



Study Estimate Design Guide

July 22, 2011

Design Best Practices and Performance Criteria Task Force





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Introduction

Applicability

This document outlines the Design Best Practices and Performance Criteria (DBP&PC) to be used by the Transmission Owner (TO) when developing Study Estimates for the SPP footprint projects rated at voltages of 100 kV and greater. These DBP&PC have been incorporated into this Study Estimate Design Guide and are intended to promote consistency in TO Study Stage estimates.

Recognizing the importance of well defined scopes when developing cost estimates, this document also contains scoping guidelines for the Conceptual and Study estimate phases. These guidelines will promote mutual understanding of the project definition between SPP and the TOs as the project is developed and estimates are prepared for the applicable phase of the potential project.

TO Study Estimate assumptions will be detailed in the Standardized Cost Estimate Reporting Template (SCERT) as used by the SPP project cost tracking process.

Design Best Practices and Performance Criteria

Design Best Practices represent high-level, foundational principles on which sound designs are based. Design Best Practices facilitate the design of transmission facilities in a manner that is compliant with NERC, SPP, and TO requirements; are consistent with Good Utility Practice as defined in the SPP Open Access Transmission Tariff (SPP Tariff)¹; are consistent with industry standards such as NESC, IEEE, ASCE, CIGRE, and ANSI; and are cost-effective. Although not addressed here, construction and maintenance best practices must be considered during the design phase to optimize these costs and efficiencies.

Performance Criteria further define the engineering and design requirements needed to promote a more uniform cost and reliability structure of the transmission facilities and to ensure that the TOs construct project(s) within the parameters requested by SPP. Flexibility is given such that the TO's historical and current performance criteria, business processes, and operation and maintenance practices are considered. Individual sections within this document contain both Design Best Practices and Performance Criteria.

Scope Management

A well developed and rigorously managed scoping document promotes consistent estimates and helps control costs. It also ensures that the SPP and TO have a clear understanding of the project being reviewed.

¹ The SPP Tariff defines Good Utility Practice as follows: "Good Utility Practice: Any of the practices, methods and acts engaged in or approved by a significant portion of the electric utility industry during the relevant time period, or any of the practices, methods and acts which, in the exercise of reasonable judgment in light of the facts known at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practices, reliability, safety and expedition. Good Utility Practice is not intended to be limited to the optimum practice, method, or act to the exclusion of all others, but rather to be acceptable practices, methods, or acts generally accepted in the region, including those practices required by Federal Power Act section 215(a)(4)."

Design Best Practices & Performance Criteria

Transmission Lines

General

Any criteria established for the design of transmission lines must consider safety, reliability, operability, maintainability, and economic impacts. The NESC contains the basic provisions considered necessary for the safety of utility personnel, utility contractors, and the public. However, the NESC is not intended to be used as a design manual, so Good Utility Practice must also be considered. Where applicable, [RUS guidelines](#) should also be considered.

Siting and Routing

The impact of the transmission facility to the surrounding environment should be considered when developing the study estimate. Sensitivity to wetlands, cultural and historical resources, endangered species, archeological sites, existing neighborhoods, and federal lands, are examples that should be considered when siting transmission facilities. The TO must comply with the requirements of all appropriate regulatory agencies during the siting process, and all applicable environmental and regulatory permits must be obtained for the transmission facilities. The TO should describe any known or anticipated environmental issues and associated estimated costs in the Study Estimate, as well as any estimated regulatory siting and permitting costs. Study Estimates will use a default assumption for line mileage that is based upon right angle design absent better assumptions. Where two or more TOs are directed by the SPP to build a project, the TOs shall agree between them how much of the project should be built by each. The TOs will then submit a Study Estimate in accordance with these design best practices.

Electrical Clearances

The clearances of the NESC shall be adhered to in the design of transmission lines. Conductor-to-ground and conductor-to-conductor clearances should include an adequate margin during design to account for tolerances in surveying and construction. Sufficient climbing and working space for NESC and OSHA working clearances should be considered when establishing the geometrical relationships between structure and conductors. Appropriate clearances should be maintained considering NESC requirements, maximum operating temperature, and extreme ice loading. Conductor-to-conductor clearances should account for sag and tension, wire movement variances, and minimum approach distances. Where applicable, dynamic effects (e.g. galloping conductors, ice-drop, etc.), should be considered.

Structure Design Loads

Structures will be designed, at a minimum, to NESC standards and in accordance to the TO's design practices, as appropriate.

Design Load Application

Structures and foundations should be designed to withstand a combination of gravity, wind, ice, conductor tension, construction, and maintenance loads. The following loadings, based on *ASCE Manual of Practice (MOP) 74*, should be considered to help ensure structural integrity under most probable loading combinations. Dynamic loading (e.g. galloping, ice-drop, etc.) of conductors should also be considered.

Loads with All Wires Intact

- NESC requirements
- Extreme wind applied at 90° to the conductor and structure
- Extreme wind applied at 45° to the conductor and structure
- Combined wind and ice loadings
- Extreme ice loading

Unbalanced Loads

- Unbalanced loads as described below should be considered to prevent local and cascading failure. Spacing for cascading should be predicated on TO practices.
 - Longitudinal loads due to unbalanced ice conditions (ice in one span, ice fallen off of adjacent span) with all wires intact
 - Longitudinal loads due to a broken ground wire or one phase position (the phase may consist of multiple sub-conductors)

Construction and Maintenance Loads

- Construction and maintenance loads shall be applied based on the recommendations of *ASCE MOP 74*.
- These loads may be modified based on local TO construction, maintenance, and safety practices.

Structure and Foundation Selection and Design

Structure types may be latticed steel towers or steel, concrete, or wood poles at the TO's discretion. The choice should be based on consideration of structural loading, phase configuration, total estimated installed cost and other economic factors, aesthetic requirements, siting restrictions, and right-of-way requirements.

Structure design should be based on the following as they apply:

- *ASCE Standard No. 10, Design of Latticed Steel Transmission Structures*
- *ASCE Standard No. 48, Design of Steel Transmission Pole Structures*
- *ASCE Publication Guide for the Design and Use of Concrete Poles*
- *ANSI 05-1, Specifications and Dimensions for Wood Poles*
- *IEEE Std. 751, Trial-Use Design Guide for Wood Transmission Structures*

Structures may be supported on concrete piers, grillages, piles, or they may be directly embedded. The method selected shall be based on known or anticipated geotechnical conditions and structure loading.

Insulation Coordination, Shielding, and Grounding

Metallic transmission line structures shall be grounded. Overhead static wires (shield wires) should also be grounded, or a low impulse flashover path to ground should be provided by a spark gap. Individual structure grounds should be coordinated with the structure insulation level and static wire shielding angles (with reference to the phase conductors) to limit momentary operations of the supported circuit(s) to the targeted rate. The coordination of grounding, shielding and insulation should be established considering the effects of span lengths, conductor-to-ground clearances, lightning strike levels, and structure heights.

Rating of Phase Conductors

The maximum operating temperature of phase conductors shall be based on metallurgical capacity (i.e., the maximum temperature the conductor can withstand without incurring damage due to heat) and assuming a reasonable loss of strength.

The conversion to ampacity shall be based on *IEEE Publication No. 738, Standard for Calculating the Current-Temperature of Bare Overhead Conductors*, and SPP Criteria 12.

The TO should select environmental parameters based on its experience and historical and current line rating and operating procedures.

Selection of Phase Conductors

Phase conductors should be selected based on the anticipated power flow of the circuit, metallurgical and mechanical properties, and proper consideration for the effects of the high electric fields.

Minimum Conductor Sizing

The conductor size shall be selected by the TO based on metallurgical (losses, impedance), mechanical, and corona performance. The TO should also consider: electrical system stability (voltage and stability), ampacity, and efficiency effects when selecting conductor size.

The following minimum normal amperage ratings should be considered:

Voltage (kV)	Amps
100 - 200	As Specified by SPP
230	1,200
345	3,000
500	3,000
765	4,000

Reconductoring

TOs should consider the application of advanced conductors for reconductoring projects if existing structures are adequate and have sufficient life expectancy to preclude tear down and rebuilds.

Optical Ground Wire

Optical Ground Wire (OPGW) is preferred for all overhead shield wires to provide a communication path for the transmission system. Where there are multiple static wires only one is recommended to be OPGW. Consideration should be given to installing both wires as OPGW at voltages of 345 kV and higher to provide redundancy for protection schemes. Where there is an underground fiber communication path OPGW is not preferred. The size shall be determined based on the anticipated fault currents generating from the terminal substations.

Adequate provisions should be made for OPGW repeater redundancy as well as power supply redundancy at each repeater.

Reactive Compensation

Project cost estimates should include reactive compensation as appropriate. The following table contains the suggested reactive compensation per mile of line:

Voltage (kV)	Reactive Compensation (MVAR / mi)
100 - 200	0.1
230	0.3
345	1
500	2
765	4.5

Transmission Substations

General

Criteria established for the design of transmission substations must consider safety, reliability, operability, maintainability, and economic impacts. The NESC contains the basic provisions considered necessary for the safety of utility personnel, utility contractors, and the public. However, the NESC is not intended to be used as a design manual, so Good Utility Practice must also be considered. Where applicable, [RUS guidelines](#) should also be considered.

Substation Site Selection and Preparation

When selecting the substation site, careful consideration must be given to factors such as line access and right-of-way, vehicular access, topography, geology, grading and drainage, environmental impact, and plans for future growth. Each of these factors can affect not only the initial cost of the facility, but its on-going operation and maintenance costs. Storm water management plans and structures must comply with all federal, state, and local regulations.

Electrical Clearances

The clearances for substation design shall be in accordance with all applicable standards and codes. Vertical clearances to ground shall meet or exceed the NESC requirements. When the exposed conductors are in areas where foot traffic may be present, a margin may be added to the NESC clearance. Substation phase spacing shall meet *IEEE C37.32* and NESC requirements.

Sufficient space for OSHA working clearances should be provided when establishing the geometrical relationships between structure and conductors.

Design Load Application

Structures and foundations should be designed for all loads acting on the structure and supported bus or equipment, including forces due to gravity, ice, wind, line tension, fault currents and thermal loads. The following loadings should be considered:

Line Structures and Shield Wire Poles

- NESC requirements
- Extreme wind applied at 90 degrees to the conductor and structure
- Combined wind and ice loadings
- Extreme ice loading

Equipment Structures and Shield Poles without Shield Wires

- Extreme wind, no ice
- Combined wind and ice loadings
- In the above loading cases, wind loads shall be applied separately in three directions (two orthogonal directions and at 45 degrees, if applicable)
- Forces due to line tension, fault currents and thermal loads shall also be considered
- Deflection of structures should be limited such that equipment function or operation is not impaired

Structure and Foundation Selection and Design

Structures may be designed and fabricated from tapered tubular steel members, hollow structural steel shapes, and standard structural steel shapes. The selection of structure type (e.g., lattice, tubular, etc.) should be based on consideration of structural loading, equipment mounting requirements, total estimated installed cost and other economic factors, and aesthetic requirements.

Structure design should be based on the following, as appropriate:

- *ASCE Standard No. 10, Design of Latticed Steel Transmission Structures*
- *ASCE Standard No. 48, Design of Steel Transmission Pole Structures*
- *ASCE Standard No. 113, Substation Structure Design Guide*
- *AISC's Steel Construction Manual*

Structures may be supported on concrete piers, spread footings, slabs on grade, piles, or they may be directly embedded. The method selected shall be based on known or anticipated geotechnical conditions, structure loading, and obstructions (either overhead or below grade).

Grounding

The substation ground grid should be designed in accordance with the latest version of *IEEE Std. 80, Guide for Safety in AC Substation Grounding*. The grid should be designed using the maximum anticipated fault current.

Substation Shielding

All bus and equipment should be protected from direct lightning strikes using an acceptable analysis method such as the *Rolling Sphere Method*. *IEEE Std. 998, Guide for Direct Lightning Stroke Shielding of Substations*, may be consulted for additional information.

Bus Selection and Design

Bus selection and design must take into consideration the electrical load (ampacity) requirements to which the bus will be subjected, in addition to structural loads such as gravity, ice, wind, short circuit forces, and thermal loads. Bus conductor and hardware selection are also critical to acceptable corona performance and the reduction of electromagnetic interference. Allowable span lengths for rigid-bus shall be based on both material strength requirements of the conductor and insulators, as well as acceptable bus deflection limits. Guidelines and recommendations for bus design can be found in *IEEE Std. 605, Guide for Bus Design in Air Insulated Substations*.

Bus Configuration

Substations should be designed to accommodate future expansion of the transmission system (e.g. converting ring bus to a breaker and a half as terminals are added). The following table provides suggested bus configurations.

Voltage (kV)	Number of Terminals	Substation Arrangement
100 - 499	One or Two	Single Bus
	Three to Six	Ring Bus
	More than Six	Breaker-and-a-half
500/765	One or Two	Single Bus
	Three to Four	Ring Bus
	More than Four	Breaker-and-a-half

Rating of Bus Conductors

The maximum operating temperature of bus conductors should be based on metallurgical capacity (i.e., the maximum temperature the conductor can withstand without incurring damage due to heat) and assuming a reasonable loss of strength.

The conversion to ampacity shall be based on the *IEEE Std. 738, Standard for Calculating the Current-Temperature of Bare Overhead Conductors*, and *IEEE Std. 605, Guide for Bus Design in Air Insulated Substations*. The TO should select environmental parameters based on its experience and historical and current bus rating and operating procedures. Bus conductors should be sized for the maximum anticipated load (current) calculated under various planning conditions and contingencies. The bus should be designed so as to not be the limiting element.

Substation Equipment

Future improvements should be considered when sizing equipment.

Surge protection should be applied, where appropriate, on all line terminals with circuit breakers and considered on all oil-filled electrical equipment in the substation such as transformers, instrument transformers and power PTs.

All substation equipment should be specified such that audible sound levels at the edge of the substation property are appropriate to the facility's location.

Bus and Equipment Insulation Levels

Minimum BIL ratings for substation insulators, power transformer bushings, potential transformer bushings, current transformer bushings, and power PTs are found in the tables below. When placed in areas of heavy contamination (coastal, agricultural, industrial), insulator contamination can be mitigated by using extra-creep insulators, applying special coatings to extra-creep porcelain insulators, and using polymer insulators.

Substation Insulators

Nominal System L-L Voltage (kV)	BIL (kV Crest)	BIL (kV Crest) Heavy Contaminated Environment
115 - 138	550	650 (Extra Creep)
161	650	750 (Extra Creep)
230	900	900 (Extra Creep)
345	1050	1300 (Extra Creep)
500	1550	1800 (Standard Creep)
765	2050	2050 (Standard Creep)

Power Transformers, Potential Transformers and Current Transformers

Nominal System L-L Voltage (kV)	Power Transformer Winding BIL (kV Crest)	Power PTs (kV Crest)	PT and CT BIL (kV Crest)	Circuit Breaker BIL (kV Crest)
115	450	550	550	550
138	650	650	650	650
161	650	650	650	650
230	825	900	900	900
345	1050	1300	1300	1300
500	1550	N/A	1550 / 1800	1800
765	2050	N/A	2050	2050

Rating Margins for Substation Equipment

Substation equipment shall be rated to carry the anticipated worst-case loading.

Minimum Interrupting Fault Current Levels

Minimum substation design symmetrical fault current ratings can be found in the following table. The fault current capability must exceed expected fault duty.

Voltage (kV)	Interrupting Current Symmetrical (kA)
100 – 345	40
500	50
765	50

Minimum Rating of Terminal Equipment

Minimum ratings of substation terminal equipment should be as follows:

Voltage (kV)	Amps
100 - 200	1,200
230	1,200
345	3,000
500	3,000
765	4,000

Minimum Bus Rating

Minimum ratings of substation bus should be as follows:

Voltage (kV)	Amps
100 - 200	2,000
230	2,000
345	3,000
500	3,000
765	4,000

Substation Service

There should be two sources of AC substation service for preferred and back-up feeds. An acceptable substation service alternative would be to feed the substation service transformers via the tertiary winding of an autotransformer or connect power PTs to the bus. Distribution lines are not preferred as the primary AC source because of reliability concerns, but can be used when other sources are unavailable. If there are no feasible alternatives for a back-up substation service, provision of a generator should be considered.

Control Enclosures

Control enclosures may be designed to be erected on site, or they may be of the modular, prefabricated type. Enclosures may be constructed of steel, block, or other alternative materials, and should be designed and detailed in accordance with the applicable sections of the latest editions of the following:

- *AISC Specification for Structural Steel Buildings*
- *AISI Specification for the Design of Cold-Formed Steel Structural Members*
- *ACI 530/530.1, Building Code Requirements and Specification for Masonry Structures and Related Commentaries*
- *ACI 318, Building Code Requirements for Structural Concrete and Commentary*

Design loads and load combinations should be based on the requirements of the *International Building Code* or as directed by the jurisdiction having authority. Enclosure components shall also be capable of supporting all cable trays and attached equipment such as battery chargers and heat pumps.

Wall and roof insulation should be supplied in accordance with the latest edition of the *International Energy Conservation Code* for the applicable Climate Zone.

Oil Containment

Secondary oil containment should be provided around oil-filled electrical equipment and storage tanks in accordance with the requirements of the United States EPA. More stringent provisions may be adopted to further minimize the collateral damage from violent failures and minimize clean-up costs. Additional design information can be found in IEEE Std. 980, *Guide for Containment and Control of Oil Spills in Substations*

Single Pole Switching / Breakers / Controls

Facilities 500kV and above should consider single pole switching.

Transmission Protection and Control Design

General

Criteria for employing protection and control principles in the design and construction of new substations must adhere to *NERC Reliability Standards* and *SPP Criteria*, as well as individual TO standards.

These guiding principles and best practices center on the following criteria:

- Communication Systems
- Voltage and Current Sensing Devices
- DC Systems

Primary and Backup Protection Schemes

Communication Systems

Power Line Carrier (PLC) equipment or fiber as the communication medium in pilot protection schemes is recommended to meet the high-speed communication required. PLC equipment is typically used on existing transmission lines greater than five miles in length. Fiber protection schemes should be considered on all new transmission lines being constructed using OPGW. Compatible relays, considering the use of the same manufacturer, should be installed at both ends. Other forms of communication, i.e. microwave or tone, may be considered.

Voltage and Current Sensing Devices

Independent current transformers (CTs) are recommended for primary and backup protection schemes in addition to independent secondary windings of the same voltage source (i.e., CCVTs).

DC Systems

DC systems should be designed in accordance with NERC standards, SPP Criteria, and TO practices.

Primary and Backup Protection Schemes

Primary and backup protection schemes should be required for all lines and be capable of detecting all types of faults on the line. The primary scheme should provide high-speed, simultaneous tripping of all line terminals at speeds that will provide fault clearing times for system stability as defined in *NERC Transmission Planning and Reliability Standards TPL-001 through TPL-004*.

The following criteria should be used to determine if one or two high speed protection systems are needed on a line. While it is possible that the minimum protective relay system and redundancy requirements outlined below could change as *NERC Planning and Reliability Standards* evolve it will be the responsibility of each individual TO to assess the protection systems and make any modifications deemed necessary.

Line Applications:

765 / 500 kV

At least two high speed pilot schemes using a dual battery design and dual direct transfer trip (DTT) using PLC and/or fiber are required. Fiber should be used on all new transmission lines using OPGW, and PLC equipment for existing lines (Mode 1 coupling to all three phases). Where there is an underground fiber communication path OPGW is not preferred. PLC-based protection schemes using directional comparison blocking (DCB) require automatic checkback features to be installed to ensure the communication channel is working properly at all substations.

345 kV

Dual high speed pilot schemes and one direct transfer trip (DTT) using PLC and/or fiber are required. Dual DTT is required if remote breaker failure protection cannot be provided with relay settings. Fiber should be used on all new transmission lines using OPGW and PLC equipment for existing lines. Where there is an underground fiber communication path OPGW is not preferred. Independent PLC communication paths may be required for proper protective relay coordination. PLC-based protection schemes using directional comparison blocking (DCB) require automatic checkback features to be installed to ensure the communication channel is working properly at all substations.

Below 300 kV

A minimum of one high speed pilot scheme using PLC and/or fiber is suggested. Fiber should be used on all new transmission lines using OPGW and PLC equipment for existing lines. Where there is an underground fiber communication path OPGW is not preferred. Dual pilot schemes may be required for proper relay coordination. If dual high speed systems are needed, independent communication channels will be used. PLC-based protection schemes using directional comparison blocking (DCB) require automatic checkback features to be installed to ensure the communication channel is working properly at all substations.

Transformer Applications:

765 / 500 kV

Transformer protection for three (3) single phase banks should be designed considering a dual station battery design, with the protection divided into two systems. The first system should be an overall differential protection scheme. The second system should provide protection for other needs such as internal differential, highside and lowside lead differential, backup overcurrents, sudden pressure and loss of cooling protection. The two protection systems should be separated as much as is practicable.

345 kV - 100 kV

The transformer protection should be divided into two systems, an overall differential protection scheme, and a second system providing protection for other needs such as internal differential, highside and lowside lead differential, backup overcurrents, sudden pressure and loss of cooling protection.

Bus Applications:

765 / 500 kV

Bus protection at this voltage level should be designed considering a dual station battery design. Low impedance bus differential protection should be considered. The protection should be divided into two systems with their own dedicated lockout relay.

345 / 230 kV

Low impedance bus differential protection should be used with the protection divided into two systems with their own dedicated lockout relay.

200 kV and below

Current summation (unrestrained differential) should be typically used in new stations at these voltage levels with the protection scheme divided into two systems with their own dedicated lockout relay. To improve reliability at these voltages, bus one-shot capabilities should be provided when a capacitor bank is installed on the bus and its protection is not accounted for in the bus differential scheme. If bus fault levels are greater than 20kA, then high impedance or low impedance protection solutions must be considered.

Substation Devices

For substation devices, such as capacitor banks, Static VAR Compensators, reactors, appropriate protection systems should be incorporated with due consideration of redundancy and flexibility to facilitate system operations and maintenance.

Phase Measurement Units (PMUs)

PMUs, or Intelligent Electronic Devices (IEDs) capable of providing PMU measurements, should be installed in all new 230 kV and above substations.

SCADA and RTUs

SCADA should be considered for all substations. The capability to retrieve fault records should also be considered.

Scoping Requirements

This section describes the Scoping Requirements to be used by the SPP when developing Conceptual Estimates and the TOs when developing Study Estimates for transmission facilities for the SPP footprint.

Conceptual Estimate Scope Requirements

(Developed by SPP and provided to the TO)

Transmission Line Projects

- Description of project
- Termination points of each transmission line (Point A to Point B) Voltage
- Estimated Line length
- Line Ampacity
- Reactance requirements
- Need Date

Transmission Substation Projects

- Description of project
- Voltage
- Need Date
- Transformer requirements

Study Estimate Scope Requirements

(Developed by the TO and provided to SPP)

The Study Estimate Scope document should include the Conceptual Estimate Scope requirements in addition to the information listed below.

Transmission Line Projects

- Structures
 - Structure types - specify lattice structures, poles (wood, steel, concrete, etc.)
 - Number of storm structures, dead ends, running corners, tangents
 - Foundation information
- Number of circuits
- Conductor size, type and number/phase

- Static wire (EHS/OPGW)
- Protection control and communications
- Type of terrain
- Switch requirements
- Legal requirements (e.g. CCN process)
- Geotechnical assumptions
- Special material requirements
- Preliminary line route (rough location when practical)
- Access road requirements
- Design criteria
 - Weather loading
 - Live line maintenance
 - Unbalanced structural loads
- Distribution/Joint Use requirements
- Right-of-Way
 - Right-of-Way acquisition
 - Right-of-Way clearing requirements
 - Right-of-Way width
- Permitting Concerns
 - Traffic control requirements
 - FAA Requirements
- Environmental Concerns
 - Environmental Study Requirements
 - Wetland Requirements/Mitigation
 - Threatened and Endangered Species Mitigation
 - Cultural/Historical Resource Requirements

Transmission Substation Projects

- Preliminary one-line diagram
- All major equipment, including rehab of existing equipment to meet the SPP project scope, i.e. Transformers, Breakers, Control panels, Switches, CTs, PTs, CCVTs
- BIL ratings
- Contamination requirements
- Mobile substation requirements

- Required substation property/fence expansions (indicating anticipated arrangement of proposed facilities and any resulting expansion needed)
 - Control enclosure expansions (indicating anticipated panel layout and any resulting expansion needed)
 - Fiber optic requirements
 - Remote end requirements
 - Metering requirements
 - Reactive Compensation requirements
 - Wetland/T&E/Community Approval/Unusual site prep requirements.
 - SCADA requirements
 - Protection control and communications
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