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Author(s):	John (Jack) Whippen
Contractor:	Black & Veatch Special Projects Corp.
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KANDAHAR HELMAND POWER PROJECT DESIGN MANUAL POWER DELIVERY

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1.0 Introduction

This document describes electrical and civil/structural design criteria to be used for the design of new substations, transmission lines, and distribution systems in Afghanistan for the United States Agency for International Development (USAID).

1.1 Codes and Standards

The design and specification of work shall be in accordance with all applicable laws and regulations of the government of Afghanistan and with the applicable local codes and ordinances and relevant standards referred to in various sections. The project shall also be in accordance with USAID Guidelines (most recent applicable standard) and the OSHA regulations.

All material used and equipment supplied and all workmanship and tests shall be in accordance with the latest editions of IEC and ISO Standards, or where International Standards are not applicable, with national standards such as ANSI, ASA, ASTM, BW, EN, IEEE, NEMA, or VDE + DIN. Where such standards and codes are national or relate to a particular country or region, other authoritative standards that ensure substantial equivalence to the standards and codes specified will be acceptable.

To reduce hazards to labor, the Project shall be erected following local safety laws and the standards and regulations in force at the start of the project. These shall include norms, regulations, standards, and legal norms such as, but not limited to, the following:

American Concrete Institute (ACI).

American National Standards Institute (ANSI).

American Society for Testing and Materials (ASTM).

ANSI/ASCE-Standard 10-90, Design of Latticed Steel.

ASCE/SEI 48-05 Design of Steel Transmission Pole Structures.

BS 215 Aluminum Conductors and Aluminum conductors, Steel-Reinforced – for Overhead Power Transmission, Part 2: Aluminum Conductors, Steel-Reinforced.

BS 4449 Steel for Reinforcement of Concrete – Weldable Reinforcing Steel – Bar, Coil and Decoiled Product – Specification.

BS 5467 Cables with Thermosetting Insulation for Electricity Supply for Rated Voltages of Up To and Including 600/1000V.

BS 5896 Specification for High Tensile Steel Wire and Strand for the Prestressing of Concrete.

DIN 126, 127, 267, 555, Bolts, Washers, Nuts.

DIN 1045 Concrete, Reinforced and Prestressed Concrete Structure.

DIN 48204 Steel Reinforced Aluminum Stranded Conductors.

EN/ISO 2063 Thermal Spraying – Metallic and Other Inorganic Coatings – Zinc, Aluminum and Their Alloys.

EN 197-1 Cement, Part 1: Composition, specifications and conformity criteria for common cements.

EN 1370 Founding – Surface Roughness Inspection by Visual Tactile Comparators.

EN 50503 Fluids for Electrotechnical applications.

EN 60044 Instrument transformers.

EN 60071-1 Insulation Coordination.

EN 60076 Power Transformers.

EN 60099-4 Surge arresters.

EN 60137 Insulating bushings for alternating voltages above 1000V.

EN 60156 Insulating Liquids – Determination of the Breakdown Voltage Power Frequency – Test method.

EN 60270 Partial Discharge Measurements.

EN 60296 Fluids for Electrotechnical Applications – Unused Mineral Insulating Oils for Transformers and Switchgear.

EN 60305 Insulators for overhead lines with a nominal voltage above 1000 V - Ceramic or glass insulator units for AC systems - Characteristics of insulator units of the cap and pin type.

EN 60372 Locking devices for ball and socket couplings of' string insulator units - Dimensions and tests.

EN 60383 Insulators for overhead lines with a nominal voltage above 1000 V.

EN 60437 Radio interference test on high-voltage insulators.

EN 60517 Gas-Insulated Metal Enclosed Switchgear.

EN 60529 Degrees of protection provided by enclosures.

EN 60652 Full Scale Tower Load Test.

EN 60814 Insulating Liquids – Oil-Impregnated Paper and Pressboard – Determination of Water by Automatic Coulometric Karl Fischer Titration.

EN 60694 Common specifications for high voltage switchgear and control gear standards.

EN 60889 Hard-drawn aluminum wire for overhead line conductors.

EN 61166 High-voltage alternating current circuit-breakers - Guide for seismic qualification of high-voltage alternating current circuit-breakers.

EN 62271-100 High-voltage switchgear and controlgear: alternating current circuit breaker.

EN 62271-102 High-voltage switchgear and control gear: alternating current disconnectors and earthing switches.

EN 62271-200 High-voltage switchgear and controlgear: AC metal-enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52 kV.

IEC 815 Guide for the selection of insulators in respect of polluted conditions.

IEC 60060 High voltage test techniques.

IEC 60120 Dimensions of ball and socket couplings of string insulator units.

IEC 60265-2 High voltage switches for rated voltage of 52 kV and above.

IEC 60364-5-54 Selection and erection of electrical equipment – Earthing arrangements, protective conductors, and protective bonding conductors.

IEC 60797 Residual strength of string insulator units of glass or ceramic material for overhead lines after mechanical damage of the dielectric.

IEC 60826 Design Criteria of Overhead Transmission Lines.

IEC 60888 Zinc-coated steel wires for stranded conductors.

IEC 61089 Round wire concentric lay overhead electrical stranded conductors.

IEEE 80 Guide for Safety in AC Substation Grounding.

IEEE 81 Guide for measuring earth resistivity, ground impedances and earth surface potentials of a grounding system.

IEEE 524 – IEEE Guide to Installation of Overhead Transmission Line Conductors.

IEEE 946 – Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations.

IEEE 979 – IEEE Guide For Substation Fire Protection.

IEEE 980 – IEEE Guide for Containment and Control of Oil Spills in Substations.

International Organization for Standardization (ISO).

GOST 13109-97 Electrical Energy Quality Norms in General Purpose Electrical Power Supply Systems.

National Electrical Safety Code (NESC).

National Fire Protection Association (NFPA).

NFPA 70 – National Electrical Code.

NFPA 850 – Recommended Practice For Fire Protection For Electric Generating Plants and High Voltage Direct Current Converter Systems.

1.2 Soil Characteristics

The soil characteristics shall be obtained for each site to be used for designing the grounding system, foundations and grading for the site.

1.3 Seismic Characteristics

The following spectral response values are based on a 10 percent probability of exceedance in a 50 year period.

Kajakai	
Seismic Design Data	
Occupancy Category/Importance Factor (Seismic Loads), I_E	III / 1.25
Short Period Mapped Spectral Acceleration, S_S	0.16 g
One Second Period Mapped Spectral Acceleration, S_1	0.07 g
Site Class	Note 1

Kandahar	
Seismic Design Data	
Occupancy Category/Importance Factor (Seismic Loads), I_E	III / 1.25
Short Period Mapped Spectral Acceleration, S_S	0.16 g
One Second Period Mapped Spectral Acceleration, S_1	0.07 g
Site Class	Note 1

Note 1: The Site Class Definition (A-F) shall be determined based on the results of the geotechnical study for the site and IBC2006, Table 1613.5.2 (IBC2003, Table 1615.1.1).

For equipment procurements only and when the actual site conditions are not known, the Site Class Definition D shall be used in accordance with IBC. Site class D shall be used for equipment procurement if a site geotechnical study is not available or if the equipment will be used at multiple sites.

1.4 Meteorology

The site specific (outdoor) weather conditions are as follows:

Air Temperature	
Average	+24°C
Maximum	+48°C
Minimum	-24°C
Wind	
Maximum Velocity (3 second gust)	41 m/s (148 km/h)
Wind and Dust	Sand and dust storms in summer
Isokeraunic Level	19 thunderstorms days/year
Altitude	Less than 1,100 meters msl
Pollution	IEC Level IV
Rainfall Rate	50 mm/hr

2.0 Substation Design Criteria

The new substation shall be arranged in one of following configurations:

Node or switching substations will be arranged in a breaker and one-half configuration with multiple line and transformer positions as indicated in the long term plan. The site will be graded for the future positions, but equipment and grounding will not be installed, unless required to meet safe step and touch potentials. Motor operated line/XFMR disconnect switches will be installed to provide SCADA control. Breaker disconnect and grounding switches will be manually operated.

Distribution substations will be arranged in a three breaker ring bus configuration with two line and one transformer position. The configuration will be designed such that it can be easily expanded to a four breaker ring to accommodate a second transformer position. The site will be graded for the future positions. Motor operated line/XFMR disconnect switches will be installed to provide SCADA control. Breaker disconnect and grounding switches will be manually operated.

The substation shall be constructed using steel structures and primarily strain bus. Live tank circuit breakers shall be utilized with free standing potential and current transformers.

The substation shall have a control building for all ac and dc station service equipment, metering, control, protection, and SCADA/RTU equipment.

A pole or pad mounted station service transformer will be installed on the 20kV riser structure on the low side of the power transformer to provide primary AC station service power. A diesel generator will be furnished to provide an alternate power source for the AC station service upon loss of the primary source.

2.1 Site Surfacing

The substation yard will be surfaced with minimum 100 mm of crushed rock.

2.2 Grading and Drainage

The substation site shall be graded so that drainage is achieved using sheet flow. Drainage toward or into the cable trenches shall be avoided. The grading and drainage shall be designed to prevent flooding and to prevent standing water after a rain event. The slope of the site will be between 0.5% to 3.0%.

Waste water management systems will be installed to ensure that there will be no unacceptable impacts on the surrounding land or water bodies.

2.3 Perimeter Wall and Safety Fence

New substation will be encircled by both a perimeter wall and a safety fence, with a permanent guard house constructed to control access to the site. Substations built at sites with a perimeter wall or other security measures will only require that a chain link safety fence be installed and not the perimeter wall and guard house.

2.4 Substation Steel Structures

Substation bus and equipment support structures shall be self-supporting (no guy wires), galvanized, and designed and fabricated in accordance with the requirements of the AISC specification for Structural Steel Buildings. Structures may be wide flange, square or rectangular structural tubing, eight or twelve sided tapered tubular, or lattice steel. Height and type of structures shall be established based on electrical requirements. All structures of outgoing and incoming lines shall be designed for ±30 degree angle of deviation of line in horizontal plane and ±20 degree deviation in vertical plane and the resulting worst combination of forces shall be considered for design.

2.4.1 Structure Loading Cases

The following design criteria shall be used for the design of the steel structures. Abbreviations used are as follows:

Overload factor (OLF).

Transverse loads (T).

Vertical loads (V).

Longitudinal loads (L).

A shape factor of 1.6 shall be applied to wind loads on flat surfaces:

	Bus and Equipment Support Structures	
Case 1	Extreme wind	41 m/s wind, 15°C
Case 2	Short-circuit force and extreme wind	Available fault current, 41 m/s wind, 15°C
Case 3	Short-circuit forces, wind and ice (only if rigid bus is attached to the structure)	Available fault current, 22 m/s wind, 15 mm ice, -5°C
	Gantry Structures	
Case 1	Extreme wind	41 m/s, 15°C
Case 2	Short-circuit forces, wind and ice (only on insulators)	Available Fault Current, 41 m/s wind, 15°C
Case 3	Ice and reduced wind	15 mm ice, -5°C
Case 4	Precamber (for single pole, H-frame, or similar type structures with an unbalanced everyday load)	No Wind, 15°C

Overload Factors	
Overload factors for the load cases shall be in accordance with the following:	All cases: 1.25 wind, 1.0 short circuit, 1.25 gravitational

2.4.2 Structure Member Stresses and Deflections

Under each loading condition, calculated member stresses shall remain below AISC and ASTM design stresses. Deflections shall be determined without using an overload capacity factor and shall be limited to the following:

Switch Stands	
Horizontal members – with respect to their supports	
Horizontal deflection	Span/200
Vertical deflection	Span/200
Vertical members – at equipment mounting elevation	
Horizontal deflection	Height/100
Bus Supports and Surge Arrester, CVT, and CT Stands	
Horizontal members – with respect to their supports	
Horizontal deflection	Span/100
Vertical deflection	Span/200
Vertical members – at equipment mounting elevation	
Horizontal deflection	Height/50
For condition "Short-Circuit and Extreme Wind," deflection limits shall not be applied.	
Gantry Structures	
Horizontal members – with respect to their supports	
Horizontal deflection	Span/100

Vertical deflection	Span/200
Vertical members – at the wire dead-end elevation	
Horizontal deflection	Height/50

The structures and material shall conform to pertinent AISC and ASTM standard specifications and the following requirements:

Wide flange members	ASTM A992. Minimum yield point of 345 MPa (50 ksi); 5 mm (3/16 inch) minimum thickness except as noted on drawings.
Rolled steel shapes, plates, and latticed members	ASTM A36/A36M. Minimum yield point of 250 MPa (36 ksi) including appurtenant materials; 5 mm (3/16 inch) minimum thickness.
Square and rectangular structural tubing members	ASTM A500 Grade B. Minimum yield point of 320 MPa (46 ksi); 5 mm (3/16 inch) minimum thickness.
Round structural pipe	ASTM A500 Grade B. Minimum yield point of 290 MPa (42 ksi); 5 mm (3/16 inch) minimum thickness.
High strength steel shapes and plates	ASTM A572/A572M weldable quality or ASTM A36/A36M modified to 345 MPa (50 ksi) minimum yield strength; 6 mm (1/4 inch) minimum material thickness.
Connection bolts	ASTM A325/A325M; hexagon bolts and nuts, flat or beveled washers. All bolting materials shall be galvanized. ASTM A394, Type 0, with hex head
Anchor bolts, nuts, and washers for structures	ASTM A36/A36M threaded bars; heavy hexagon nuts conforming to ASTM A563/A563M Grade A, galvanized.
Welding electrodes	Low hydrogen types
ASTM A36/A36M steel, ASTM A 500	AWS D1.1 (as specified in Table 4.1.1 "Matching Filler Metal Requirements"). Tensile strength range of 485 MPa (70 ksi) minimum.

Structure finish shall be as specified below:

Galvanizing

Shapes and plates	ASTM A123, ASTM A384, and ASTM A385.
Bolts, nuts and washers	Galvanized as specified in ASTM A325/A325M and ASTM A153.

2.5 Foundations

The foundation design shall conform to ACI 318, Building Code Requirements for Reinforced Concrete, and shall be in accordance with the following general criteria:

Concrete Strength	f_c = 27.6 MPa (4,000 psi) at 28 days
Reinforcing Steel	ASTM A615 Gr 60 f_y = 413.7 MPa (60,000 psi)
Frost Depth	80 to 90 cm

Safety factors against soil failure shall be as follows:

Shallow Footings	
Overturning	1.5
Sliding	1.5
Bearing	3.0

Equipment and Structure Foundations
Ground support pieces of equipment such as the circuit breakers and transformers shall be supported by cast-in-place reinforced concrete slabs.

Foundations for the equipment support structures, such as bus supports, disconnect switches, etc., shall be spread footings or piers.

Control Enclosure will be supported by reinforced concrete slab which will be based on the subsurface soil conditions and enclosure design. Concrete stoops at each doorway will be provided.

2.6 Oil Containment

Oil containment systems shall be designed and implemented in accordance with IEEE 980 – IEEE Guide for Containment and Control of Oil Spills in Substations.

Transformer and reactor oil containment shall be concrete containment pits sized to hold 100 percent of the oil volume in the unit plus a 150 mm freeboard (an additional pit depth of 150 mm) to accommodate rainfall. The finished surface of the bottom of the containment pit will be above the top of rock of the substation. A manually operated valve will be installed at the bottom of the pit to allow water to be drained. The pit will be filled with aggregate for fire suppression. The pit sizing calculation shall account for the aggregate fill.

An oil monitor shall be provided that sends an alarm signal to the substation SCADA system when it detects the presence of oil in any of the oil containment systems.

2.7 Fire Containment Wall

A wall designed to both contain a fire as well as to limit the dispersion of hot or sharp objects shall be between oil-filled equipment containing more than 190 liters of oil and other equipment or buildings located within 15 m of the oil filled equipment.

The height of a fire barrier shall be at least 0.3 m above the height of the oil-filled tank, bushing, vents, etc. The fire barrier shall extend at least 0.6 m horizontally beyond the line of sight between all points on adjacent equipment. The height of the fire barrier shall be not less than that required to break the line-of-sight from any point on the top of the tank to any adjacent bushing and/or surge arrester mounted on the equipment.

The wall material shall have a 1 hour fire rating and shall meet the requirements of NEC, NFPA 850 and IEEE 979.

2.8 Substation Earthing

A new earthing grid shall be installed. Earthing shall be designed and installed in accordance with IEEE 80, Guide for Safety in AC Substation Grounding. Resistivity measurements shall be obtained using the Wenner 4 pin method as described in IEEE 81 Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

The minimum thickness of the aggregate surfacing shall be 100 mm and the earth conductor shall be installed a minimum of 450 mm below rough grade. A galvanized steel grate earth mat shall be provided at each disconnect and earthing switch operator location and shall be positioned such that the operator's feet are on the mat when the handle is operated. The earth mat shall be installed on the top of the aggregate surfacing and shall be bonded to the earth grid and operating handle.

The aggregate surfacing shall comply with the requirements of the grounding calculations and shall extend 1.25 meter outside of the substation area. Crushed concrete is not acceptable. The nominal size of the aggregate shall be 20 mm to 25 mm.

Equipment grounds within a control enclosure shall conform to the following general guidelines:

All electrical equipment, such as switchgear, power centers, motor control centers, relay cubicles, panel boards, control cubicles, etc., shall have integral earth buses which shall be connected to the station earth grid by two separate distinct connections each having 100 percent capacity.

Electronic cubicles and equipment, where required, shall be earthed utilizing an insulated earth wire connected in accordance with the manufacturer's recommendations. Where practical, electronics earth loops shall be avoided. Where this is not practical, isolation transformers shall be furnished.

Each continuous laid length of cable tray shall be earthed at a minimum of two places to the earthing grid. The distance between the earthing points shall not exceed 30 meters.

Raceway shall not serve as the earth conductor.

Earth directly to the earth grid system when an earth pad is provided.

All electrical equipment buildings disconnect switch stands, and shielding masts, if required, shall be provided with two paths to earth. Bus supports and similar structure shall be provided with at least one path to earth.

An earthing conductor shall be routed parallel to all power conductors operating above 250 volts.

All earth wires installed in conduit shall be insulated.

Above grade, connections shall be mechanical and below grade, connections shall be exothermal.

Earthing materials furnished are described in the following:

Earth grid and riser conductors shall be copper. Earth grid conductor cross-sectional area shall be a minimimum of 120 mm^2.

Riser conductors shall be a minimum of 95mm^2

Earth wires installed in conduit shall be copper with Class 2 stranding, and green/yellow colored 750 volt PVC insulation.

2.9 Substation Raceway System

The outdoor below grade raceway system shall be composed of direct buried polyvinyl chloride (PVC) conduit and waterproof fittings. The conduit shall be buried a minimum of 750 mm below rough grade.

Above grade raceway shall be rigid galvanized steel conduit. Short runs of liquidtight flexible conduit may be used where it is impractical to bend rigid conduit.

Cables in the substation shall be routed in trenches and conduits.

2.9.1 Trenches

Cable trenches shall be shall be of adequate size. The trenches located within the substation shall project at least 100 mm above the finished grade so that no storm water shall enter into the trench. Where the cable trenches can be crossed by vehicles, they shall be designed for highway loadings, H20, or equivalent. Otherwise, the cable trench shall be designed for pedestrian loadings.

2.9.2 Raceway Fill

The maximum percent fill of raceway shall not exceed the listed percentages below. The total cross-sectional area of all cables divided by the total internal cross-sectional area of the raceway shall be used to determine the percent fill:

Type of Installation	**Maximum Percent Fill**
Conduit	
One cable	53
Two cables	31
Three or more cables	40
Cable Tray	
Power cables only (150 mm deep tray)	40
Power cables only (200 mm deep tray)	30
Power and control cables combined	40

2.10 Substation Equipment Electrical Ratings

The equipment and system modifications shall be designed for the following voltage ratings:

	20 kV System	**110 kV System**
Rated voltage	24 kV	123 kV
Rated lightning impulse voltage	125 kV	550 kV
Rated switching impulse voltage	N/A	N/A
Rated frequency	50 Hz	50 Hz
Rated normal current – busbar	1250 A	1600 A
Rated normal current – feeder	650 A	1250 A
Rated short-time withstand current	25 kA	31.5 kA
Rated peak withstand current	62.5 kA	78.75 kA
Rated duration of short circuit	1 second	1 second
Voltage variation		
Normal	± 5%	± 5%

	20 kV System	110 kV System
Emergency	± 10%	± 10%
Transient (< 20 seconds)	-30%, + 20%	-30%, + 20%
Frequency variation		
Transient (< 20 seconds)	± 4%	± 4%

2.11 Electrical Clearances and Spacing

The design of the substation shall maintain the following minimum electrical clearances. The clearances indicated shall be increased as required to provide safety and working clearances. Substation road clearances shall be based on a 4 meter tall vehicle:

Spacing	20 kV System	110 kV System
Minimum phase to phase	220 mm	1,100 mm
Minimum phase to earth	220 mm	1,100 mm

2.12 Substation Bus Design Criteria

The following criteria shall be used for the design of the substation bus:

Available fault current	Refer to the rated short-time withstand current
X/R ratio	20.
Continuous operating current	Refer to the rated normal current in the article 2.10. Multiple conductors per phase may be used for current rating and corona requirements.
Load Cases	
Short-circuit forces and extreme wind	Available fault current, 41 m/s, 15°C.
Short-circuit forces, reduced wind and ice	Available fault currents, 15 mm ice, -5°C.
Overload factors for the load cases shall be in accordance with the following	All cases--1.25 wind, 1.0 short circuit, 1.25 gravitational, 1.3 gust factor.

2.13 Insulation Coordination

The coordination of insulation of electrical equipment and the application of protective devices to safeguard the equipment shall conform to the requirements and recommendations of EN 60071.

The pollution performance of all insulators and bushings shall comply with IEC 815, and the creepage distance shall be 31 mm/kV_{LL}.

All substation high voltage equipment and bus shall be protected against direct lightning strikes by means of spikes on gantry structure columns or separate lightning protection masts. The shield design shall be based on the "rolling sphere" method and the radius of the strike sphere shall be calculated using the bus height.

Columns, masts, and earth wires shall be connected to the earth grid of the substation.

2.14 Electrical Enclosures

Electrical enclosures except junction boxes and pull boxes 100 mm trade size and smaller, shall be as follows:

Location	Enclosure Type
Indoor (Nonhazardous)	
Dry area	IP 42
Wet area (Areas where moisture conditions are more severe than those for which IP 42 enclosures are intended)	IP 54
Outdoor (Nonhazardous)	IP 55
Hazardous area	In accordance with the requirements of the appropriate codes and standards for the location

The construction of electrical enclosures located in areas subject to conditions classified as hazardous shall be of a type designated as suitable for the environment in which they are located.

The enclosures of all electrical equipment shall be designed and specified for such indoor and outdoor environmental operating conditions as are necessary for satisfactory long-term operation, including taking due regard for the electromagnetic compatibility of high current 50 hertz and low current VHF electronic equipment.

Electrical enclosures, except those of cast metal and fiberglass, shall be constructed from steel plate reinforced as required to provide true surface and adequate support for devices mounted thereon. Enclosures shall be of adequate strength to support mounted components during shipment and to support a concentrated load of 90 kg on their top after erection.

All junction boxes or pull boxes 100 mm trade size or smaller in any dimension shall be galvanized mild steel or die cast aluminum.

Junction boxes and pull boxes larger than 100 mm trade size in all dimensions for use in indoor locations shall be sheet steel hot-dip galvanized after fabrication and those for use in outdoor or damp locations shall be galvanized malleable iron or acceptable equal cast ferrous metal, sheet steel hot-dip galvanized after fabrication, or sheet steel epoxy coated inside and outside after fabrication.

All boxes shall be constructed such that they prevent the entrance of insects, lizards, and rodents when closed and secured.

2.15 Lighting

Lighting for the substation and buildings shall be according to the following requirements.

2.15.1 Substation Lighting

Substation lighting shall be designed to provide adequate illumination for security, emergency egress within the substation, and an indication of the position of the disconnect switch and the earth switch switchblades.

The lighting levels within the substation shall have the following minimum levels:

Area	Lux Level
Disconnect and earth switch switchblades	22
Substation bus area (general horizontal under bus and structures at ground level)	22

Outdoor equipment control cabinets	50
Fence and open areas within the substation (at ground level)	3
Roadways (between or along buildings)	11
Roadways (not bordered by buildings)	5.5

2.15.2 Control Building, Switchgear Building and Guard House Lighting

The substation control building and guard house lighting levels shall have the following minimum levels:

Area	Lux Level
Entrances	110
General areas	110
Floor	150
Vertical face of control and protection panels (1.225 meters above floor, front of panel)	270

2.16 Protective Relaying and Metering

Protective relaying and metering shall be as follows.

Relaying schemes shall be as indicated in the Guide for High Voltage Systems Protective Relaying Design in Appendix A.

2.16.1 Relays

Required relays are shown in the table below:

Protective Relay Manufacturer and Model

Protective Relay	Manufacturer and Model
Circuit Breaker and Bay Control	SEL 451-5
Line Protection - Primary	SEL 421
Line Protection – Back Up	Siemens 7SA 52 or GE D60
Transformer Protection – Primary	SEL 787
Transformer Protection – Back Up	SEL 387A
Bus Protection – Primary	SEL 587Z
Bus Protection – Back Up	SEL 587Z
20 kV Switchgear	SEL 451

Refer to Guide for High Voltage System Protective Relaying in Appendix A for the substation protective relaying and metering requirements.

2.16.2 Power Line Carrier Frequencies

The power line carrier frequencies between the substations shall be as follows:

Durai Junction XMT to Kajakai:	108 – 112 kHz
Durai Junction RCV from Kajakai:	88 – 92 kHz
Durai Junction XMT to Kandahar Breshna Kot:	100 – 104 kHz
Durai Junction RCV from Kandahar Breshna Kot:	80 – 84 kHz
Durai Junction XMT to Lashkar Gah:	120 – 124 kHz
Durai Junction RCV from Lashkar Gah:	140 – 144 kHz

2.16.3 Line Trap Blocking Bands

The line traps shall be wide band type that will block the following frequencies:

Durai Junction to Kajakai line:	88 – 116 kHz
Durai Junction to Kandahar Breshanka Kot line:	80 – 108 kHz
Durai Junction to Lashkar Gah line:	120 – 156 kHz

2.17 Substation Equipment Technical Data

This section summarizes the ratings of the major items of equipment to be installed in the substation yard and in the Control/Switchgear Building.

2.17.1 SF_6 Circuit Breakers

The power circuit breakers shall be SF_6 gas insulated type. The standard ratings for circuit breakers are as shown below:

Ratings	110 kV System
Rated Voltage, U_r	123 kV
Rated Insulation Level	550 kV
Rated Frequency, f_r	50 Hz
Rated Normal Current, I_r	1600 A
Rated Short-Time Withstand Current, I_k	31.5 kA
Rated Peak Withstand Current, I_p	78.75 kA
Rated Duration of Short Circuit, t_k	1 second
Number of Poles	3
Class	Outdoor
Rated Operating Sequence	O - 0.3s - CO- 3 minutes -CO
Operating Time, cycles	3
Trip and Close Requirements	3 pole ganged trip and close
Mechanical Operations	M2
Tank Design	Live Tank

2.17.2 Outdoor Disconnect Switches

Outdoor disconnect switches shall be furnished in accordance with the following requirements.

Ratings	20 kV System	110 kV System
Rated Voltage, U_r	24 kV	123 kV
Rated Insulation Level	125 kV	550 kV
Rated Frequency, f_r	50 Hz	50 Hz
Rated Normal Current, I_r	1250 A	1600 A
Rated Short-Time Withstand Current, I_k	25 kA	31.5 kA
Rated Peak Withstand Current, I_p	62.5 kA	78.75 kA
Rated Duration of Short Circuit, t_k	1 second	1 second
Earthing Switch Rated Short Circuit Making Current	25 kA	31.5 kA
Rated Mechanical Endurance	M2	M2
Rated Value for Electrical Endurance for Earthing Switches	E1	E1

2.17.3 Capacitor Voltage Transformers

Capacitor voltage transformers shall be furnished in accordance with the following requirements:

Ratings	110 kV System
Rated Insulation Level	550 kV
Rated Frequency, f_r	50 Hz
Rated Primary Voltage, U_{pr}, A-N	110 kV/√3,
Rated Secondary Voltage, U_{sr}, a-n	100V/√3 / 100V/√3
Number of bushings for each CVT	1

2.17.4 Inductive Voltage Transformers

Inductive (wire wound) oil filled voltage transformers (VTs) and line tuners shall be furnished in accordance with the following requirements.

Ratings	20 kV System
Rated Insulation Level	125 kV
Rated Frequency, f_r	50 Hz
Rated Primary Voltage, U_{pr}, A-N	20 kV/ √3
Rated Secondary Voltage, U_{sr} a-n	100 V/ √3
Rated Output	10 VA 25 VA
Accuracy Class	0.5/3P
Number of bushings for each VT	1

2.17.5 Surge Arresters

Porcelain housed surge arresters shall be furnished in accordance with the following requirements.

Ratings	20 kV System	110 kV System
Maximum System Voltage, U_m	24 kV	123 kV
Rated Insulation Level	125 kV	550 kV
Rated Frequency, f_r	50 Hz	50 Hz
Rated Nominal Discharge Current	10,000 A	10,000 A
Rated Voltage U_r	24	120
Maximum Continuous Operating Voltage, U_c	19.2 kV rms	78 kV rms
Line Discharge Class (IEC 60099-4)	2	2
Minimum Creepage Distance, mm/kV_{LL}	31	31

2.17.6 Free-Standing Current Transformers

Free standing current transformers shall be multi-ratio furnished in accordance with the following requirements.

Ratings	110 kV System
Rated Voltage, U_m	123 kV
Rated Insulation Level	550 kV
Rated Frequency, f_r	50 Hz
Rated Normal Current, I_r	1600 A
Rated Short-Time Withstand Current, I_k	31.5 kA
Rated Peak Withstand Current, I_p	78.75 kA
Rated Duration of Short Circuit, t_k	1 second
Rated Secondary Current	1A
Rated Continuous Thermal Current I_{cth}	150%
Revenue Metering Accuracy Class	15VA 0.2FS5
Protective Relaying Accuracy Class	15VA 5P20

2.17.7 Auto Power Transformers – Not Used.

2.17.8 Distribution Power Transformers

Distribution power transformers shall be furnished in accordance with the following requirements:

110kV/20kV Power Transformers	
Capacity, MVA @ 65°C rise	20 MVA
Winding Configuration	Two winding
Vector group	Dyn1

Frequency, Hz		50		
Cooling Class		ONAN/ONAF/ONAF		
Service		Outdoor, 3 - phase		
Winding/Bushing Data				
Winding or Bushing	Nominal (mid-tap) Voltage (kilovolts)	Winding BIL (kilovolts)	Bushing Voltage (kilovolts)	Bushing BIL (kilovolts)
High voltage, HV	110	450	123	550
Low voltage, LV	20	95	24	125
Neutral, XO	--	95	24	125
Minimum creepage distance, mm/kV_{LL}		31		
Winding Impedances				
Impedances (with manufacturer's standard tolerances) shall be as follows:				
HV to LV (%)	Per IEC Standard	at nominal voltage, on		20 MVA base
Tap Changer				
High voltage, HV		On Load Tap Changer (LTC) with remote tap changer controller (RTCC)		
Low voltage, LV		--		

2.17.9 Shunt Reactors – Not Used.

2.17.10 Line Traps

Line traps shall be furnished in accordance with the following requirements; they shall be placed on the “B” phase of an A-B-C phase designated system.

	110 kV System
Rated Frequency (fr)	50 Hz
Rated normal current (Ir)	1600 A
Rated short-time withstand current (Ik)	31.5 kA
Rated peak withstand current (Ip)	78.75 kA
Rated duration of short circuit (tk)	1 second
Rated supply frequency	50 Hz
Rated inductance	1 mH
Rated band width	Wide band, shall simultaneously block XMT and RCV frequencies
f1N:	See Article 2.16.2
f2N:	See Article 2.16.2
Mounting	pedestal

Terminal pads	4 - hole pads, 14.3 mm holes on 44.5 mm centers

2.17.11 AC Station Service Emergency Generator Set

The AC station service emergency generation set shall be furnished in accordance with the following requirements:

Generator Set	
Mode of Operation	Automatic Standby
Output, kW	Site specific
Rated voltage	380 VAC
Rated frequency	50 hZ
Rated power factor (cos ϕ)	0.8
Starting at full load operation	≤ 15 s
Starting type	Automatic – remote operated
Output Rating	Stand by
Overload capability (1 hour in 8)	N/A
Location	Outdoor
Engine	
Type	Diesel, 4 stroke
IEC Emissions Stage	Site and installation date specific
Generator	
Connection	Star, with neutral brought out and earthed
Rated voltage	380/220 V
Maximum voltage	440/253 V
Number of phase	3
Internal automatic circuits for closing generator circuit breaker	No
Auxiliary Power system	
Phase	3, 4 wire
Rated voltage	380/220 V
Mode of operation	Automatic Standby (Emergency)
Output, kW	Site specific
Rated voltage	380/220 V
Maximum voltage	440/253 V

Number of phase	3
Rated frequency	50 Hz
Rated power factor (cos ϕ)	0.8
RPM	1500
Starting at full load operation	≤ 15 s
Starting type	Automatic – remote operated
Location	Outdoor
Engine	
Fuel Type	No. 2 diesel
Fuel Tank	24 hours, sub-base or day tank
Generator	
Connection	Star, with neutral brought out and earthed

2.17.12 Capacitor Banks – Not used.

2.17.13 Vacuum Circuit Breakers

Vacuum circuit breakers shall be furnished in accordance with the following requirements:

System Voltage	20 kV
Rated voltage (U_r)	24 kV
Rated insulation level/lightning impulse withstand voltage (peak)	125 kV
Rated frequency (f_r)	50 Hz
Rated normal current (I_r)	1250 A
Rated short-time withstand/breaking current (I_k)	25 kA, rms, 1 second
Rated short-circuit making current (I_p)	62.5 kA, peak
Rated pressure of vacuum interrupters	Manufacturer's standard
Number of poles	3
Class	Outdoor
Rated operating sequence	O-0.3 sec-CO-3 min-CO
Rated supply control voltage (U_a), dc	220 V DC
Rated supply voltage (U_a), ac	220/380, 3 phase AC
Rated supply frequency	50 Hz
Switching Capability	
Each breaker shall be capable of 180 degree out-of-phase switching.	

2.17.14 Arc Resistant Metal-Clad Switchgear

Arc Resistant Metal-clad switchgear shall be furnished in accordance with the following requirements.

System Voltage	20 kV
Rated Voltage, U_r	24 kV
Rated Insulation Level	125 kV
Bus Bar Insulation	Air
Rated Frequency, f_r	50 Hz
Rated Normal Current, I_r (bus, main, tie)	1250 A
Rated Normal Current, I_r (feeders)	630A
Rated Short-Time Withstand Current, I_k	25 kA
Rated Peak Withstand Current I_p	63 kA
Rated Duration of Short Circuit, t_k	3 second
Partition Class	PM (Partition Metallic)
Loss of Service Continuity Category (LSC)	LSC 2B
Accessibility Type	A – Restricted to Authorized Personnel
Type of Accessibility of Enclosure	F – Front Side R – Rear Side
Internal Arc Withstand Current/Internal Arc Duration	25kA / 0.5 second
Degree of Protection by Enclosure	Indoor, IP 42 (Inside of Premanufactured Metal Control Building)
Gas Exhaust Duct	Located on top of the switchgear and exhausted away from equipment and personnel.
Circuit Breaker Class	E2, C2, M2

2.17.15 AC and DC Station Service Equipment

The 220V DC station service system for 110kV substations shall consist of one (1) battery and two (2) chargers.

The equipment shall be furnished in accordance with the following requirements.

Battery	
Battery type	Flooded-Ventilated, Lead-Acid
Nominal voltage	220V DC, 2 wire, ungrounded

Voltage variation, percent of nominal	+/-10 percent at DC distribution panels
End of discharge voltage	1.75 V/cell
Number of cells	106 Cells
Sizing method	IEEE 485
Design ambient temperature	25°C (77°F)
Design margin	15 percent
Aging factor	25 percent
Design life	20 years
Minimum capacity	100 AH
Battery duty cycle duration	8 hours
Positive plate construction	Supplier's standard design
Battery rack	Two tier configuration with battery drip pan below
Location	In Electrical Room, HVAC climate controlled, and ventilated

Battery Charger	
Recharging Time	8 hour
Number of battery chargers required	Two (2) battery chargers, each 100%
Nominal input voltage	220V AC, 1 Phase, 50 Hz
Nominal input voltage variation, percent of nominal	+/- 10 percent
Sizing method	IEEE 946 Shall be sized to continuously float charge a battery while supplying power to DC load required.
Cooling method	Natural convection
Location	In Electrical Room, HVAC climate controlled

The AC station service system will consist of a normal and a backup system. The normal AC station service will be provided from a pole or pad mounted station service transformer connected to a 20kV source from the substation. The back up station service will be provided from a stand-by diesel generator.

The AC station service system will include a safety disconnect switch furnished low side of the normal and back up power supply, an automatic transformer switch, and ac distribution panels.

The station service shall be sized with 20% spare margin.

The equipment shall be furnished in accordance with the following requirements.

Automatic Transfer Switch	
Switch Type	Open transition

Nominal voltage	380/220V AC

2.17.16 Substation SCADA System

Substation Supervisory Control and Data Acquisition System (SCADA) equipment shall be provided in accordance with the following requirements.

Nominal Cubicle size	
Width, mm	800
Height, mm	2,300
Depth, mm	800
Cubicle Wire	
Service	Minimum Wire Size, mm^2
Power supplies and packaged control systems	10
Current transformer circuits	6
Potential transformer circuits	4
Control wiring	2.5
Annunciator wiring	2.5
Analog circuits	2.5 (shielded cable)
IRIG distribution	Twisted shielded pair or coax cable
Earth Bus	
Vertical earth bus for cable shields to be provided	Yes
RTU	
RTU Location	Class C: sheltered Locations
RTU Temperature Requirement	- 40°C to + 85°C
RTU Humidity Requirement	10 to 95 percent non-condensing
Protocols (IED, Distributed I/O, and/or SCADA master)	
Type	Serial DNP 3.0 or DNP 3.0 over IP CTCP and UDP
Power Supply	Station DC Battery
Time Synchronization	
Type	Match time synch equipment
Physical connection	Match time synch equipment
Status Inputs Wetting Voltage	
Station Battery/DC-DC Converter	Station Battery
RTU Supply	Station Battery
Distributed I/O Type	Manufacturer's Standard

Status Inputs Type	Sequence of Events
Pulse Accumulator or Counter Inputs Type	Form C
Counter Maximum Values	16-bit binary counter (65,535 counts)
Analog Inputs Type	± 1 mA, 0-1 mA, Digital with IED
Analog Outputs Type	Not required
Controls Type	Trip/Close (T/C), Raise/Lower (R/L)
Status Points	
The following points for each piece of equipment indicated shall be wired into the RTU and communicated to the NLCC SCADA master. RTU shall be sized to accommodate all future equipment plus 10 percent spare points	
Binary Status Points	
SF6 Circuit Breakers	
Normally open "a" contact[1]	Yes
Normally closed "b" contact[2]	Yes
Remote control enabled	Yes
Breaker Low Gas	Yes
Breaker trouble (common status point for any remaining alarms)	Yes
Disconnect Switches	
Normally open "a" contact[1]	Yes
Normally closed "b" contact[2]	Yes
Remote control enabled	Yes
Earthing Switches	
Normally open "a" contact[1]	Yes
Normally closed "b" contact[2]	Yes
Auto Transformers	Not Used
Distribution Power Transformers	
High oil temperature	Yes
High winding temperature	Yes
Sudden pressure alarm	Yes
LTC high oil temperature	Yes
XFMR trouble (common status point for any remaining alarms)	Yes
LTC in follower operation mode	Yes
Shunt Reactors	Not Used
Generator	
Generator running	Yes

Generator circuit breaker closed	Yes
Generator trouble (common status point for alarms)	Yes
Relay Communication	
Communication trouble (one alarm for each transmission line communication scheme)	Yes
Relays and GPS Equipment	
Relay failure alarm from each microprocessor based relay	Yes
Vacuum Circuit Breakers	
Normally open "a" contact	Yes
Normally closed "b" contact	Yes
Remote control enabled	Yes
Breaker trouble (common status point for any remaining alarms)	Yes
MV Metal-Clad Switchgear	
Main breaker normally open "a" contact	Yes
Main breaker normally closed "b" contact	Yes
Main breaker connected	Yes
Main breaker remote control enabled	Yes
Main breaker earthing switch closed	Yes
Main breaker trip coil failure	Yes
Feeder breaker normally open "a" contact	Yes
Feeder breaker normally closed "b" contact	Yes
Feeder breaker connected	Yes
Feeder breaker remote control enabled	Yes
Feeder breaker earthing switch closed	Yes
VT disconnect (withdrawable case only)	Yes
Miscellaneous Status Points	
Reclose enabled for each transmission line with reclosing capability	Yes
Fire alarm	Yes
Intruder Alarm	Yes
DC safety switch open	Yes
DC low battery voltage for each battery system	Yes
Loss of primary ac station service source	Yes
Loss of backup ac station service source	Yes
Oil spill alarm	Yes
High control building temperature	Yes
Low control building temperature	Yes

25 spare status inputs	Yes
Control Points	
Circuit Breakers	
Trip/close pair	Yes
Disconnect Switches	
Open/close pair	Yes
Earth Switches	
None	Yes
Power Transformers	
LTC raise/lower pair	Yes
Generator	
Start/stop pair	Yes
Emergency stop	Yes
Analog Input[3]	
Busbars	
3 - voltage for each busbar section	Yes
1 - frequency for each busbar section	Yes
Transmission Lines	
3 – Voltages	Yes
3 – Currents	Yes
MW	Yes
MVar	Yes
Auto Transformer	Not Used
Distribution Power Transformer	
3 – Voltages	Yes
3 – Currents	Yes
MW	Yes
MVar	Yes
LTC position	Yes
Reactors	Not Used
Capacitor Banks	Not Used
Station Service stand-by Generator	
Fuel level low	Yes
Digital Communication	
Microprocessor relays	Yes
Revenue meters	Yes

Notes:

1. Independent pole operated devices shall have three (one from each phase) normally open "a" contacts wired in series to provide positive indication the device is closed.
2. Independent pole operated devices shall have three (one from each phase) normally closed "b" contacts wired in series to provide positive indication the device is open.
3. Analog indications may be obtained via digital communications with IEDs.

2.17.17 Conductors

The substation conductor for low voltage (LV) and medium voltage (MV) and system shall be in accordance with the following requirements.

Multiconductor LV Power and Control Cable:	
Conductor	Class 2 copper, normal maximum operating temperature 90°C
Insulation	XLPE, 750 V, normal maximum operating temperature 90°C, wet or dry
Shield	Copper tape, 5 mils nominal thickness 2 mils nominal thickness of adhesive coating on both sides or None
Conductor jacket	None
Cable jacket	PVC
Conductor color	Cable assemblies with four conductors or less shall be as listed below. Cable assemblies with five or more conductors shall be black with white numbers: Conductor 1 – Black Conductor 2 – Brown Conductor 3 – Grey Conductor 4 – Blue
Cable jacket color	Black.
Cable assembly	The conductors shall be cabled together with polypropylene fillers, as necessary, to make the finished cable round.

Single Conductor LV Power Cable:	
Conductor	Class 2 copper, normal maximum operating temperature 90°C
Insulation	PVC, 750 V, normal maximum operating temperature 90°C, wet or dry
Shield	None
Conductor jacket	None
Cable jacket	None
Conductor color	Black
Conductor Color	Black
Cable jacket color	Not Applicable

Single Conductor MV (8kV) Power Cable:	
Conductor	Class 2 copper, normal maximum operating temperature 90°C
Insulation	PVC, 8kV, normal maximum operating temperature 90°C, wet or dry

Single Conductor MV (8kV) Power Cable:	
Shield	None
Conductor jacket	None
Cable jacket	None
Conductor color	Black
Cable jacket color	Not Applicable

Single Conductor MV (20kV) Power Cable:	
Conductor	Class 2 copper, normal maximum operating temperature 90°C N2XS2Y
Insulation	XLPE, 12/20kV (U_m= 24kV), normal maximum operating temperature 90°C, wet or dry
Shield	None
Conductor jacket	None
Cable jacket	Black Polyethylene (PE)
Conductor color	Black
Cable jacket color	Not Applicable

Analog Signal Cable:	
Conductor	Class 2 copper, normal maximum operating temperature 90°C.
Insulation	XLPE, 750V, normal maximum operating temperature 90°C, wet or dry.
Pair shield	Aluminum mylar, 100 percent coverage with a minimum 20 percent overlap, 0.5 mm^2 (minimum) copper drain wire.
Cable shield	Aluminum mylar, 100 percent coverage with a minimum 20 percent overlap, 0.5 mm^2 (minimum) copper drain wire.
Conductor jacket	None.
Cable jacket	PVC
Conductor color	Black and red numbered pairs.
Cable jacket color	Black.
Cable assembly	The conductors shall be cabled together with polypropylene to make round

Flexible Radio Frequency Coax Cable:	
Conductor	Class 2 copper,
Insulation	Polyethylene. (PE)
Shielding	Copper braid, minimum 95 percent coverage.
Cable jacket	PVC
Cable jacket color	Black.
Nominal impedance	50 ohms

3.0 Transmission Line Design Criteria

3.1 General

This section describes the design criteria to be used for the line design.

3.2 Codes and Standards

See Article 1.1.

The design shall also conform to all requirements for the right-of-way.

3.3 Mechanical Loading

The mechanical loading criteria for the project are as follows:

3.3.1 Structures

3.3.1.1 Design Data-Assumptions and Determinations Wind Loads
The maximum design wind velocity shall be as indicated in Section 1.4 for a 3 second gust. Reduction factors on the wind pressure, for increasing span length, shall be based on IEC 60826.

The coefficient of dynamic wind pressure shall be considered for all structures/conductors/groundwire according to IEC 60826. The dynamic wind pressure coefficient for the line conductor is 1.0. The dynamic wind pressure coefficient for the insulator set is 1.2.

The total effect of wind on subconductor bundles shall be taken equal to the sum of the wind load on each subconductor without considering any masking effect of one subconductor on the other.

3.3.1.2 Design Spans
The term "basic span" shall mean the horizontal distance between centers of adjacent supports on level ground from which the height of standard supports is derived with the specified conductor clearances to ground in still air at maximum temperature.

The term "wind span" shall mean half the sum of adjacent horizontal span length supported on any one structure. The term "weight span" shall mean the length of conductor, the weight of which is supported at any structure at minimum temperature in still air. At a suspension position, the minimum weight of conductor supported shall not be less than 25 % of the total weight of conductor in the two adjacent spans.

3.3.1.3 Design Loading Assumptions
The structures shall be designed to withstand the following load combinations as a minimum:

High wind at 90 degrees angle to the line:
Maximum wind speed at a conductor temperature of + 28°C.

High wind at 45 degrees angle to the line:
Maximum wind speed at a conductor temperature of + 28°C.

Combined Ice and Wind Loads:
15 mm radial ice thickness, wind is calculated based on maximum design velocity, ice thickness, reduced wind -5°C

Ice density, based on the different expected ice types, and related considerations shall be as per IEC 60826.

Exceptional conditions:

Broken wire condition and longitudinal overload condition at +28°C final tension in accordance with IEC 60826.

3.3.1.4 Design Loading Requirements
The line loading shall be as determined from all the relevant requirements of IEC 60826. This includes factors on wind and the structures, security loads, component strength including insulators and fittings and for the loading combination requirements above.

As per clause 6.2.1 of IEC 60826, the design will account for the increased wind speeds due to funneling and sloping ground, affecting the line and structure loading.

Loading Condition	Radial Ice Thickness (mm)	Wind Pressure (Pa)	Temperature (degrees C)	Constant to be Added to Resultant
Extreme Wind	0	Calculate based on maximum design velocity	+28	0
Ice and Wind	15	Calculate based on reduced wind velocity	-5	0
Min. Temp (Cold Curve)	15	0	-5	0
Max. Operating Temperature (Hot Curve)	0	0	Refer to cable manuf. specs.	0
Broken Wire	15	Calculate based on reduced wind velocity	-5	0

Radial ice thickness shall be applied to conductors and shield wire/OPGW and not structures or equipment. Wind pressures shall be adjusted by the appropriate shape factors.

3.4 Overload Capacity Factors

The overload capacity factors shall be applied to the loading conditions for the ruling span listed below.

	20 kV	110 kV
Ruling span, meters	50	300

Loading Condition	Overload Capacity Factor			
	Vertical	Transverse Wind	Transverse Tension	Longitudinal
Broken Wire (Suspension)	1.00	1.00	1.00	1.00
Ice and Wind	1.25	1.25	1.25	1.25
Ice Only	1.25	1.25	1.25	1.25
Concrete First Crack	1.00	1.00	1.00	1.00
Extreme Wind	1.25	1.25	1.25	1.25
Concrete Second Crack	1.00	1.00	1.00	1.00
Maintenance	2.00	2.00	2.00	2.00
Camber/Everyday	1.00	1.00	1.00	1.00

Stringing	1.10	1.10	1.10	1.10

3.5 Conductors, Shield Wire, and OPGW

The conductor and OPGW shall be as follows.

20 kV Conductor	50, 70, and 120 mm^2 ACSR (min)
110 kV Conductor	"ELK" ACSR
OPGW	AlumaCore Optical Ground Wire AC-96/606 or equal

* OPGW will contain 24 single mode (1310nm) fibers.

The conductor tension, in percent of the breaking strength, shall not exceed the following limits:

Loading Condition	Limit
5°C, initial	20% of the UTS
48°C, final	20% of the UTS

The tensions for the shield wire and OPGW shall be based on maintaining 75 percent of the conductor sag at a 28°C, no wind, no ice, final condition.

Conductor, shield wire, and OPGW shall be protected from Aeolian vibration in accordance with recommendations from manufacturers of protection devices.

Bundled conductor may be installed in either a horizontal or a vertical configuration. Spacers, without damping capability, shall be used on conductor jumper loops on dead-end structures. Spacer-dampers shall be used for maintaining the appropriate subconductor spacing in the bundled conductor system and for controlling conductor Aeolian vibration and wind induced subconductor oscillation.

3.6 Structures

Structures shall be designed to meet requirements specified in the specifications. Loading combinations for line angle structures shall include the full effect of transverse loads, using the entire wind span length without reduction, plus transverse loads associated with wire tension due to line angle.

Structures shall be designed so that all members shall withstand normal and broken wire conditions with load factors as specified in this document.

Connections shall be designed for the same member forces and according to the standards mentioned in this document. No damage or permanent distortion on any members, bolts, connections of fitting or elongation of bolt holes shall be permitted for these design conditions.

The total loading for the structure shall include the dead weight of the structure plus transverse wind load on the structure plus the simultaneous application of loading as specified above. Wind loads on the tower leg extension shall be taken into consideration.

Terminal structures shall be designed to face the direction of incoming line, and shall withstand the load of all conductors and shieldwires.

The stress analysis calculation for the structure members of all tower types and for each specific load condition shall be preformed.

3.7 Foundations

Foundation for the transmission line structures will be case-in-place reinforced concrete drilled piers, rock anchor, or spread footings; whichever is appropriate based on the subsurface soil information. Anchor bolts for all support structures will be of sufficient length to allow for use of leveling nuts.

The foundations shall be designed to resist uplift, overturning, vertical, and horizontal pressure. Foundations shall also be able to withstand the stresses, which may be imposed upon them under erection and stringing operations.

Ultimate loads derived from the structure calculations shall be increases by 10% for application in the foundation design. Where unstable soil conditions exist, as well as lack of sufficient soil data, an increased load factor can cover uncertainties in the design. Soil properties shall be determined from the original design information, and confirmed by the site specific testing.

3.7.1 Drilled Pier Foundations

Drilled pier foundations shall be sized using an electronic software package. The design loading shall be based on the worst case ultimate loading (including overload factors) specified in the design calculations provided by the steel pole supplier.

These loads shall be further multiplied by a safety factor of 1.10 for tangent structures and 1.25 for angle and dead-end structures. A maximum of 100 mm of deflection at the pier head shall be allowed under the worst-case ultimate loading condition with safety factor.

The top of concrete elevation shall be a minimum of 150 mm above existing grade.

3.7.2 Direct Embedded Structures

Direct embedded structures shall have the embedments as required to resist the loads imposed. The embedded portion of the structures shall be coated as specified in the specifications and be backfilled with crushed rock. Intermediate structures may be spotted or concrete may be used to backfill to achieve the deflection requirement of no more than 100 mm at the ground line.

3.7.3 Ground Anchors

Ground anchors shall be designed to resist the factored ground line reactions produced by the structures. The ground anchor design loads shall also include a safety factor of 1.1 for tangent structures and 1.25 for deadend structures.

3.8 Blowout Restrictions

The line design shall ensure that the conductor maintains NESC horizontal building clearance requirements to the edge of right-of-way with the conductors and insulators displaced accordingly.

The transmission conductor shall maintain 750 mm of clearance to the edge of right-of-way under extreme wind loading condition. Structure deflection need not be considered in this calculation.

3.9 Clearances

All clearances used in the design of the transmission line shall equal or exceed those required by the NESC.

The following minimum clearances between conductor and ground shall be maintained at a maximum conductor operating temperature in still air and final sag, i.e. pole spotting temperature:

Conductor Ground Clearance, meters	**20 kV**	**110 kV**
Ground accessible to pedestrians only	4.4	5.0
Ground in urban areas, road crossings and water without sea traffic	5.6	5.7
Telecommunication lines	1.50	1.95

For other objects not listed in the schedule above the requirements for minimum clearance shall comply with the NESC. A distance of 0.5 m shall be added to the clearance values above to allow for survey and drawing errors. Above minimum clearances shall be kept after final settling of conductors, i.e. including 5 years creep.

Groundwire sag shall not be larger than the conductor sag under any circumstances.

3.10 Conductor Spacing

To avoid phase clashing in spans, diagonal conductor-to-conductor spacings are to be checked to ensure minimum spacing as derived from the following formula is met:

$$x^2 +(1.2y^2) \geq 0.4 \times f + l + 0.007 \times U$$

where:

x = projected horizontal distance in meters between conductors at midspan

y = projected vertical distance in meters between the conductors at midspan

f = final conductor sag at + 75°C in m

l = length of insulator set in m

U = highest voltage in kV.

3.10.1 Conductor Clearance of Structures

The following clearances shall be maintained under the specified swing of insulator sets and jumpers:

Conductor Structure Clearance, meters	**20 kV**	**110 kV**
Minimum clearance phase-earth at temperature + 48°C, still air	0.40	1.20
Minimum clearance phase-earth at temperature + 10°C, reduced wind	0.40	1.00
Minimum clearance phase-earth at temperature + 48°C, full wind	0.40	0.70

3.11 Grounding

All structures shall be grounded by use of copper ground rod bonded to the structure. The OPGW shall be bonded to each structure.

Every structure shall be permanently and effectively grounded to achieve a low footing resistance. All cradle guard and buildings with metal sides or roofs, and other objects as necessary, which lie under or within falling the distance of the line, shall be earthed at two points in an approved manner.

The footing resistance of any structure shall be less than 10 ohms. Individual structure earthing shall be made with earthing rods or when this is not possible, with a radiating earth conductor.

The groundwire shall be directly connected to the structure with bolted connectors of an approved material suitable for use with the groundwire such that galvanic action, i.e. chemical reaction between copper and galvanized steel, is minimized. Connections to the substation's earthing grid shall be made by compressed clamps or bolted connectors of approved design.

3.12 Insulators and Support Hardware

Insulators for this project may be either polymer or porcelain. Insulator assemblies for tangent and angle structures may be suspension or vee-string. All support hardware shall be corona free and shall be sized to meet or exceed the ultimate rated strength of the insulator strings which they are supporting.

Insulation strings for tangent and angle structures, and dead ends shall be designed using either porcelain or polymer. If polymer insulators are selected, they shall have a flashover and leakage distance values equal to or greater than the porcelain string.

Nominal L-L Voltage in kV	Number of Bells in String		Rated Dry Flashover voltage (kV)
	Suspension	Deadend	
20	3	5	50
110	8	10	230

3.13 Line Route

The selected line route shall be cleared. The clearing shall consist of the removal and disposal of trees and other vegetation within the right-of-way. All tall trees which after falling could cause danger to the transmission line shall be removed. All trees which would cause flashover from a conductor deflected up to 75° from the vertical shall be removed. In determining the flashover clearance and in estimation the mean height of the bush or forest due allowance shall be made for seasonal growth.

3.13.1 110 kV Transmission Line Profile Survey

The topographical line survey shall be carried out along the approved line route. The theodolites used and measuring techniques applied shall be state of the art, employing digital recording technique.

Horizontal and vertical coordinates of all features affecting the line construction shall be indicated on the profile plan. Crossings of existing overhead lines shall be documented with measured elevations and locations of their top and bottom conductors, at centerline and side profile limits, together with the air temperature at the time of measurement. All qualified crossings and approximations shall be covered by individual clearance calculations, to be shown on the profile plan. Structure center coordinates and all elevations shall be reduced to UTM (Universal Transverse Mercator) datum, and indicated on the profile plans.

Benchmarks and reference points already existing in the project area shall be located and indicated.

The line route shall be marked in the field by timber survey pegs of sufficient length, with a cross section of min. 50 x 50 mm, to be driven flush into the ground. The accurate centerline shall be shown on the pegs by a single nail, to be driven into the peg's top. Terminal and angle pegs shall be secured by a concrete foundation. Straight line pegs shall be driven along the OHL centerline, at a minimum of 4 per km, and to either side of every line crossing. After approval of the structure

distribution on the profile plans, structure center pegs shall be driven at site. After final approval of structure locations, insurance pegs shall be driven to either side of each structure centre peg, in line direction.

Different kinds of pegs shall be distinguishable by a paint marking system. All pegs or other marks shall be preserved until their removal is authorized. For the purpose of profile/structure location inspection all terminal, angle, and other relevant line points shall be marked by red flags, with a minimum size of 1.5 x 1.5 m, to be mounted on minimum 5 m high poles.

The number of structure locations between line angle points, without exceeding the structure/conductor design limits shall be minimized. The structure distribution shall be performed by means of a recognized computerized optimization program.

3.14 110 kV Transmission Line Plan and Profile Drawings

The plan and profile drawings shall be accompanied with a cover sheet which shall include but not be limited to, general notes, cable data, catenary constants, and drawing list.

A title block shall be shown with the appropriate titles, drawing numbers, owner logos, and revision blocks. There shall also be a north arrow and a legend displayed. The plan and profile drawings shall display the ground profile as the centerline of the alignment along with left and right side profile lines under the outermost conductors and shall be shown as different broken lines. The ground clearance line shall be shown as a broken line. The catenary of the conductor shall be displayed at 75 degrees Celsius and at still air. The OPGW shall be displayed as a cold curve in still air.

Along with a vertical and horizontal scale as well as span lengths, the profile view shall display the following for each structure.

- Structure number
- Station
- Structure height
- Structure type
- UTM coordinates

Along the bottom of the profile view, a strip plan of the line route, extending approximately to the right-of-way, shall be shown. This plan shall show but is not limited to the following.

- Aerial photographic or topographic information
- Street crossing labeled by street name
- River crossing labeled by river name

4.0 Distribution System Design Criteria

The following 20kV class distribution system equipment, materials, and accessories shall be designed according to the following.

4.1 Prestressed Concrete Pole

Prestressed concrete poles dimension shall be as specified below:

Height of Pole (meters)	Buried Length (meters)	Working Load (kg)	Testing Line from Butt End (mm)
9.0	1.5	300	1,500
12.0	1.8	600	1,800
12.0	1.8	700	1,800
12.0	1.8	850	1,800
15.0	2.1	600	2,100
15.0	2.1	900	2,100

4.1.1 Reinforcing Steel

Steel reinforcement shall be one of the following:

Hot-rolled mid steel round bars complying with British Standard (BS) 4449
High yield steel cold worked deformed bards complying with BS 4449
High tensile steel wire for prestressing BS 5896

4.1.2 Cement

Portland cement conforming to EN 197-1 and EN 1370 shall only be used for casting poles.

4.1.3 Holes and Earth Conductor

The fixed position and size of the holes shall in accordance with the drawings.

The holes shall be cast during the fabrication of the pole using the tubes which shall be accurately located on the pole outlines.

Each terminal base (earthing nut) and connection should be provided and fixed to specific points on the poles as shown on the drawings.

Each pole shall have embedded in the concrete, clear of any holes, minimum size of 35 mm^2 tinned copper earth conductor. This earth conductor shall be bonded with an earthing rod and terminated in the ground.

4.1.4 Markings.

The following markings shall be embossed on each pole during casting:

Pole size and working load.
Date of casting.
Serial number of the pole.
Name/identification number of manufacturer.

4.1.5 Earthing for Poles and Crossarms

An electrical earthing system shall be furnished and installed in accordance with the following specifications.

The earthing connections for pole and crossarms utilizing 35 mm^2 tinned copper earth conductor shall be provided. An external earthing pad/connector attached to the pole shall be connected to earth rod(s).

Earth rods shall be copper clad, cold drawn carbon steel manufactured in accordance with latest applicable EN and IEC standard.

The copper cladding shall be electrolytically bonded to the steel rod or bonded by a molten welding process. Cold rolled copper cladding will not be acceptable. Earth rods shall have a conical taper on one end to facilitate soil penetration. Individual earth rod shall be 20 mm diameter and 3000 mm long.

The earth rod(s) shall be buried in the soil near the base of the pole. After connection of earth rods to the earthing system, the earth resistance measurement to assure the resistance of earth shall be 25 ohms or below. Additional earth rod(s) shall be added, if required.

All hardware on concrete poles shall be effectively grounded using a tinned copper conductor accordingly.

4.2 Insulators

The insulator material shall be made of glazed porcelain. The insulator shall be suitable for the conductor size required for the medium voltage (MV) distribution system required.

The relevant vertical dimensions of the insulator shall be such that, when combined with the pin insulator spindle, the design requirements for conductor electrical clearance from the crossarm shall be met.

The design shall be such that stresses due to expansion and contraction in any part of the insulator shall not lead to deterioration. Precautions shall be taken to prevent chemical reaction between cement and metal fittings, by the choice of suitable materials or by the method of construction. Single piece insulator construction is preferred.

The insulating material shall not engage directly with hard metal. Pin insulators shall be provided with a thimble of suitable material. Cement used in the construction of the insulator shall not cause fracture by expansion or loosening by contraction and proper care shall be taken to locate the individual parts correctly during cementing. The insulators may be with or without a center tap groove.

4.2.1 Pin Insulator Accessories.

Each insulator shall be supplied complete with a hot dip galvanized forged steel straight pin, nut, lock nut, and elastic washer.

The pins shall be two types, suitable for concrete poles and for steel crossarm (angle) and fittings. The ultimate strength of the pin insulator assembly shall be equal to the under mentioned mechanical falling load.

4.2.2 String Insulator Accessories.

Conductor attachment to insulator units at angle, tension and terminal poles shall be made by means of a compression dead-end assembly matching with the conductor material.

Each dead-end assembly shall be capable of developing not less than 95 percent of the ultimate strength of the conductor and shall have a conductivity and current carrying capacity of each joint and tension clamp not less than those of an equal length of an un-jointed conductor.

All of accessories shall be made of steel.

All parts of accessories for a string insulator offered shall comply with the mechanical characteristics and performance specified below:

Mechanical Characteristic	**Required**
Breaking load	80 kN minimum
Routine load	40 kN minimum

Termination shall be designed to anchor the bare or covered conductor.

The different component parts such as anchor shackle, eye link, socket clevis, ball clevis, eye nuts, and extension link shall be designed so as to be connected with above termination and string insulator.

For corrosion protection, all parts shall be hot-dip galvanized.

4.3 Recloser

Pole mounted, three-phase, medium voltage, automatic reclosers shall be supplied to auto-reclose feeders. The recloser shall be vacuum interrupter type immersed in suitable insulator medium, solid insulation, or SF_6 or oil medium with electronic control, and shall have the facility to detect over-current conditions on phase fault and earth fault, to time and interrupt such fault currents, and to re-energize the line by re-closing automatically after a predetermined time delay.

If a fault is persistent, the recloser shall lock open after a pre-set number of operations and isolate the faulty section from the main part of the system. The units shall be capable of operating at more than 2,500 operations at rated load without maintenance.

The operating mechanism shall consist of a device mounted internally to the automatic recloser. Contact closing energy shall be provided by a low voltage (LV) closing solenoid or magnetic actuator, which shall also store up energy in the trip mechanism. The mechanism shall operate to open and close the three phases of the device simultaneously.

If lockout has occurred, it shall only be removed by a manual closing operation or through substation SCADA system after proper unlocking safety procedure.

An operation counter shall be provided.

The means shall be provided to permit manual tripping, closing and lockout of the automatic recloser locally. After manual tripping, the automatic reclosing shall lock out.

The units shall be capable of manual operation from ground level both by means of a portable hook stick and by means of a control cubicle push button. The units shall be equipped along with a visual indication of the open/close position visible from ground level.

The bushings shall be rated to carry full line current. The current carrying parts shall be made of copper, bronze or aluminum. Contacts shall be made of suitable material to ensure long life with a low maintenance operation.

The tank shall be made of stainless steel, galvanized steel or aluminum and strong enough to support dynamic short circuit forces and the vibration of the automatic recloser during operation and for transportation.

4.4 Aluminum Conductor Steel Reinforced (ACSR)

The conductors shall be furnished accordance with the following standards which shall not exclude other equivalent or superior standards:

EN 60889	Aluminum wire for overhead conductors
IEC 61089	Round wire concentric lay overhead electrical stranded conductors
EN/ISO 2063	Metallic coating-protection of iron and steel against corrosion
DIN VDE 48204	Steel Reinforced Aluminum Stranded Conductors
BS 215, Part 2	Aluminum Conductors and Aluminum Conductors, Steel-Reinforced – For Overhead Power Transmission, Part 2: Aluminum Conductors, Steel-Reinforced

4.4.1 Cable Reels/Drums

The conductors shall be delivered to the jobsite on reels/drums conforming to IEC and/or EN standards, sufficiently sturdy and or sufficiently large reel/drum diameter to provide protection against damage during shipping, handling and stringing operations.

Reels/drums shall be matched. Each reel/drums shall be plainly weatherproof marked and in addition to marks required for shipping purposes, each drum shall show the serial number, type of conductor, length of conductor, arrow to show the correction direction for rolling from place to place and gross, tare and net weights.

Each reel/drum shall be protected by a wooded lagging on the circumference with a thickness of at least 40 mm.

4.4.2 Conductor Accessories

All conductor accessories and fittings have to be marked durable and visible (e.g. by punching) with the manufacturers' name or sign and the rated mechanical strength. All steel parts have to be hot-drip galvanized. Care has to be taken to eliminate the possibility of electrolyte corrosion.

The design of the clamps to be used shall be such to reduce to minimum the possibility of faulty assembly. Individual parts of clamps shall be interchangeable.

All bolts shall be captive and external nuts shall be locked in an approved manner. There shall be no relative movement within the clamp between individual layers of the conductor itself.

4.4.3 Compression Splice (Full Tension)

Mid span joints of conductor shall be of the compression type exclusively. Each compression splice shall consist of a compression sleeve matching with the conductor material for the complete cable and an aluminum plug for sealing the holes in the sleeve through which a heavy filler paste, i.e., an approved oxide inhibiting compound is to be injected. It should be applied in such a manner as to exclude air or moisture. Each compression splice shall be capable of developing not less than 95 percent of the ultimate strength of the conductor and shall have conductivity not less than that of the conductor.

4.4.4 Repair Sleeves

Repair sleeves of the compression type of the material best suited for the conductor material shall be applied to reinforce a conductor having some of the strands damaged. No repair sleeves shall be placed on spans crossing roads.

4.4.5 Line Tap "H Type" for Main Line Connection

The line tap shall be "H" shaped aluminum bolted or compression connector, suitable for main line tension jumper connections and tee off connections.

The line tap shall be of piece type, suitable to accommodate conductors of equal or unequal size, as required by the design.

The die to be used shall match the connector size, the conductor type, and size type of tool (mechanical/hydraulic).

4.5 Disconnect Switch

All load interrupter switches shall be group operated, load-break, 3-pole, single-throw, utilizing a stored energy, direct acting, spring charged, and quick make/quick break mechanism for both opening and closing functions.

Switches shall have main and arcing contacts and be designed to provide maximum endurance for load interrupting and fault closing. All switches shall be arranged with the hinged end of the switch blade de-energized when the switch is in the open position.

The switches shall be capable of interrupting transformer magnetizing currents as well as switch continuous current equal to the continuous (normal) current rating.

Switches shall have provisions for padlocking in both the open and closed positions.

Switches shall not be capable of being positioned in any intermediate position between fully opened and fully closed.

Each load interrupter switch shall be opened and closed by means of an externally mounted manual operating mechanism. The manual operating handle shall be padlockable.

The manual operating handle shall be non-removable, self-levering, and padlockable.

The open and closed position shall be indicated on each switch.

4.6 Surge Arrester

Surge arresters shall be furnished in accordance with the following requirements.

	20 kV Distribution System
Rated voltage (U_r)	24 kV
Rated frequency (f_r)	50 Hz
Type	Station metal oxide, Gapless
Housing	Porcelain
Color	Brown
Rated continuous operating voltage (U_c):	19.5 kV
Rated nominal discharge current	10,000 A
Line discharge class (IEC 6099)	2

Maximum residual voltage	
For a steep impulse current, 1/2 μsec front, 10 kA	71 kV
For lightning impulse current, 8/20 μsec, 10 kA	67 kV
For switching impulse current 30/60 μsec, 0.5 kA	52 kV
Energy absorbing capacity	4.3 kJ/kV
High current impulse withstand (4/10 μsec)	100 kA
Temporary overvoltage withstand	24 kV
Installation	Pole mounted, both sides of disconnect switch

Appendix A

Guide for High Voltage Systems Protective Relaying Design

Revision: A
Date: June 24, 2010

Table of Contents

Introduction

High voltage ac transmission systems are designed and built to transfer ac power from one transmission facility to another. Major parts of transmission and substation systems are high voltage lines, buses, switches, circuit breakers, transformers, reactors and capacitors. Protective relaying systems are designed and implemented to protect these major parts. Other objectives of protective relaying systems are identified in the next individual sections. The purpose of this guide is to discuss protective relaying schemes and to establish general guidelines associated with the schemes for new 110 kV, 220 kV and 500 kV transmission and substation systems. In the event of retrofitting an existing substation, the existing protective systems should be evaluated and upgraded. If there are any reasons that it is impractical to upgrade the existing systems, it will become a judgment to adopt a workable solution.

Wording and Definitions

Should - designates a recommendation

A fault is an unintended connection that may occur between phases or from phase(s) to ground. Such connection may be solid (zero impedance) or may contain impedance.

Independent primary and backup schemes are a setup that includes primary and backup protective relays utilizing separate relays and associated fuses and test switches.

Pilot scheme is a communications-assisted protective relaying scheme to achieve high speed concurrent tripping of line terminals to clear a line fault.

Reliability is the measure of a protection scheme's ability to operate when required.

Security is the protection scheme's ability to refrain from operating when not required.

Objectives

Protective relaying systems are critical to transmission and substation systems and interconnected power systems as a whole. Protective relaying systems are designed to achieve the following objectives: (1) To operate with a high level of reliability and security (2) To protect transmission and substation system equipment and lines by interrupting fault(s) as fast as possible (3) To minimize outage time and area (4) To maintain system stability.

To support these objectives, required components for protection schemes such as protective relays, current transformers (CT's), potential transformers (PT's), circuit breaker trip circuits, direct current (dc) power supply, and types of communications for pilot schemes must be identified and the schemes must operate correctly. The protection schemes for different parts of transmission and substation systems will be discussed in the respective protection sections in this guide. The intent of these protection sections is to provide general guidelines for the design of protective relaying schemes.

Line Protection

The intent of this section is to cover the general guidelines for new 110 kV, 220 kV and 500 kV line protection. The protection for 110 kV lines should consist of a pilot scheme as primary protection and a non-pilot scheme as backup protection. The protection schemes for 220 kV and 500 kV lines should consist of two independent pilot schemes as primary and backup protection. The pilot schemes should be of two different types. In addition, a direct transfer trip scheme should be included for 220 kV and 500 kV line protection.

110 kV line primary and backup schemes:

Primary protection should be directional comparison blocking (DCB) which consists of protective relay(s) and a carrier set. Power line carrier communications should be used for the communication medium.

Backup protection should be a two-zone phase distance non-pilot scheme for phase fault protection and a directional overcurrent scheme for earth fault protection.

220 kV line independent primary and backup schemes and a direct transfer trip scheme:

Primary protection should be directional comparison blocking (DCB) which consists of protective relay(s) and a carrier set. Power line carrier communications should be used for the communication medium.

Backup protection should be phase comparison which consists of protective relay(s) and a carrier set. Power line carrier communications should be used for the communication medium.

To enhance the security level, direct transfer trip (DTT) scheme should be a dual frequency shift key (FSK) system using power line carrier (PLC) communications.

500 kV line two independent primary and backup schemes and a direct transfer trip scheme:

Primary protection should be directional comparison blocking (DCB) which consists of protective relay(s) and a carrier set. Power line carrier communication should be used for the communication medium. A second set of relay(s) should be used to provide non-pilot phase and ground fault protection.

Backup protection should be phase comparison which consists of protective relay(s) and a carrier set. Power line carrier communications should be used for the communication

medium. A second set of relay(s) should be used to provide non-pilot phase and ground fault protection.

To enhance the security level, direct transfer trip (DTT) scheme should be a dual frequency shift key (FSK) system using power line carrier (PLC) communications.

110 kV/220 kV/500 kV line protection:

Line protection scheme should provide under/over voltage protection, ground fault protection, switch onto fault (SOF) protection, stub bus (STB) protection, and power swing blocking.

Line Protective Relay Criteria and Design Requirements

The line relays should be installed with test switches for testing and removal purposes. Output contacts of the line relays should be used to actuate auxiliary relays. Contacts of the auxiliary relays should be used to trip the associated high voltage circuit breaker(s). Output contacts from either the line relays or the auxiliary relays should be used to initiate stuck breaker failure and breaker reclosing.

Upon receipt of DTT signal from the remote end, the DTT scheme receivers' contacts in series should operate self-resetting relay(s) which trip and block close the associated line terminal circuit breaker(s).

The 220 kV and 500 kV primary and backup line relays should be fed from two separate dc battery systems. Independent circuit breaker trip coils should be used. The 110 kV primary and backup line relays may be fed from one battery system.

The 110 kV and 220 kV line relays should perform three-phase tripping. The single-phase tripping requirement of the 500 kV line relays will be determined on a case by case basis based on stability analysis.

CT/PT Connections

Primary and backup protective relays should be connected to independent sets of CT cores. CT connections should provide two independent protection zones. For the PT connections, the primary and backup protective relays should be connected to different windings of the same PT's.

Transformer Protection

The intent of this section is to cover the general guidelines for new 500-220 kV and 220-110 kV transformers protection. High voltage breakers are typically installed on the low and high sides of the transformers. New transformer protection should consist of independent primary and backup schemes.

Primary Scheme

The transformer primary protection should be current differential. The primary protection relay should also include time overcurrent and instantaneous overcurrent protection.

Backup Scheme

The transformer backup protection should be current differential. The backup protection should also include time overcurrent and instantaneous overcurrent.

In addition, a scheme should be implemented to trip transformer high and low side breakers when there is a rapid rise in transformer oil pressure.

Restricted Earth Fault protection should be included in the transformer protection. The transformer neutral CT should be used to connect to a protective relay for the restricted earth fault protection. The restricted earth fault protection should be an integral function of the transformer backup relay.

The tertiary winding of a three-winding transformer bank should be included in the transformer differential relay zone. The tertiary winding of an autotransformer that is brought out to supply load should also be included in the transformer differential relay zone.

Where there are no nearby distribution lines, a tertiary winding of the transformers is often used to provide an ac station service feed. Overcurrent and grounded phase protection should be provided for the tertiary station service feed utilizing a separate protective relay. This protective relay should be supplied by three CT's.

Power Transformers (40 MVA or Smaller) for Distribution Application

The primary scheme for this type of transformer should be identical to the primary scheme for the 500-220 kV and 220-110 kV transformers. The backup scheme should be the same as the backup scheme for the 500-220 kV and 220-110 kV transformers with the exclusion of the current differential.

Overexcitation Protection Scheme

An overexcitation protection scheme should be applied to transformer(s) where overexcitation conditions might exist during light load periods.

Transformer Protective Relay Criteria and Design Requirements

The transformer relays should be installed with test switches for testing and removal purposes. Output contacts of the primary and backup transformer protective relays should be used to actuate separate lockout relays respectively. Contacts of the lockout

relays should be used to trip and block close the associated high voltage circuit breakers. Output contacts from either transformer relays or auxiliary relays should be used to initiate stuck breaker failure.

The primary and backup transformer relays should be fed from two separate dc battery systems for 220 kV and 500 kV substations. Independent circuit breaker trip coils should be used. The primary and backup transformer relays may be fed from one dc battery system for 110 kV substations.

The transformer relays should perform three-phase tripping.

CT/PT Connections

Current transformers from the transformer low and high side circuit breakers should be used to connect to separate restraint windings in the primary and backup transformer relays. Primary and backup protective relays should be connected to independent sets of CT cores. CT connections should provide two independent protection zones.

The primary and backup transformer differential protection zones should be extended to cover the high and low side circuit breakers. This will eliminate the need for separate protection for the bus sections between the breakers and the transformer.

For the overexcitation protection scheme, the transformer low side PT's should be used to connect to the protective relay.

Bus Protection

The intent of this section is to cover the general guidelines for new 110 kV, 220 kV, and 500 kV bus protection. The protection of 110 kV bus should consist of primary and backup schemes. The protection of 220 kV and 500 kV buses should be two independent primary and backup schemes.

Primary Scheme for 110kV, 220 kV and 500 kV bus

Primary bus protection should be current differential.

Backup Scheme for 220 kV and 500 kV bus

Backup bus protection should also be current differential.

Backup Scheme for 110 kV bus

The backup bus protection should include time overcurrent and instantaneous overcurrent.

Bus Protective Relay Criteria and Design Requirements

The bus relays should be installed with test switches for testing and removal purposes. Output contacts of the primary and backup protective relays should be used to actuate separate lockout relays respectively. Contacts of the lockout relays should be used to trip and block close the associated high voltage circuit breakers. Output contacts from either the bus relays or auxiliary relays should be used to initiate stuck breaker failure.

The primary and backup 220 kV and 500 kV bus relays should be fed from two separate dc battery systems. Independent circuit breaker trip coils should be used. The primary and backup 110 kV bus relays may be fed from one dc battery system.

The bus relays should perform three-phase tripping.

The bus differential relays should be provided with dead zone transfer trip capabilities to clear faults that occur between the breaker and the free standing current transformers.

CT Connections

Primary and backup protective relays should be connected to independent sets of CT cores. CT connections should provide two independent protection zones. To maximize performance of the differential schemes, CT's should have the same ratio and similar characteristics.

Shunt Reactor Protection

The intent of this section is to cover the general guidelines for new shunt reactor protection. The protection schemes in this section are for shunt reactors to be installed in a substation.

Primary Scheme

Primary protection should use current differential.

Backup Scheme

Backup protection should consist of instantaneous, time delay phase overcurrent and time delay neutral overcurrent for winding to earth faults.

Restricted Earth Fault protection should be included in the reactor protection where applicable.

A Buchholz relay (gas accumulator) should be provided as part of the reactor for turn-to-turn fault protection.

Different relays should be used for protection and backup protection.

Shunt Reactor Protective Relay Criteria and Design Requirements

The shunt reactor relays should be installed with test switches for testing and removal purposes. Output contacts of the primary and backup protective relays should be used to actuate separate lockout relays respectively. Contacts of the lockout relays should be used to trip and block close the associated high voltage circuit breaker(s). Output contacts from either shunt reactor relays or auxiliary relays should be used to initiate stuck breaker failure.

The primary and backup relays should be fed from two separate dc battery systems for 220 kV and 500 kV substations. Independent circuit breaker trip coils should be used. The primary and backup relays may be fed from one dc battery system for 110 kV substations

The shunt reactor relays should perform three-phase tripping.

CT Connections

Primary and backup protective relays should be connected to independent sets of CT cores. CT connections should provide two independent protection zones.

Shunt Capacitor Protection

The intent of this section is to cover the general guidelines for new shunt capacitor protection. The protection schemes in this section are for shunt capacitors to be installed and connected to a substation bus through high voltage circuit breaking device(s).

For very large capacitor banks at 220 kV and 500 kV, the following protection schemes should be applied:

Primary Scheme

Primary protection should include phase and ground overcurrent. A second set of protective relay(s) should provide an unbalance detection scheme.

Backup Scheme

Backup protection should be the same as the primary protection.

A case by case engineering analysis will be required to determine a most appropriate method of unbalance detection scheme for a shunt capacitor installation. The unbalance detection scheme should be used to prevent an overvoltage of more than 110 % of rated voltage imposing on the capacitor cans.

For capacitor banks at 110 kV, one phase and ground overcurrent scheme and one unbalance scheme might suffice. An analysis of the capacitor bank installation will be required to determine if additional protection is needed to obtain an optimal solution.

Shunt Capacitor Protective Relay Criteria and Design Requirements

The shunt capacitor relays should be installed with test switches for testing and removal purposes. Output contacts of the primary and backup protective relays should be used to actuate separate lockout relays respectively. Contacts of the lockout relays should be used to trip and block close the associated high voltage circuit breaker(s). Output contacts from either shunt reactor relays or auxiliary relays should be used to initiate stuck breaker failure.

The primary and backup relays should be fed from two separate dc battery systems for 220 kV and 500 kV substations. Independent circuit breaker trip coils should be used. The primary and backup relays may be fed from one dc battery system for 110 kV substations

The shunt capacitor relays should perform three-phase tripping.

CT/PT Connections

Primary and backup protective overcurrent relays should be connected to independent sets of CT cores. CT connections should provide two independent protection zones. CT/PT connections for unbalance detection schemes will vary depending on which method is chosen. Primary and backup unbalance detection relays should be connected to separate CT's cores or different windings of the same PT.

Breaker Failure

The intent of this section is to provide the breaker failure protection guidelines for 110 kV, 220 kV and 500 kV circuit breakers. The breaker failure protection should be a non-directional instantaneous overcurrent relay that starts a timing relay. Any protective trip of the breaker should enable the breaker failure relaying scheme.

The breaker failure scheme should make one attempt to retrip the failed breaker before actuating the breaker failure scheme lockout relay(s).

Pole disagreement relaying will be provided for circuit breakers that have single pole tripping/closing capability. The pole disagreement protection should trip all three poles if all three poles are not in the same position. The inherent time delay in pole position for single phase tripping and closing should be considered.

The breaker failure scheme may be a separate stand alone scheme, integral to a breaker or bay control relay or integral to a back-up protection scheme that trips that breaker.

Breaker Failure Protective Relay Criteria and Design Requirements

If not included as an integral function of another relay, breaker failure relays should be installed with test switches for testing and removal purposes. If the breaker failure relay is integral with another relay, the input and outputs of the breaker failure relay should be installed with test switches for testing and isolation purposes.

Output contacts of the breaker failure relays should be used to actuate a separate lockout relay. Contacts of the lockout relay should be used to trip **(both trip coils)** and block close the associated high voltage circuit breaker(s).

The breaker failure scheme should perform three-phase tripping.

Output contacts of the breaker failure relay should enable the breaker failure schemes of adjacent breakers and direct transfer trip schemes associated with the 220 kV and 500 kV lines or actuate an auxiliary relay which will perform the same function. Once the breaker failure condition has been removed, the signal to enable adjacent breaker failure and DTT schemes associated with the 220 kV and 500 kV lines should be disabled.

CT Connections

The breaker failure relay should be connected to the CT core used for the back-up protective relays.

Synchronism Check

The intent of this section is to cover the general guidelines for synchronism check relaying for 110 kV, 220 kV and 500 kV breakers. With the exception of high speed automatic reclosing, synchronism check will be performed and supervise the closing of the circuit breakers. The synchronism relay should monitor the single phase voltages on the line (or load) side and bus (or source) side of the circuit breaker. System operating requirements and good engineering practices should be used to determine hot line (HL), dead line (DL), hot bus (HB) or dead bus (DB) synchronism check requirements.

Where it is determined that HB/HL synchronism check is required, the relay should be set such that the maximum slip frequency between the two sides of the breaker is not exceeded. The following relay settings are suggested.

Locations without generation:
Phase angle: 40 degrees
Time delay: 2.5 seconds

Locations without generation, but where a phase angle greater than 40 degrees is required
Phase angle: 60 degrees
Time delay: 3.5 seconds

Locations with generation

Phase angle: 20 degrees (or as required by the generator manufacturer)

Time delay: 2.0 seconds (or as required by the generator manufacturer)

The above relay settings are suggestions only and should be verified with system study data and modified as required to meet system requirements or generator manufacturer's requirements.

Synchronism Check Relay Criteria and Design Requirements

The synchronism relays should be installed with test switches for testing and removal purposes.

Reclosing

The intent of this section is to cover reclosing guidelines for 110 kV, 220 kV and 500 kV transmission line circuit breakers. Reclosing for transformers, capacitors, reactors, generators, bus couplers, bus faults should not be provided.

Single shot (one attempt) high speed automatic reclosing should be provided for one end of 220 kV, and 500 kV transmission lines that are not electrically close to generation sources. Appropriate time delay should be provided to allow deionization of the fault arc. Two shot (two reclose attempts) should be provided for one end of 110 kV transmission lines.

The circuit breaker closest to the generation source (lead breaker) should be closed first. For configurations where there are two breakers, such as breaker and one-half or ring bus configurations, one breaker on the line should be designated as the lead breaker.

After the lead breaker is successfully closed, the remaining (follow) breakers should be closed starting with the second breaker, if any, at the same end of the line as the lead beaker. Reclosing of the follow breakers should use synchronism check.

High speed reclosing should only be initiated if at least one line relaying scheme is in service.

Reclosing should be blocked for direct transfer trip, breaker failure conditions and breaker trips caused by other system component trips such as bus faults, transformer faults, etc.

If the transmission line is electrically close to a generation source, high speed reclosing should not be provided and reclosing should be delayed. The time delay and synchronism check should be determined based on the generator manufacturer's requirements.

Reclosing for underground cables should not be provided. For combined underground and overhead (air insulated) transmission lines, the requirement for reclosing for the overhead portion of the line will be determined on a case by case basis

Reclosing Relay Criteria and Design Requirements

If not included as an integral function of another relay, reclosing relays should be installed with test switches for testing and removal purposes.

It is preferred that the line reclosing function be contained in a circuit breaker or bay control relay. If the reclosing is not an independent stand alone scheme or contained in the breaker or bay control relay, it should be part of the primary line protection relay.

Load Shedding

Power systems are interconnected to provide power transfer path(s) between interconnected power systems. Major faults can cause the interconnected power systems to be separated into smaller systems. When there is a large mismatch between the power being generated and the heavy connected loads in the system, the system frequency will decrease due to the heavy loads causing a drag on the system. Without any proper actions, the system frequency dipping below the unacceptable level will result in a major system shutdown. One method to mitigate the underfrequency problem is to shed some of the connected loads at the substation level using a load shedding scheme. Underfrequency relay(s) are used in the scheme to detect the system frequency. The intent of this section is to cover the general guidelines that should be observed in developing load shedding scheme.

1. The load shedding scheme should be designed to meet or exceed the frequency deviation norms as stated in GOST 13109-97.

2. The load shedding scheme should be designed to shed load in steps.

3. Loads being tripped by load shedding scheme should not have an auto-reclose function.

Underfrequency Relay Criteria and Design Requirements

The underfrequency relays should be installed with test switches for testing and removal purposes.

The load shedding detection scheme should be designed with a high level of security to ensure there are no misoperations.

Undervoltage and Overvoltage

Undervoltage conditions are a result of faults not completely isolated. Overvoltage conditions can occur when faults, switching and lightning happen in the power system. Without proper overvoltage protection, severe damages to transmission and substation equipment can result from the imposition of overvoltages over an unacceptable period of time. Transformers, reactors, and capacitors are highly susceptible to overvoltage conditions. There are different levels of overvoltage protection provided in the transmission and substation systems. The protection level in this section is associated with over/under voltage protective relaying system for substations.

The intent of this section is to cover the suggested relay settings associated with undervoltage and overvoltage protection.

1. The undervoltage and overvoltage protection settings should meet or exceed the voltage norms as stated in GOST 13109-97.

2. The undervoltage settings are typically 90%-95% of normal voltage.

3. The overvoltage settings are typically 106%-110% of normal voltage.

The above relay settings are suggestions only and should be verified with system study data and modified as required to meet system requirements or equipment manufacturer's requirements.

Under- and Overvoltage Protective Relay Criteria and Design Requirements

If not included as an integral function of another relay, the under- and overvoltage relays should be installed with test switches for testing and removal purposes. If the relays are integral with another relay, the input and outputs of the multi-function relays should be installed with test switches for testing and isolation purposes.