order to reduce unnecessary maintenance inquiry and an additional maintenance cost, documentation is very important business both contractor and utility group.

APPENDIX D QUESTIONNAIRE

Optimizing Engineering and Construction Cost of AIS Substation

Purpose of this document

This document is a questionnaire prepared by the CIGRE Working Group B3.15 'Cost Reduction of AIS'. The purpose of the document is to assess the optimizing engineering and construction cost of Air Insulated Substations (AIS).

Scope of Work

The main objectives of this study is to identify how the following could influence the optimization engineering and construction cost of AIS.

* Equipment Standardization
* Design Standardization
* Use of New Design
* Requirements such as engineering, construction
* Use of New Technology
* Quality Control
* Commissioning
* Documentation

Background

The objective of this Working Group (WG) is to produce a set of guidelines for effective and efficient design, construction, and commissioning processes to minimize re-designs, re-works, and multiple checks. The WG will also present cost reduction opportunities achieved by using pre-engineering, pre-fabricated, pre-integrated equipment and installations for AIS. Although application may vary from one company to another depending on local requirements and conditions, common value will be identified.

To achieve this goal, this questionnaire is designed as supporting item of the brochure and will be reflected to it.

Table of Contents of Brochure (Draft)

1 Introduction
1.1 Process
1.2 Boundary of this Brochure
2 Design Process
2.1 Standardization
2.2 Constructability
2.3 Dependability
2.4 Optimized Technology, Repeatable Design
2.5 Engineering Quality Control
2.6 Use of pre-engineering / -fabricated / -tested/ -commissioned / -moduled
3 Construction Process
3.1 Construction Method
3.2 Site logistics
3.3 Transportation
3.4 Construction Quality Control
3.5 Outage Management
4 Test and Commission Process
4.1 Elimination of Duplicated Testing
4.2 Training
5 Procurement Process
5.1 Specification of Industry standard, limited custom design.
5.2 Alliances with supplier
5.3 Strategic Sourcing
5.4 Pre-qualification
5.5 Innovation
6 Project Close Out
6.1 Documentation
6.2 Site Clean-up
7 Case study

Format

Please answer questions which are related to your area as much as possible. To access the “check boxes”, please click on the check box. To access the descriptive question, please fill the provided field appropriately. We request that this survey be completed and returned to the convenor **by December 8, 2006**. The final results of the questionnaire will be fed back into a technical brochure which is going to be established by B3.15. All information supplied by respondents will be treated with professionalism and confidentiality. Upon completion of the study, a summary of the survey results will be mailed to each of the contributors.

We need your voice. We thank you for your cooperation.

Sincerely,

Koji Kawakita, Convenor CIGRE WG B3.15

Sender's Information

Name of Your Organization:	
Web address of your organization:	
Name of sender:	
Your position/ function in the organization	
Email address:	
Telephone Number:	
Fax Number:	
Postal Address:	

To be returned to:	Koji Kawakita
Address:	Electric Engineering Department
	Chubu Electric Power Co., Inc.
	1 Toshin-cho, Higashi-ku
	Nagoya, Aichi 461-8680
	Japan
Telephone:	
Fax:	
E-mail:	

Please check all applicable boxes apply and fill out all empty fields.

Q1.1 Name of Your Company & Organization: ______________________

Country Where Your Company & Organization Resides: ______________________

Number of Employees: ______________________

Q1.2 Main characteristics of your utility/ organization:

- ☐ Government utility/ organization (incl. those with major Gov. shares)
- ☐ Industrial utility/organization (fully or major private shares)
- ☐ Power Generation
- ☐ Power Transmission
- ☐ Sub-transmission/ Distribution
- ☐ Engineering Company
- ☐ Manufacturing Company
- ☐ Institute & University
- ☐ Others

Q2.1 Standardization

At the basic design/decision of equipment stage, the application of the present international standards (i.e. IEC/IEEE) contribute in providing quality to the components and shorting their construction period. Please give your position on this statement, for the following class of components, on the basis of your experience and with an eye to the cost optimization by choosing one of the two options.

(1) Power Transformers

How you think if international standards satisfactory or not?

☐ Satisfactory ☐ Unsatisfactory

Please list the reasons should you consider unsatisfactory the contribution of the standards to cost optimization.

(2) Circuit Breaker

How you think if international standards satisfactory or not?

☐ Satisfactory ☐ Unsatisfactory

Please list the reasons should you consider unsatisfactory the contribution of the standards to cost optimization.

(3) Disconnecting Switch

How you think if international standards satisfactory or not?

☐ Satisfactory ☐ Unsatisfactory

Please list the reasons should you consider unsatisfactory the contribution of the standards to cost optimization.

(4) Shielding

How you think if international standards satisfactory or not?

☐ Satisfactory ☐ Unsatisfactory

Please list the reasons should you consider unsatisfactory the contribution of the standards to cost optimization.

(5) Grounding

How you think if international standards satisfactory or not?

☐ Satisfactory ☐ Unsatisfactory

Please list the reasons should you consider unsatisfactory the contribution of the standards to cost optimization.

Q 2.2 Configuration

Following questions are related to specification / standard configuration of AIS substations.

(1) Standard Bus Configuration

Which of the following bus configurations does your company have per voltage level?

Please indicate the voltage level of the substation in the appropriate category.

#	Bus Configuration	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Single-Bus w/o Bus Section				
2	Single-Bus w Bus Section (Segmented Bus)				
3	Single Ring-Bus w Bus Section (s) (Segmented Bus)				
4	Double-Bus w/o Bus Coupler				
5	Double-Bus Double Breaker				
6	Double-Bus w Transfer Bus w/o Bus Coupler				
7	Double-Bus w One Bus Coupler				
8	Double-Bus w Two Bus Couplers & Two Sections (Segmented Bus)				
9	1 1/2 Breaker Bus				
10	Ring Bus				
11	Other: Please Elaborate				

(Single line diagrams are provided in another sheet.)

(2) Insulation coordination

Please elaborate your past experiences how to optimize insulation coordination to meet with your design condition.

(3) Allowable Minimum Clearances

Does your company have following clearance specifications of AIS substations?

If yes, please list typical two example with maximum rated voltage (Um).

(1) For the receiving steel structure: Between live conductors phase in air

(2) For the equipment: Between live conductor and grounding

(3) For safety: Distance from live conductors to road on which traveling vehicles runs when patrol, inspection and maintenance

(4) For live work: Distance from live work position and live conductors

	Ex. #1		Ex. #2	
(1) Please Select	(m)	(kV)	(m)	(kV)
(2) Please Select	(m)		(m)	
(3) Please Select	(m)		(m)	
(4) Please Select	(m)		(m)	

Q2.3 Constructability

(1) Do you control construction deviations from design? ***Please Select***

If yes, please elaborate.

(2) Do you have a formal feedback process from construction to modify engineering star ***Please Select***

If yes, please elaborate.

(3) Is constructor involved at the conceptual phase stage of substation proj ***Please Select***

If yes, please elaborate.

Q2.4 Dependability (Maintainability)

(1) Do you consider maintenance aspects from design? ***Please Select***

If yes, please elaborate.

(2) Do you have a formal feedback process from maintenance to modify engineering sta ***Please Select***

If yes, please elaborate.

(3) Is maintenance Engineer involved in the conceptual phase of a substatic ***Please Select***

If yes, please elaborate.

Q2.5 Repeatable design specification (Repeatability)

Which of the following technology, repeatable design specifications does your company have per voltage level?

Please indicate the voltage level of the substation in the appropriate category.

	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Do you have template Design? (Including minor modifications)				
	Are there deviations from existing template design for;				
2	- Bus Layout				
3	- Switchgear Layout				
4	- Main Transformer Design/Specification				
5	- Switchgear Design/Specification				
6	- Insulation Design/Specification				
7	- Bus rated current specification				
8	- Instrument transformer specifications				
9	- Power Cable Design/Specification				
10	- Reactive Power Compensation Equipment Design/Specificat				
11	- Protection Relay Design/Specification				
12	- Station services supply				
13	- Building Layout/Room Space				
14	- Seismic Specification				
15	- Lightning Specification				
16	- Contamination such as Salt, Sand and Dust Specification				
Other: Please Elaborate					

Q2.6 Engineering Quality Control

Q2.6.1 Does your company have any in-house design standard for ***Please Select***

If yes, what kind of items does the standard include?

Q2.6.2 Does your company have following design engineers' education syst ***Please Select***

If yes, please check related check box(es)

- ☐ In-House Substation Design Education Course
- ☐ Substation Design Education Course in Outside Companies
- ☐ Design Case Competition
- ☐ Training Course in Equipment Manufacturers
- ☐ Other: Please Elaborate:

Q2.6.3 Does your company have following internal licensing system / restriction imposed on design engineers? ***Please Select***

If yes, please check related check box(es)

- ☐ A Certain Level of Work Experience
- ☐ A Certain Level of Inspection Experience for primary circuit
- ☐ A Certain Level of Inspection Experience for secondary circuit
- ☐ Other: Please Elaborate

Q2.6.4 Does your company have following internal quality control check system other than quality control system supplied by manufacturers / contractors at the constru ***Please Select***

If yes, please check related check box(es)

- ☐ Equipment Base Center / Level
- ☐ Climate Condition at Internal Equipment Assembling
- ☐ Electric Field Strength at ground level / specified level
- ☐ Short Circuit Test at Site
- ☐ Dielectric Strength Test at Site
- ☐ Partial Discharge Test at Site
- ☐ Actual Loading Test on Site
- ☐ Audible Noise Measurement on Site Property Line
- ☐ Grounding Resistance Measurement
- ☐ Other: Please Elaborate

Q2.7 Use of pre-engineering / -fabricated / -tested/ -commissioned / -module

Which of the following pre-engineering/ -fabricated/ -tested/ -commissioned/ - module items does your company use per voltage level?

Please indicate the voltage level of the substation in the appropriate category.

#	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Duct/Tunnel/Box Culvert for power/control cable				
2	Dead End Tower/Gantry Frame				
3	Support Structure/Frame for Switchgear, Post insulator etc.				
4	Packaging Switchgear				
5	Integration of Transformer and Switchgear				
6	Control Panel				
7	Protection Panel				
8	Power Cable Joint				
9	Power Distribution Switchboard				
10	SCADA/Protection Relay System Package in House				
11	Other: Please Elaborate				

Q3.Construction Process

Q3.1.1 Construction Method

What Kind of Construction Method do you use to construct a new AIS?

☐ Turnkey

☐ In-house engineering/procurement/construction

☐ In-house engineering/procurement and giving out construction to contractor

☐ In-house engineering and giving out procurement and construction to contractor

☐ Other: Please Elaborate

Q3.1.2 What kind of method do you mainly use in case of following expansions?

#	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Power Transformer Expansion				
2	Feeder Expansion				
3	Bus Coupler and/or Bus Section Installation				

1. Turnkey
2. In-house engineering/procurement/construction
3. In-house engineering/procurement, and giving out construction to contractor
4. In-house engineering, and giving out procurement and construction to contractor
5. Other: Please Elaborate with Item number

Q3.1.3 What kind of method do you mainly use in case of following replacement and/or upgrading?

#	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Power Transformer				
2	Feeder				
3	Bus Coupler and/or Bus Section				

1. Turnkey
2. In-house engineering/procurement/construction
3. In-house engineering/procurement, and giving out construction to contractor
4. In-house engineering, and giving out procurement and construction to contractor
5. Other: Please Elaborate with Item number

Q3.2 Site logistics

What kind of logistics strategy do you mainly use the assets under construction in following equipment/materials?

#	Item	On Time delivery	Stock in manufacture storage before use it	Stock in user storage before use it	Other
1	Power Transformer	☐	☐	☐	☐
2	Circuit Breaker	☐	☐	☐	☐
3	Disconnector	☐	☐	☐	☐
4	Instrument transformers	☐	☐	☐	☐
5	Surge Arrestor	☐	☐	☐	☐
6	Power Cable	☐	☐	☐	☐
7	Control Cable	☐	☐	☐	☐
8	Power Wire/Conductor	☐	☐	☐	☐
9	Insulator	☐	☐	☐	☐
10	Structural Steel	☐	☐	☐	☐

If 'Other', please elaborate how to manage site logistics.

Q3.3 Transportation

What kind of design to deal with transportation restriction does your company adopt per voltage level?

		Voltage Level (kV)			
#		<50	50-170	170-245	>245
1	On-Site Reassembly MTr in dust and humidity controlled room	☐	☐	☐	☐
2	1-Phase MTr	☐	☐	☐	☐
3	3-Phase 5-Leg Core Type MTr	☐	☐	☐	☐
4	3-Phase in 1-Tank Type MTr	☐	☐	☐	☐
5	3-Phase in an Individual Tank Type MTr	☐	☐	☐	☐
6	OLTC/ULTC Separation Transportation	☐	☐	☐	☐
7	All-in-One Transportation of MTr	☐	☐	☐	☐
8	All-in-One Transportation of one GIS Bay	☐	☐	☐	☐
9	Grouping Transportation of GIS (2 or More Bays)	☐	☐	☐	☐
10	Lowering Lightning Impulse Level Voltage	☐	☐	☐	☐
11	Graded-Insulation to Neutral of MTr	☐	☐	☐	☐

MTr: Main Power Transformer

Please elaborate cost implementation

Q3.4 Transportation Quality Control

What kind of transportation quality control does your company adopt per voltage level?

		Voltage Level (kV)			
#		<50	50-170	170-245	>245
1	Acceleration record during transportation and installation	☐	☐	☐	☐
2	Dry Air/Nitrogen Gas Filling Transportation	☐	☐	☐	☐
3	Carrier Certification	☐	☐	☐	☐
4	Pre-Road Survey	☐	☐	☐	☐
5	Test Run	☐	☐	☐	☐

Q3.5 Outage Management for Expansions

Q3.5.1 How do you mainly manage substation outage/shutdown in the following expansions?

#	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Power Transformer Expansion				
2	Feeder Expansion				
3	Bus Coupler and/or Bus Section Installation				

P: Partial Shutdown in Step by Step, F: Full Shutdown,

M: Use of Mobile Substation, T: Use of Temporary Substation

Please elaborate cost implementation

Q3.5.2 How long is the typical shutdown period in the expansion on a daily basis?

#	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Power Transformer Expansion				
2	Feeder Expansion				
3	Bus Coupler and/or Bus Section Installation				

Please elaborate cost implementation

Q3.5.3 How long is the typical expansion period from the engineering design to the completion on a monthly basis?

#	Item	Voltage Level (kV)			
		<50	50-170	170-245	>245
1	Power Transformer Expansion				
2	Feeder Expansion				
3	Bus Coupler and/or Bus Section Installation				

Please elaborate cost implementation

Q3.6 Outage Management for Replacement and/or Upgrading

Q3.6.1 How do you mainly manage substation outage/shutdown in the following replacement and/or upgrading?

		Voltage Level (kV)			
#	Item	<50	50-170	170-245	>245
1	Power Transformer				
2	Feeder				
3	Bus Coupler and/or Bus Section				

P: Partial Shutdown in Step by Step, F: Full Shutdown,

M: Use of Mobile Substation, T: Use of Temporary Substation

Please elaborate cost implementation

Q3.6.2 How long is the typical shutdown period in replacement and/or upgrading on a daily basis?

		Voltage Level (kV)			
#	Item	<50	50-170	170-245	>245
1	Power Transformer Expansion				
2	Feeder Expansion				
3	Bus Coupler and/or Bus Section Installation				

Please elaborate cost implementation

Q3.6.3 How long is the typical replacement and/or upgrading period from the engineering design to the completion on a monthly basis?

		Voltage Level (kV)			
#	Item	<50	50-170	170-245	>245
1	Power Transformer Expansion				
2	Feeder Expansion				
3	Bus Coupler and/or Bus Section Installation				

Please elaborate cost implementation

Q4.Test and Commission Process

Q4.1 Elimination of Duplicated Testing

Q.4.1.1 What kind of tests do you require for Main Transformer?

#	Test Item	TYT	FAT	SAT	CMT
1	Visual and dimensional inspection	☐	☐	☐	☐
2	Oil tightness test	☐	☐	☐	☐
3	Vacuum test	☐	☐	☐	☐
4	Winding resistance	☐	☐	☐	☐
5	Voltage ratio	☐	☐	☐	☐
6	Polarity and phase relationship	☐	☐	☐	☐
7	Excitation current and no load loss	☐	☐	☐	☐
8	Impedance voltage and load loss (3 phase test)	☐	☐	☐	☐
9	Impedance voltage (single phase test)	☐	☐	☐	☐
10	Measurement of zero sequence impedance	☐	☐	☐	☐
11	Impulse voltage withstand test	☐	☐	☐	☐
12	Power frequency voltage withstand test	☐	☐	☐	☐
13	Switching impulse test	☐	☐	☐	☐
14	Separate-source over voltage withstand test	☐	☐	☐	☐
15	Induced over voltage withstand test and partial discharge test	☐	☐	☐	☐
16	Insulation resistance	☐	☐	☐	☐
17	Insulation power factor and capacitance	☐	☐	☐	☐
18	Noise level	☐	☐	☐	☐
19	Vibration test	☐	☐	☐	☐
20	Test on On load tap changer	☐	☐	☐	☐
21	Temperature rise test	☐	☐	☐	☐
22	Over load temperature rise test	☐	☐	☐	☐
23	Short circuit impedance at low voltage	☐	☐	☐	☐
24	No load current at low voltage	☐	☐	☐	☐
25	Auxiliary power measurement	☐	☐	☐	☐
26	Gas analysis test and oil test	☐	☐	☐	☐
27	Harmonics of the no load current	☐	☐	☐	☐
28	Core insulation resistance	☐	☐	☐	☐
29	Function test for protective accessory	☐	☐	☐	☐
30	Inspection of BCT	☐	☐	☐	☐
31	Inspection of On load tap changer	☐	☐	☐	☐
32	Inspection of Bushing	☐	☐	☐	☐
33	Inspection of cooling fans	☐	☐	☐	☐

If 'Other', please elaborate.

TYT: Type Test FAT: Factory Acceptance Test, SAT: Site Acceptance Test, CMT: Commissioning Test

Q4.1.2 What kind of tests do you require for Circuit Breaker?

#	Test Item	TYT	FAT	SAT	CMT
1	Visual inspection	☐	☐	☐	☐
2	Resistance of main circuit	☐	☐	☐	☐
3	Tests to verify the resistance of tripping and closing coil	☐	☐	☐	☐
4	Test to verify insulation resistance	☐	☐	☐	☐
5	Power frequency voltage test	☐	☐	☐	☐
6	Partial discharge test	☐	☐	☐	☐
7	Dielectric tests on auxiliary circuit	☐	☐	☐	☐
8	Gas tightness test	☐	☐	☐	☐
9	Test for gas density detectors	☐	☐	☐	☐
10	Mechanical operating test	☐	☐	☐	☐
11	Pressure test of enclosure	☐	☐	☐	☐
12	Seismic Test	☐	☐	☐	☐
13	Flashover Test	☐	☐	☐	☐
14	Impulse voltage withstand test	☐	☐	☐	☐
15	Short Circuit Breaking Current Test	☐	☐	☐	☐

If 'Other', please elaborate.

TYT: Type Test FAT: Factory Acceptance Test, SAT: Site Acceptance Test, CMT: Commissioning Test

Q4.2 Training

(1)Does your company, owner, or utility require following kind of training conducted by contractor / supplier?

If yes, please check, and fill the length in hour and select its effectiveness

- ☐ Operation Training ________ Hours ***Please Select***
- ☐ Maintenance Training ________ Hours ***Please Select***
- ☐ Protection Relay Training ________ Hours ***Please Select***
- ☐ SCADA Training ________ Hours ***Please Select***
- ☐ Installed New Technology Trainin ________ Hours ***Please Select***
- ☐ Other: Please Elaborate.

Q4.3 Capital Spending

(1)Considering the total yearly capital program for substations, please indicate, on average, the following percentages for new substation projects.

Engineering ________ %

Project Management ________ %

Material ________ %

Construction ________ %

Commissioning ________ %

Other, Please Specify with % ________ % ________________

(2)Considering the total yearly capital program for substations, please indicate, on average, the following percentages for refurbishment and/or addition of substation equipment.

Engineering ________ %

Project Management ________ %

Material ________ %

Construction ________ %

Commissioning ________ %

Other, Please Specify with % ________ % ________________

Q5. Procurement Process

Q5.1 Alliances with supplier

Do you have any alliance with supplier?

☐ Sole supplier contract order for discount

☐ Long-term order for discount

☐ Large-volume order for discount

☐ Spare parts order for equipment performance

Q5.2 Strategic Sourcing

Do you have following Strategic Sourcing?

☐ Source is segmented by Primary Voltage

☐ Source is segmented by Equipment

☐ Source is segmented by Substation

☐ Source is segmented by Location

☐ Source is decided by general open bidding

Q5.3 Pre-qualification

Do you have pre-approved system (technical e.g. type tests, quality assessment) Yes/ No

Please Select

If yes, on what kind of equipment do you apply?

Please Elaborate:

Q5.4 Innovation

Have you ever employed following innovative technology to AIS for cost reduction in case of refurbishment, new construction?

☐ Reducing Lightning Impulse Withstand Voltage by using high-performance SA

☐ Reducing clearance distance between conductors, structures, and ground by revising electrical characteristics

☐ Reducing fault level by using current limiting devices

☐ Applying Mixed technology switchgears

☐ Applying composite insulator for bushing, support etc.

☐ Non conventional equipment layout (such as Vertical AIS Bus, Two-Decker Switchgear Layout etc.)

☐ Please provide case study /actual example.

Q6.Project Close Out

Q6.1 Documentation

Are following documents required as completion drawings?

- ☐ Substation Plan Drawing
- ☐ Foundation Drawing
- ☐ Grounding System
- ☐ Equipment Layout
- ☐ Power Cable Layout
- ☐ Single Line Diagram
- ☐ SCADA / Relay Panel Layout, manual
- ☐ Equipment (Transformer, Circuit Breaker etc.) Instruction Manual
- ☐ AC power supply single line diagram
- ☐ DC power supply single line diagram
- ☐ Control Cable Connection Drawing
- ☐ Architectural Drawing
- ☐ Civil Drawing
- ☐ Relay setting calculation
- ☐ LV AC/DC calculation
- ☐ Civil structural calculation
- ☐ Earthing Calculation
- ☐ Power Cable current calculation
- ☐ Insulation coordination study document

Please list any other special documents.

Q6.2 Site Clean-up

What kind of work do you perform at Site Clean-up? Please Elaborate.

Q7 Negative force for optimization and cost reduction on construction of AIS substations

Please elaborate what is the major negative force for optimization and cost reduction on construction of AIS substations in your experience.

THANK YOU VERY MUCH FOR YOUR COOPERATION