IEEE Std 1646™-2004

IEEE Standards

1646™

IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation

IEEE Power Engineering Society

Sponsored by the
Substation Committee

IEEE

3 Park Avenue, New York, NY 10016-5997, USA

25 February 2005

Print: SH95283
PDF: SS95283

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IEEE Std 1646™-2004

IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation

Sponsor

Substation Committee
of the
Power Engineering Society

Approved 3 September 2004

IEEE-SA Standards Board

Approved 23 March 2005

American National Standards Institute

Abstract: A standard defining communication delivery times of information to be exchanged within and external to substation integrated protection, control, and data acquisition systems is described. Communication capabilities and system capabilities to deliver data on time are also specified.
Keywords: automatic control, data acquisition, SCADA, supervisory control, communication, intelligent electronic devices, IED, distributed processing, communication message delivery performance measures

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Print: ISBN 0-7381-4502-5 SS95283
PDF: ISBN 0-7381-4503-3 SS95283

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Introduction

(This introduction is not part of IEEE Std 1646-2004, IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation.)

This standard applies to systems used to communicate between intelligent electronic devices (IEDs) for substation integrated protection, control and data acquisition. The requirements of this standard are in addition to those contained in standards for individual devices (e.g., relays, switchgear).

This standard applies to a rapidly changing technology. It is anticipated that frequent revision may be desirable.

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IEEE Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation

1. Overview

1.1 Scope

This standard defines communication delivery times of information to be exchanged within and external to substation integrated protection, control, and data acquisition systems.

1.2 Purpose

Utilities will use communication performance requirements as part of a procurement specification to develop new substation automation systems, or to modify existing substation automation systems. Vendors will use communication performance requirements to build open system communication interfaces for intelligent electronic devices for substation automation.

1.3 IEEE 1646 is communication protocol and data model neutral

IEEE 1646 is a specification of communication delivery time performance requirements, other than for time synching; it does not specify an underlying protocol nor does it specify the data model used to exchange information. End users must consider the bandwidth available for communication within an electric power substation, between substations, and between substations and other entities. End users must also select a comprehensive data model describing the semantics of the information to be exchanged.

1.4 Document organization

In addition to the overview, described in this clause, normative references are described in Clause 2 and definitions, acronyms and abbreviations are defined in Clause 3.

Communication delivery time performance requirements are described in Clause 4 to specify the measurable criteria for complying with this standard. Clause 5 and Clause 6 describe the communication capabilities and system capabilities required to deliver data within specified times.

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Two informative annexes are part of this standard.

Annex A (informative) Bibliography
Describes references that are commonly used in power system engineering and communications between intelligent electronic devices.

Annex B (informative) Example applications
Summarizes example applications for protection, distribution, local control, EMS/DMS/SCADA, and planning and maintenance functions.

2. References

This standard shall be used in conjunction with the following normative publications. When the referenced standard is superseded by an approved revision, the revision shall apply.

IEEE Std 1588™-2002, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.[1]

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards, Seventh Edition [B7],* should be referenced for terms not defined in this clause. The following conventions are used for cross-referencing:

Contr: Refers to a term that has an opposed or substantively different meaning.
See: Refers to a related term that has a similar, but not synonymous meaning.
Syn: Indicates that the term has the same meaning as another term, which is referenced.

3.1.1 adjacent component protection: Protection of power system equipment at one substation based on data measured at others, e.g., line differential protection and teleprotection.

3.1.2 alarm processing: Alarm analysis procedures to improve presentation of alarm data. It ranges from updating alarm lists and producing group alarms up to more intelligent evaluations.

3.1.3 asynchronous transmission: In data communications, a method of transmission in which sending and receiving of data is controlled by control characters rather than by a timing sequence.

3.1.4 automatic switching sequences: Automatic sequential operation of groups of power system devices to reduce operator workload and/or switching time and to avoid unsuccessful or unnecessary switching attempts.

3.1.5 availability of data: State in which data are where the user needs them, when the user needs them, and how the user needs them.

3.1.6 breaker: A device that connects and disconnects power circuits, with fault-interrupting capability; *Syn:* **circuit breaker.**

3.1.7 breaker (health) monitoring: A function that measures a breaker's parameters for decisions on needed maintenance or repair.

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3.1.8 breaker failure protection: Backup protection scheme to trip all connected breakers if a breaker fails to clear a detected fault.

3.1.9 broadband: Transmission that typically employs nondiscrete (analog) signals that are continuously transmitted over a transmission media in the form of electromagnetic waves. Discrete information is encoded into analog waves by using amplitude, frequency, or phase modulation of the base (carrier) signal; *Contr:* **baseband.**

3.1.10 broadcast mode: Concurrent transfer mode of information to all connected receivers with one message from the information source; *Contr:* **unicast mode; multicast mode.**

3.1.11 calibrate function: Process of adjusting internal parameters of a measurement unit to reduce errors in its measured values.

3.1.12 client: (A) A system entity (combination of hardware and software components) which requests particular services to be done on its behalf from another entity (i.e., the server); **(B)** An intelligent electronic device (IED) object that requests information from, or invokes the procedures, of another (i.e., the server).

3.1.13 cold load pickup: Restoration of a circuit where all load diversity is lost.

3.1.14 communication interface: Serial interface of a device that allows exchange of (physical and logical) information among devices of the same or different functional levels in a hierarchical system. An interface specifies the connection of a communication link, with regard to the mechanical connection as well as to the signal's physical and functional characteristics.

3.1.15 communication safety: Measures and controls to avoid any deterioration or losses of information (reliability).

3.1.16 device: Physical entity connected to the communication network composed of at least one communication element (the network element), which may have a control element, and/or a monitoring element (transducer, actuator, etc.).

3.1.17 digital fault recorder (DFR): Device that samples and stores analog and related binary data during power system transients; *Syn:* **Transient fault recorder (TFR).**

3.1.18 disconnect switch: Device that connects and disconnects de-energized power circuits; *Syn:* **isolator.**

3.1.19 equipment clock synchronization: Automated procedure to maintain consistent time data throughout the substation or power system; e.g., for time tagging or synchronized sampling.

3.1.20 equipment load monitoring: Automated procedures to detect equipment overload. The goal is to tolerate temporary overload, support for adaptive protection and maintenance on request.

3.1.21 fault isolation: A procedure to operate feeder-sectionalizing switches (isolators) to disconnect a faulted feeder section.

3.1.22 fault recording: Process for collection, storage and analysis of power system fault data.

3.1.23 feeder fault isolation: A procedure to disconnect the power network device (transformer, busbar, switchgear, etc.) in which a fault has occurred.

3.1.24 feeder switching: A procedure to manage feeder connectivity changes; *See also:* **automatic switching sequences.**

3.1.25 generator protection: Function of protecting generator from fault and abnormal operating conditions.

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3.1.26 global positioning system (GPS) receiver: Device that acquires precision time and position data from the U.S. Department of Defense system of low-orbit satellites. For substations, it is used as time receiver for equipment clock synchronization.

3.1.27 high integrity: Integrity where a vanishing small probability of undetected error must be achieved; *See also:* **integrity.**

3.1.28 high-speed sampled data: Raw sampled data provided by an analog-to-digital converter located close to the voltage transformers (VTs) and current transformers (CTs). A process bus, or dedicated point-to-point links, transfers such data samples from the converter to protection intelligent electronic devices (IEDs).

3.1.29 insolation: Incident solar energy flux per unit area.

3.1.30 integrity: Immunity requirements to the network of data transfer errors due to accidental or intentional interference; *See also:* **high integrity; low integrity; medium integrity.**

3.1.31 interoperability: The ability of two intelligent electronic devices (IEDs) to exchange information via the communications system as needed for their on-line operation. This is normally achieved by using only published standard data and object definitions, standard commands and standard protocols.

3.1.32 interrupts: Means of an information source with higher-priority data to pre-empt communication capability currently in use by traffic of lower priority.

3.1.33 isolator: Device that connects and disconnects power circuits; *See also:* **disconnect switch.**

3.1.34 latency (communications): The delay between the time the data is sent from its origin and received at its destination. Latency determines how responsive the link will be; *See also:* **bandwidth**.

3.1.35 line fault location: Procedure to locate line faults.

3.1.36 line load monitoring: Automated supervision procedure to support line operation.

3.1.37 line protection: Scheme to detect line faults and trip all breakers attached to the faulted line.

3.1.38 load flow control: Procedure to manage voltage profiles and current flows throughout an electrical network.

3.1.39 load tap changer control: Device that receives scaled system voltage, current or other signals, compares existing operating conditions to that desired and accordingly commands load tap changer action.

3.1.40 load tap changer controller: Device that manages the operation of a load tap changer on a transformer or step-voltage regulator. Synonymous with voltage regulating relay when used for control of the system voltage.

3.1.41 low integrity: Integrity where errors are merely a nuisance to the data recipient; *See also:* **integrity.**

3.1.42 medium integrity: Integrity where inherent data redundancy provides adequate error immunity; *See also:* **integrity.**

3.1.43 message: A communication between objects that conveys information with the expectation that activity will ensue. The receipt of a message is normally considered an event.

3.1.44 multicast forwarding: A forwarding decision made for each multicast internet protocol (IP) packet received.

3.1.45 multicast routing: Activities performed by internet protocol (IP) routers in order to determine how to forward multicast IP packets, either from some particular source to a group, or from any source to a group.

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3.1.46 multifunction meter: Device that uses sensor data to calculate quantities such as power, energy, voltages, and currents.

3.1.47 node: A run-time physical object that represents a computational resource, generally having at least memory and often processing capability as well. Run-time objects and components may reside on nodes.

3.1.48 phase shifter control: Procedure to control phase shifting transformers to manage phase angles and load flows.

3.1.49 phasor measurement unit: Device that extracts power system frequency phase angle and magnitude data from sensor signals.

3.1.50 pilot channel monitoring: Automated procedure that reports detected failures of protective relaying signaling channels.

3.1.51 portability: Ability to move, with minimal changes, application software between computers.

3.1.52 power quality monitoring: Procedure for collection, storage, and analysis of power quality data at subtransmission and distribution load points.

3.1.53 precondition: A constraint that must be true when an operation is invoked.

3.1.54 priority: Ability of the communication network to support several levels of message priority. Higher priority messages are given access to communication resources before lower priority messages.

3.1.55 process bus: The serial bus closest to the process providing raw data or data processed very near to the switchgear or instrument transformers. In the area of process automation, very often called the field bus.

3.1.56 projection: A mapping from a set to a subset of it.

3.1.57 reactor/capacitor protection: Scheme for detailed monitoring of reactive devices to detect internal faults and to trip all breakers connected to the faulted reactor/capacitor.

3.1.58 receiver: The object accepting a message from a sender object; *Contr:* **sender.**

3.1.59 recloser: *See:* **automatic circuit recloser.**

3.1.60 recloser controller: Hardware used for fault detection, tripping and reclosing of a recloser.

3.1.61 recloser status monitoring: Automated procedure to detect recloser state and operations.

3.1.62 relay setting control: Procedure to manage the adjustment of setpoints in protective relay equipment.

3.1.63 relay setting update: Procedures that report existing setpoints of protective relays and support the delivery of revised settings.

3.1.64 relay testing: Procedures that support testing of protective relay equipment.

3.1.65 revenue meter: Device that uses sensor data to calculate real and reactive power and energy.

3.1.66 semantic variation: A particular interpretation choice for a semantic variation point; *See also:* **semantic variation point.**

3.1.67 semantic variation point: A point of variation in the semantics of a metamodel. It provides an intentional degree of freedom for the interpretation of the metamodel semantics; *See also:* **semantic variation.**

3.1.68 sender: The object passing a message to a receiver object; *Contr:* **receiver.**

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3.1.69 sequence of events (SOE) recorder: Device that samples and stores events (contact status changes, trips, limit violations, etc.), for later analysis and possibly replay. The events are time tagged.

3.1.70 sequence of events (SOE) monitoring: Procedure to manage the collection, analysis and presentation of SOE data.

3.1.71 server: Object that provides information or service to another (i.e., client). Typical examples of servers are station computers and bay control/protection units. In substation applications servers have real-time requirements and are running with real-time operating systems; *Contr:* **client.**

3.1.72 signal: A named event that can be explicitly invoked ("raised"). Signals may have parameters. A signal may be broadcast or directed toward a single object or a set of objects.

3.1.73 signature: The name and parameters of an operation, message, or event. Parameters may include an optional returned parameter.

3.1.74 soft real-time: A system where timeliness of response is important but not a matter of complete system failure. The acceptable frequency of missed deadlines is dictated by design.

3.1.75 substation automation: Deployment of substation and feeder operating functions and applications ranging from Supervisory Control and Data Acquisition (SCADA) and alarm processing to integrated volt/var control in order to optimize the management of capital assets and enhance operation and maintenance (O&M) efficiencies with minimal human intervention; *See also:* **substation integration.**

3.1.76 substation integration: Integration of protection, control and data acquisition functions into a minimal number of platforms to reduce capital and operating costs, reduce panel and control room space, and eliminate redundant equipment and databases; *See also:* **substation automation.**

3.1.77 switch: Common denominator for circuit breakers and isolators (i.e., for the switching elements in the power network).

3.1.78 switch (in data network): Network (communication) device that filters, forwards, and floods frames based on the destination address of each frame. The switch operates generally at the data link layer (layer 2) of the open system interconnection (OSI) model. Switches provide a unique network segment on each port, thereby separating collision domain. They are often used to replace hubs (concentrators) to increase network performance and bandwidth. Some switches perform network switching (layer 3) in order to alleviate the burden on centralized routers.

3.1.79 synchro check: A procedure to check if frequency, voltage and phase angle are within defined limits.

3.1.80 synchronous message: A message where the sending-object pauses to wait for results.

3.1.81 system reconfiguration: (A) Procedure to manage changes in power system connectivity; **(B)** Procedure to overcome failures in redundant secondary or communication systems.

3.1.82 tap changer controller: Device that manages the operation of load tap changers or voltage regulators for control of voltage level; *Syn:* **voltage-regulating relay.**

3.1.83 time event: An event that occurs at a particular time. It may be expressed as a time expression; *See also:* **event.**

3.1.84 time expression: An expression that resolves to an absolute or relative value of time.

3.1.85 time to live (TTL): A field in the internet protocol (IP) packet that controls how far an IP packet may travel. Each router decrements a packet's TTL field by one when forwarding it. The largest possible TTL is 255. If a router ever receives a packet whose TTL equals 1, it cannot forward the packet any further.

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3.1.86 timing mark: A denotation for the time at which an event or message occurs. Timing marks may be used in constraints.

3.1.87 transformer circulating reactive current control: Automated procedure to detect and reduce excessive circulating reactive currents.

3.1.88 transformer protection: Scheme to detect transformer faults and to trip all breakers connected to a faulted transformer.

3.1.89 transient fault recorder (TFR): *See:* **digital fault recorder (DFR).**

3.1.90 unit tripping: Automatic disconnection of a faulted generator unit.

3.1.91 var controller: Device that manages the operation of equipment control of reactive power flow.

3.1.92 volt and var control: Procedures to use voltages and var flows for the control of power system elements.

3.1.93 weather monitoring: Procedures to monitor and report weather conditions that may affect the operation of the power network.

3.1.94 weather sensors: Special purpose sensors to monitor climatic conditions.

3.2 Acronyms and abbreviations

BFI	breaker failure initiate
CT	current transformer
DFR	digital fault recorder
DMS	distribution management system
EMS	energy management system
GPS	global positioning system
GSP	generic service provider
HMI	human machine interface
IP	internet protocol
LTC	load tap changer
OSI	open system interconnection
SBO	select before operate
SCADA	supervisory control and data acquisition
SWC	surge withstand capability
TLV	type, length, value [ASN.1 specification]
TFR	transient fault recorder
TTL	time to live
VT	voltage transformer

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4. Communication delivery time performance requirements

Communication delivery time performance is specified to provide some guidance to the general level of performance to exchange information or transfer data between specific entities or functions in terms of update intervals and message delivery times for selected information types.

4.1 Overview of message delivery performance

Substation automation functions need to be allocated to the communication interfaces defined in Table 1. Table 1 shows an overview of the qualitative performance requirements and Table 2 shows quantitative message delivery time for each substation communication interface.

Table 1— Overview of message delivery performance across substation communication interfaces

Communication Interface	Performance Requirement
Substation Computer to Protection	Low
Event Notification for Protection	High
Data Transfer for Protection	Medium
Control to Protection	Medium
VT & CT Analog	Very High
Transformer Synchrophasor Measurements	Medium
Control to Switchgear	Low
Substation Computer to Control	Low
Substation Computer or IED to Technical Services	Low
Control to Control	Medium
Substation Computer or IED to Control Center	Low
Protection to Switchgear	Very High

Very-high-speed message delivery that is required to stream VT and CT analog sampled data and to deliver protection commands to the switchgear is normally less than 2 ms.

High-speed message delivery that is required to exchange event notification information for protection is usually in the 2 to 10 ms range.

Medium-speed message delivery that is required to exchange information between control functions and protection functions, transfer non-critical data between protection units, transfer Synchrophasor measurements, and to exchange information between control functions is normally in the range of 10 to 100 ms.

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Low-speed message delivery that is required to exchange information between nodes external to the substation (control center or technical services) and the substation computer or IEDs within the substation is normally greater than 100 ms.

Within the substation or between substations, low-speed message delivery is required to transfer data between the substation computer and control functions or protection functions and to exchange information between the control functions and switchgear is normally greater than 100 ms.

4.2 Typical data delivery time between intelligent electronic devices

The capacity of the intelligent electronic device (IED) communication facilities at any substation must be sufficient to meet the data delivery requirements including all concurrent local and off-site information transfers under worst-case operating conditions. As each new IED application is implemented at a substation, appropriate tests of its impact on the performances of all previously operational applications should be performed using the method defined in IEEE C37.115-2003. Eight information types are used to describe the typical delivery time requirements.

Table 2 describes the maximum message delivery time required for selected types of information to be exchanged between applications within the substation, and with applications external to the substation.

Table 2—Data delivery time required

Information Types	Internal to Substation	External to Substation
Protection Information, high-speed	1/4 cycle	8-12 ms
Monitoring and Control Information, medium-speed	16 ms	1 s
Operations and Maintenance Information, low-speed	1s	10 s
Text Strings	2s	10 s
Processed Data Files	10 s	30 s
Program Files	60 s	10 min
Image Files	10 s	60s
Audio and Video Data Streams	1 s	1 s

Real time data dissemination functions require each substation IED to assemble, process, and deliver periodic and event-driven data messages to other local and off-site IEDs. Each such transfer typically contains 20 to 100 data bytes, plus the associated communication overhead. The performance of real time communication functions will occasionally be slightly reduced for brief intervals when higher priority protection traffic is serviced.

For most substations, all other IED functions that use the substation data network collectively present a small additional communication load. These functions shall use the lowest communication priorities to avoid impact on the real time traffic. The data delivery time for these functions will primarily be determined by the network capacity that is not used by the real time traffic.

The network loading resulting from the real time traffic should not exceed about 15 percent of the theoretical maximum capacity of the network for 2 ms to minimize the probability of collisions[2].

[2] Buchanan [B12] provides a comprehensive discussion of load modeling.

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Future voice and full graphic HMI functions will also require sustained data streams with data transfer rates exceeding 64 kB/s and with fixed delivery times of less than one second.

4.3 Application specific communication performance requirements

Delivery time is specified in terms of the time when the message leaves the sending application to the time when the receiving application gets the message. Figure 1 shows time components that define the time requirement. Application-to-application time is defined as the sum of the times required for the sending IED communication processor to accept the data from the sending application "f1", and exit the output queue of the sender "a", plus time over the communication network (including processor time required by routers, bridges, gateways, etc.) "b", plus the time "c" required for the receiving IED communication processor to extract the message content and present it to the receiving application "f2".

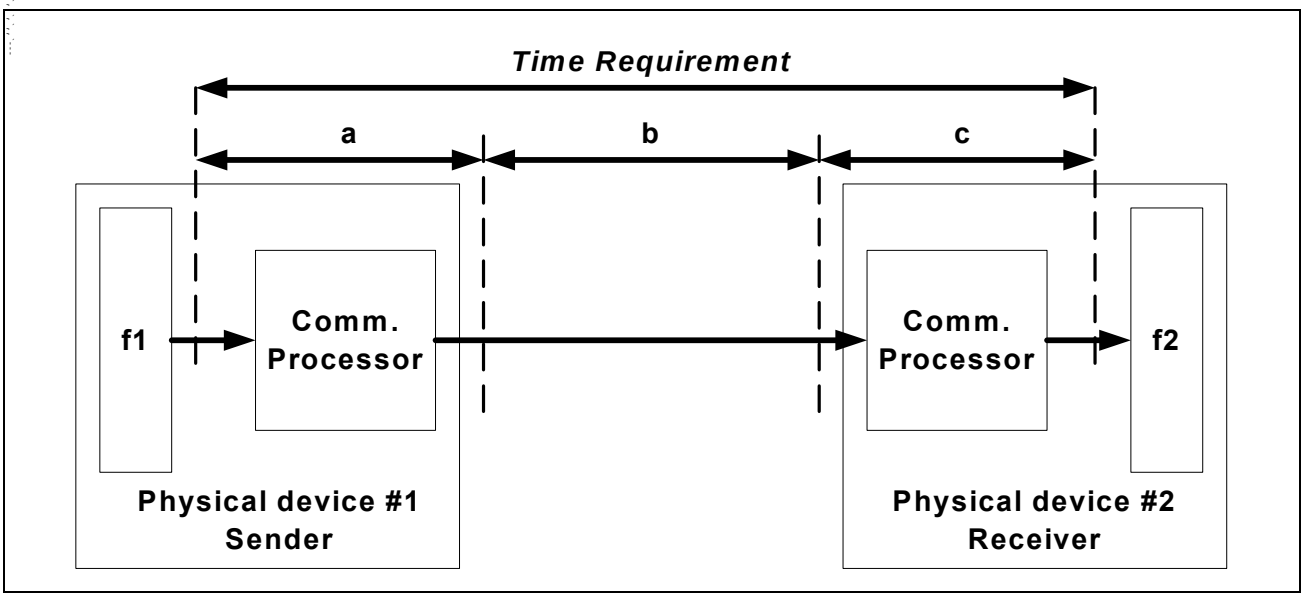

Figure 1—Application-to-application communication times

Table 3 shows communication performance requirements needed to support the substation applications that use the information[3]. Table 4 shows the future communication requirements for transferring, in near real time over the network, large volumes of data such as transducer measurements, wave-form data from current differential relays, and synchrophasor time sync data. Values in the column titled "Maximum Delivery Time" in some cases define a range, or the qualifier "up to", which means that the maximum delivery time is determined by specific implementations and operating constraints for the application.

Three levels of message criticality (criticality class) are specified: high, medium and low. In addition to message criticality, three levels of message priority (priority class) are specified: high, normal and low. Typical messages sizes are specified in terms of the number of points transferred, message bits, message bytes, or the number of operations. Rate is the frequency of updating the information or the condition that causes the message to be generated. Time skew specifies the resolution required by the data/application.

[3] Table 2 shows data grouped by information type, whereas Table 3 shows data grouped by applications that use the information.

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Table 3—Substation communication performance requirements

Data/Application	Critical Class	Priority Class	Rate	Maximum Delivery Time	Time Skew	Notes
1. Fault Recorders (up to 64analogs x 16 bits x 100,000 samples) and power quality monitors/recorders	High	Low	On Demand	Several seconds	NA	64 to 256 samples/power system cycle.
2. SCADA Data Poll Response	Med	Normal	One to ten seconds	up to 200 ms	NA	Substation to external system.
3. Peer-Peer (e.g., Substation protection processors)	High	High	On Event	1/4 cycle	NA	
4. Time Sync			Periodic depending on clock scanning	As needed to meet skew		Time skew requirements are described in Clause 5.5.
a. SOE (Sequence of Events)	Med	High			1 ms	For Sequence of Events (system wide).
b. Within the substation	Med	High			50 μs to 100 μs	In the substation, time skew of 1 degree for auto synchronizing and 2 degrees for sync check.
c. Interchange Meter Sync (System)	High	High			1 s	
d. Fault Recorder Sync (Substation)	Med	High			1 ms	
5. Initiate Data Transfer (for Engineering Analysis)	Low	Low	On Demand	Several seconds	NA	Data is time tagged.
6. Session Interrupts (urgent messages)	High	High	-	-	-	Priority depends on application.
7. **Distributed Points for Control applications**	High	Normal	On Demand	20 ms	NA	
8. System Protection – Phasor Measurement Unit	Med	Normal	250/second	20 to 30 ms	NA	See synchrophasor standard
9. Line Protection and Control			On demand for all messages		NA	
a. Breaker Tripping and Breaker Failure Initiate (BFI)	High	High		1/4 cycle		Actual breaker operation may take 1-1/2 to 8 cycles
b. Back-up Breaker Tripping (after breaker failure time out)	High	High		8 to 12 ms		
c. Breaker Reclosure including: Voltage Supervised, Multiple	Med	Normal		8 ms		
d. Control of Transfer Trip for SEND/RECEIVE	High	High		1/4 cycle		
e. Keying for Permissive Schemes	High	High		8 ms		
f. SEND/RECEIVE Trip Command	High	High		2 to 8 ms		
g. Initiate Lockout Function (Not in Mechanical Lockout)	High	High		16 ms		
h. Motor-Operated Disconnect	Med	Normal		16 ms		
I. Indicator Control (ON,OFF,BLINK, etc.)	Med	Normal		1 s		
j. Testing of Trip and Block Channels	Med	Low		1 s		

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Table 3—Substation communication performance requirements (*continued*)

Data/Application	Critical Class	Priority Class	Rate	Maximum Delivery Time	Time Skew	Notes
10. Bus Zone Protection and Test, Including:			On demand for all messages			
a. Send Trip Signals to Adjacent Zones	High	High		8 to 12 ms		
b. Block Auto Reclose for All Bus-Connected Breakers	High	High		8 to 12 ms		
c. Initiate Lockout Function for Bus Differential	High	High		16 ms		
d. Select Bus Testing Source	Med	Normal		16 ms		
e. Enable Closing of Selected Testing Source	Med	Normal		16 ms		
f. Lockout Reclosure of Breaker Following Unsuccessful Test	Med	Normal		16 ms		
g. After Successful Test, Enable Reclosure of Remaining Breaker	Med	Normal		1 s		
h. Loss of Potential	High	High		1/4 cycle		
11. Transformer Protection and Control			On demand for all messages		NA	
a. Breaker Tripping and Breaker Failure Initiate (BFI)	High	High		1/4 cycle		Actual breaker operation may take 1-1/2 to 8 cycles
b. Back-up Breaker Tripping (after breaker failure time out)	High	High		8 to 12 ms		
c. Breaker Reclosure	Med	Normal		16 ms		
d. SEND/RECEIVE Trip Command TO/FROM Adjacent Zones within the substation	High	High		1/4 cycle		
e. Initiate Lockout Function	High	High		16 ms		
f. Motor-Operated Disconnect OPEN/CLOSE	Med	Normal		2 to 4 s		
g. Ground Switch Control (to Force other Relay Trip)	High	High		8 - 12 ms		
h. Indicator Control (ON,OFF,BLINK, etc.)	Med	Normal		1 s		
12. Distribution Applications			On demand for all messages		NA	
a. Line Sectionalizing	Med	Normal		5 s		
b. Load Control and load shedding	Med	Low		10 s		Non-underfrequency condition
c. Load Shedding for underfrequency	High	High		10 ms		Triggered by underfrequency relay.
d. Fault Identification, Isolation and Service Restoration	Med	Normal		10 s		Reporting function.
e. Fault Isolation and Service Restoration	Med	Normal		Several Minutes		
f. Transfer Switching	Med	Normal		1 s		
g. VAR Dispatch	Med	Normal		1 s		
h. Voltage Dispatch	Med	Normal		1 s		
i. SCADA -- Stand-Alone or distributed	Med	Normal		1 s		

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Table 4—Future substation performance requirements

Data/Application	Critical Class	Priority Class	Rate	Maximum Delivery Time	Time Skew	Notes
1. Transducer	Med	Normal	Periodic or On Demand		NA	Data Acquisition.
2. Synchronized sampled Wave-Form Data for protective relaying (e.g., current differential relay)	High	Normal	Once per sampling period	2 ms	100 μs	
3. Synchrophasor Time Sync	High	High			1 μs	See synchrophasor standard

5. Communication capabilities required to deliver data on time

Communication capabilities required to deliver data on time are specified for real-time support, message priority, broadcast and multicast support, data delivery criticality, time synchronization, and timing constraints.

5.1 Real-time support

The selected communication protocol and data models shall provide the IEDs with the capabilities for real-time support as needed for automatic, periodic, or event-driven data (with a single "poll").. Data packets may be combined to improve efficiency of messages, but this could increase the delivery time from the sender application to the receiver application. Priority data is defined, time synchronization methods are provided, and journalizing provides for automatic logging of events or alarm conditions in real time.

Messages may be sent upon an event, change of value, or periodically. This standard has several other features for support of real-time data exchange (see Clause 4) as covered in the following subsections, and require time synchronization as specified in Clause 5.5.

5.2 Message priority

When required[4], IEDs shall provide the ability to define priority levels for control, exception reporting, periodic, report, file transfer, etc.

Priority is a ***quality of Service*** (QoS) parameter negotiated at connection time between any two IEDs. Higher priority messages originating from an application are given preferential treatment over the lower priority messages. Four (4) priority levels are defined:

Reserved: for network management
High: highest level intended for short, critical control messages
Normal: medium data level
Low: for large, non-critical files.

When a protocol suite supports only two priority levels, the top one shall be designated "high" includes network management messages, and the lower one designated "low" for the remaining message categories.

[4] Some communications architectures do not require priority levels.

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5.3 Broadcast and multicast support

The selected protocol shall provide the IEDs and network management the capability to transmit one message to all nodes (broadcast) or to selected groups of nodes (multicast).

Network management shall provide the capability to send messages to multiple destinations, such as all nodes on a communication network segment or a predefined subgroup. Broadcast/multicast messages are not acknowledged. This feature is only available where supported by the underlying protocol as only one message is sent to a given address. The address is recognized as a multiple destination address and receiving nodes are configured to respond to this address along with their specific addresses.

5.4 Data delivery criticality

Network management shall provide the capability to support three levels of data delivery criticality, respectively: **high**, **medium**, and **non-critical**. One level will be selected for a communication connection by its user application.

— High criticality is assigned where end-to-end confirmation of successful delivery is required together with immediate automatic retry of a failed transfer.

— Medium criticality is used where no end-to-end confirmation is needed, but the receiver is able to detect a loss of data.

— Non-critical is used where loss of data due to a failed transfer is acceptable with no further action by the communication system. Improved reliability of the communication service may be achieved by repetitive messages to ensure a high probability of correct message receipt.

5.5 Time synchronization

Time synchronization shall be provided to the IEDs in the substation. For example, individual Global Positioning System (GPS), IRIG-B receivers, a timing wire, or other techniques can accomplish this. Time synchronization implemented over the Substation Local Area Network (LAN) shall comply with IEEE 1588.

All time sources used by IEDs shall be synchronized to each other and, preferably, to an external date and time standard. The required synchronizing tolerances for all IEDs that process time-sensitive data at all substations in an electric power network are shown in Table 5.

Table 5—Time synchronization

IED Type	Tolerance (Jitter)	Resolution
General-purpose	±0.1 ms	1.0 ms
Synch check	±0.01 ms	0.1 ms
Synchrophasor	±0.5 μs	1.0 μs
High-Speed Sampled Data (Future)	±5.0 μs	10.0 μs

Time data values shall provide a resolution equal to or better than the above resolution limits. Synchronizing procedures shall transfer time data from a time reference source to a receiving IED with a delivery time tolerance (or jitter) less than the above limits. The rate error of a synchronized IED shall be such that the worst-case additional time error accumulated between consecutive synchronizing procedures will be less than the above jitter limits. Synchrophasor IEDs, for example, require a synchronizing signal time value with a resolution of 1 μs, a signal delivery jitter of ±0.5 μs, and an internal clock accumulated

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timing error of less than 0.5 μs between consecutive synchronizing operations. These limits are required to permit phasor measurements at 60 Hz within a tolerance of about 0.03 degrees[5].

The procedures used by an IED to define a time stamp value shall not introduce errors larger than the specified time resolution.

5.6 Timing constraints

Timing constraints are specified for update intervals and delivery times for conditioned by priority, criticality, security, and integrity.

5.6.1 Update intervals

The communication system shall support periodic data update intervals ranging from a minimum of 1 cycle up to 30 days.

Protection and control systems using phasor measurements will require delivery within and between substations of time-stamped data with update intervals and delivery times as short as one cycle[6].

5.6.2 Delivery times

The time allowed to transfer any routinely updated data element from a sending to a receiving IED shall be less than its average update interval[7].

Substation IED applications may require that a data source be able to specify to the communication network the latest acceptable time for data delivery, by means of a ***timeToLive*** (TTL) field[8] in the transmitted data [B12]. The communication network need not deliver any data with an expired TTL field. The Network Management facilities should maintain statistics on TTL expirations if the TTL function is implemented.

The communication network shall provide applications with the ability to select between several levels of message service priority[9].

Bus and transformer protection functions require substation IEDs to assemble, process, and deliver, at the highest communication priority, event-driven short data messages. For example, "Trip / Block Reclose" commands shall be delivered to other local IEDs within a total time of 4 ms[10] or 5 ms for 50 Hz substations.

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[5] Synchronized IEDs enable measured and calculated values to be directly time-stamped or implicitly time-stamped for use by protection, monitoring and control applications. The maximum permissible interval between consecutive synchronizing procedures is determined by the IED internal clock rate error. For a typical accuracy of a few seconds per month, (i.e., 1 part per million) the clocks of general-purpose IEDs must be synchronized at intervals of less than 500 seconds. Synchronizing procedures should use the second-highest communication priority, as occasional interruption by highest priority protection information will be acceptable.

[6] The shortest intervals will be used for phase angle information during a synch check or synchronizing operation and the longest for data associated with equipment monthly operations and maintenance reports.

[7] Otherwise, the sending IED, having finite buffer capacity, would occasionally be forced to discard some data as undeliverable.

[8] Using the Internet Protocol (IP) as an example, TTL is an 8 bit field in the IP header. If other protocols are considered, an equivalent field is needed.

[9] This ability permits urgent messages to minimize delivery time by interrupting transfers of lower-priority messages in progress.

[10] The delivery times of this protection data traffic, being serviced at the highest priority, will be essentially independent of the concurrent volumes of other data traffic. The delivery times of all messages with priority levels other than the highest are indeterminate, being dependent on the communication system traffic being serviced at higher priority level(s).

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Priority: The communication system shall support four levels of access priority, respectively: reserved, high, medium or average, and low. One level will be selected for a communication connection by its user application. Servicing by a communication IED of a lower-priority message will be interrupted between packets by a higher-priority message or packet.

Criticality: The communication system shall support three levels of data delivery criticality named high, medium, and non-critical (see Clause 5.4). One level will be selected for a communication connection by its user application.

Security: Communication Security is defined as the immunity of the communication network to accidental or intentional unauthorized access. The communication system shall support three levels of security of access to network resources: high, medium, and low. High security access will be limited to predefined and appropriately validated Clients. Medium and low security access will be granted respectively to Clients meeting simple or no criteria.

Integrity: Integrity is defined as immunity of the network to data transfer errors resulting from accidental or intentional interference. The communication system shall support three levels of immunity: high, medium, and low. High integrity requires a very small probability of undetected error. Medium integrity is sufficient where inherent data redundancy provides adequate error immunity. Low integrity applies where errors are only a temporary nuisance to the data recipient.

Table 6 describes the data transport requirements (H=high, M=medium, L=low) for priority, criticality, security and integrity needed to exchange specific types of information between applications within the substation and with applications external to the substation.

Table 6—Data transport requirements

Communication Message Types	Priority	Criticality	Security	Integrity
Protection Information, high-speed	H	M	H	H
Demand Information, medium-speed	M	H	H	H
Periodic Information, medium-speed	M	M	H	H
Low-speed Operations and Maintenance Information	L	L	M	H
Text Strings	L	L	M	M
Processed Data Files	L	M	H	H
Program Files	L	H	H	H
Image Files	M	L	M	L
Audio and Video Data Streams	L	L	L	L

6. System requirements to deliver data on time

System requirements are specified for external interfaces and engineering analysis.

6.1 External interfaces

External interfaces of substation IEDs shall support data paths to applications executing in other local and remote IEDs and in host computer systems. These interfaces are required to be compatible with present, and readily extendible to future standards.

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6.1.1 Corporate

Corporate systems require low-speed periodic access to substation IEDs to acquire meter and accumulated power system device operations data. Occasional low-speed information transfers are also required to support ad-hoc queries of small volumes of substation data by corporate personnel. Information fields in these transactions are typically less than 1 kB in length.

IEDs require occasional low-speed demand access to corporate systems to report power system failures and for major switching actions. These transactions, also typically less than 1 kB in length, support "Trouble Ticket" processing and similar applications.

All interactions with corporate systems shall be supported with a high level of access and data security including provision for active authentication of users and, optionally, data encryption.

6.1.2 Customer

Substation IEDs require medium-speed access to small numbers of power system switching and metering devices installed on the premises of major local customers. The required peak data throughput to each such customer is currently less than 1 kB/s. The requirements for access and data security are similar to those for corporate services (see Clause 6.1.1).

6.1.3 EMS/DMS/SCADA

One or more IEDs at each transmission and distribution substation require medium-speed access to external EMS, DMS, or SCADA systems. These data paths have historically been implemented in serial point-to-point links at data rates of 9.6 kB/s or less. With increasing application complexity, general-purpose communication network functions, performances, and security facilities become necessary.

6.1.4 Other substations

One or more IEDs providing protection and phasor measurement functions at transmission substations require high-speed access to similar IEDs at adjacent and more distant substations. The information exchanged consists of a few data bytes with data delivery times as short as 8 to 12 ms. If dedicated physical links are used, security facilities can be limited to data validity checks.

6.1.5 Feeder devices (distribution)

A distribution communications network, via a protocol converter “gateway” IED provides IEDs communication between substation and feeder if necessary.

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6.1.5.1 Switches, reclosers, and sectionalizers

Implementation of Fault Location, Fault Isolation and Service Restoration functionality may require Substation IEDs to communicate at low speed with external IEDs for switches, reclosers, or sectionalizers. These devices are located on the distribution circuits served by the substation. The priority and criticality for some communications is high.

6.1.5.2 Voltage regulators

Implementation of Voltage Dispatch on the distribution system requires low speed communications between substation IEDs and feeder IEDs. These communications are used for coordinating operation of power equipment devices on the substation with those located along distribution feeders served by the substation.

6.1.5.3 Capacitor banks

Var Dispatch requires low-speed communications between substation IEDs and IEDs located on the distribution system. These communications are used for coordinating operation of substation and feeder devices to optimize the power factor along the distribution feeder.

6.1.5.4 Metering

Power system metering, external to the substation, requires low speed communications between substation IEDs and feeder IEDs. These communications are used for quality of service, end of line voltage, distribution system operations, and revenue metering of large customers.

6.2 Engineering analysis

6.2.1 Planning

One or more IEDs at each substation require low-speed access to external databases to support long-term power system planning studies. Information transferred includes device loading, weather, and maintenance data. Occasional large (>100 kB) data files may be required but delivery times of 10 to 30 seconds are acceptable.

6.2.2 Post-event analysis

One or more IEDs at each substation require low-speed access to external databases to support engineering analysis of stored data from sequence-of-events and digital fault recorders. Occasional large (>1 MB) data files may be required but delivery times of 60 seconds or more are acceptable.

6.2.3 Maintenance

One or more IEDs at a substation are required to support the local activities of maintenance personnel. These activities will require "Client-Server" interaction with local operator terminals and external engineering databases. A combination is required of frequent medium-speed transactions with small data volumes and occasional low-speed transactions with large data files supporting display of engineering data. In the future, voice, high-resolution static image, and video data transfers will be desirable.

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Annex A

(informative)

Bibliography

A.1 EPRI reports

[B1] **RP3599:** "Substation Integrated Protection, Control and Data Acquisition, Phase 1, Task 2, Requirements Specification", Preliminary Report, Version 1.2, February 16, 1998.

[B2] **TR 109474:** "Substation Integrated Protection, Control and Data Acquisition, UCA, Interoperability Test Specification for the Utility Substation Demonstration Initiative", Draft Version 1.0, September 1, 1998.

[B3] **UCA 2.0 – GOMSFE:** "Generic Object Models for Substation & Feeder Equipment (GOMSFE), Version .92, May 2001.

A.2 CIGRE reports

[B4] **CIGRE WG 34.03:** "Communication Requirements in Terms of Data Flow Within Substations", August 23, 1996.

[B5] **CIGRE WG B5.07:** "The automation of new and existing substations: why and how", in work.

[B6] **CIGRE WG 35.07:** Draft Technical Brochure – "The Use of IP Technology in the Power Utility Environment", December 1999.

A.3 IEEE technical reports, standards, and draft standards

[B7] **IEEE 100:** "The Authoritative Dictionary of IEEE Standard Terms", Seventh Edition.

[B8] **IEEE-SA TR 1550-1999: "**Utility Communications Architecture (UCA™) Version 2.0". [GOMSFE version .82 is included in this report; the version listed under EPRI reports is a later version.]

[B9] **IEEE 1613-2002:** "Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations."

[B10] **IEEE C37.115-2004:** "Standard Test Method for Use in the Evaluation of Message Communications between Intelligent Electronic Devices in an Integrated Substation Protection, Control and Data Acquisition System."

A.4 ISO/IEC documents of interest

[B11] **IEC 61850, 2003/2004**: "Communication Networks and Systems in Substations."

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A.5 Textbooks

[B12] Buchanan, Jr., Robert, W.: "The Art of Testing Network Systems", 1996, John Wiley & Sons, Inc.

[B13] Stevens, Richard W.: "TCP/IP Illustrated Volume 1, The Protocols", 1994, Addison-Wesley Publishing Company.

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Annex B

(informative)

Example applications

Substation automation applications are summarized for protection, distribution, local control, EMS/DMS/SCADA, and planning and maintenance functions.

B.1 Protective relay applications

Protective relay applications are presented for line protection, breaker failure, and line automatic reclosing.

B.1.1 Transmission line protection

With ring bus, double breaker, or breaker-and-a-half substations, two breakers are connected to any one-transmission line. The line protective relay IED is hard-wired to the CTs and trip circuits of both breakers feeding the line, and usually to VTs for line or bus potential measurement. The line relay IED may be hard-wired to communications channel equipment, or connected to the channels via the substation LAN. The status of line breaker disconnect switches may be hard-wired or communicated to the relay IED via the substation LAN.

When a line fault occurs, trip commands from the line relay IED are conveyed to its breakers via the hard-wired connections. At the same time the trip commands are sent, the following messages (some or all) will be transmitted via the LAN: Breaker Failure Initiate (BFI), Reclosure Initiate, Reclosure Block, Remote End Transfer Trip, and Trip Alarm. When the breakers open, their new status is reported via the LAN. On a non-real-time basis, the line relay IED may report (via the LAN): fault location, targets, operation logs, oscillography, current profile, settings, and the status of its programmable logic.

B.1.2 Breaker failure relaying

A breaker failure relay IED is hard wired to the CTs and the trip circuit of the breaker it is monitoring. When a line relay IED issues a trip command to its breakers, it also issues a BFI command via the LAN to those breakers' breaker failure relay IEDs. The breaker failure relay IED may issue a re-trip command to its breaker, and start its breaker failure timer. The timer is set long enough for its breaker to clear the fault, plus a suitable margin. If, at time-out, the breaker failure relay IED still detects current flow through its breaker, it issues a multicast trip command via the LAN to all breakers (including remote breakers) feeding the failed breaker. These trip commands require the highest available transfer priority and must be received within 10 ms, preferably within 4 ms for local breakers. The multicast addresses are pre-established based on the substation topology.

On a non-real-time basis, the breaker failure relay IED will report targets, operating and trouble alarms (including trip circuit monitors), lockout, breaker currents, program logic, and the list of breakers to receive its multicast trip command.

B.1.3 Transmission line automatic reclosing

The automatic reclosing of a transmission line breaker may be supervised by a local synchrocheck relay IED, to prohibit reclosing of the breaker if the voltage or phase angle across its open contacts exceeds a preset value. Communication services are required to support high-speed transfers of voltage magnitude and phase angle (phasor) data from both sides of the breaker to the synchrocheck relay IED. The phasor data measurements must be time synchronized, or time stamped, to allow phase angle difference calculations. This data may be routinely updated at intervals of less than 20 ms, with a data delivery time of

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less than 10 ms, while the reclosing function is in progress. When the conditions for closing the breaker are met, the substation LAN within a time tolerance of less than 5 ms must transfer the close command from a synchrocheck relay IED.

B.2 Distribution applications

On distribution systems, integrated volt/var control requires a number of functions from the substation and feeder communication system. These include collection of voltage and var measurements from several points on a utility's distribution circuits, and communication of these values to the site (controller) that is executing the optimizing volt/var algorithm. In addition, communication of control messages (raise/lower setpoints, on/off commands), and monitoring of distribution circuits to detect out of tolerance conditions shall be accomplished on a timely basis.

A distributed controller model, which includes a MasterStationController, a RegionalController, and an EmbeddedDeviceController, is appropriate for this application. Using this model, the MasterStationController function might be located at the corporate headquarters. It would issue corporate-wide commands on voltage levels to be maintained, and be the source of system-wide voltage reduction commands for peak shaving. A RegionController would be located at each DDC (Distribution Dispatch Center). It would execute the volt/var algorithm for its region, issue commands to and request data from the EmbeddedDeviceControllers. An EmbeddedDeviceControllers would be located at each substation LTC transformer and capacitor bank controller, each feeder voltage regulator and capacitor bank, and at other measuring points (such as ends of feeders or critical customers). These controllers would execute commands issued by the RegionalController, report back status, monitor, and report-by-exception any out-of-limit conditions.

B.3 Local control applications

Local control applications include Load Tap Changer control and substation throwover schemes.

B.3.1 Load tap changer control

The control of Load Tap Changers on paralleled transformers has historically been done by the "circulating current" method. This method requires that hard-wired series connections be made between CTs on the two transformers. It is a surrogate for the desired measurement—the var flow through each transformer. Also, all the present design tap changer controls include their own independent measurement of the controlled transformer's secondary voltage.

With a substation LAN, if the transformer secondary voltage is being measured by another IED, then the tap changer controller need not have its own A/D converter to determine this voltage. It may be obtained over the LAN. Additionally, each tap changer controller can obtain var flow on its own transformer and on the paralleled transformer to ensure that the tap changers track each other as they regulate voltage. The data requirements are low, as the voltage and var values may be reported intervals of at ten seconds or longer or on an analog report by exception basis.

B.3.2 Substation throw-over schemes

In most two-transformer substations, a hard-wired throwover scheme is installed to transfer the entire load to one transformer if the other transformer or its supply fails. The total peak load is never allowed to grow beyond the short time rating of one transformer. However, some utilities have decided that, since the joint probability of such a transformer loss and at the same time, a peak load on the substation is very, very small, they will allow the load to increase to the sum of the nameplate ratings of the two transformers. If a transformer is lost, the throwover scheme is prevented from operating only if the load at that time is above one transformer's short time rating. This is done today by a simple overcurrent relay, whose input is the sum of the phase A currents from the two transformers. This requires hardwired CT connections between the two transformers as well as hard-wired relay output contacts to inhibit throwover under high load

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conditions. This approach allows substantially higher normal transformer loading, and thus reduces or delays the need for transformer change outs or additions.

With a substation LAN, the total substation load will be available by summing the outputs of several IEDs. The measurement can be in MVA, the analog quantity that is the best measure of transformer load (not amps, the measurement used today). The hard wiring between transformers for this function can be eliminated. If selective (by feeder or by substation) direct load control is available, then during a high load condition the substation controller could initiate a throwover even if the load exceeded the limits for one transformer. It could then start load reduction by direct load control. The data requirements for this function are nil, as the substation controller (in its normal logging) should already have the total substation load information available whenever a throwover might be initiated by a transformer loss.

When more than two transformers exist in a substation, hard-wired throwover schemes may be impractical because of all the constraints and conditional logic that may be required or desired. In this case, the use of a substation controller and data over the substation LAN may be the only cost-effective solution.

B.4 EMS/DMS/SCADA applications

Real-time EMS/DMS/SCADA monitoring and control applications arrange substations as components of a multilevel hierarchy of data acquisition and control facilities. These facilities are typically operated in a Master/Slave mode in which the substations operate as Slaves to higher-level EMS and SCADA system Masters and as Masters to lower-level DMS Slaves.

These applications require the substation communication facilities to support:

- Assembly and transfer to higher-level external IEDs of substation data
- Delivery to substation devices of control information from higher-level external IEDs
- Assembly and transfer to lower-level external IEDs of control information.

Routine (periodic) and on-demand (event-driven) data transfers upward through the hierarchy are required. Required periodic update intervals range from about one second to one hour or more with required data delivery times that are less than the update intervals. Other transport requirements (as defined in Clause 5.6.2) for periodic data transfers are high, medium or low priority, criticality, security; and Integrity. Occasional data errors and late or missing data may be acceptable when the data user can recover on receipt of the next routine update.

Event-driven data transfers upward and control information transfers (usually event-driven) downward are required to have data delivery times of less than 1 second. Other transport requirements of this medium-speed data category are:

	Priority	**Criticality**	**Security**	**Integrity**
Data transfers	M	M	M	M
Control transfers	M	H	H	H

These functions were generally implemented in a single substation RTU or automation computer equipped with a serial data link to each external system and local hardwired connections to all managed substation devices. IEDs now permit physical distribution of these functions throughout the substation to reduce the total number of hardwired connections. In addition, physical distribution of functions may possibly avoid the consequences of a failure in a single processor that services all substation data.

Management of bulk power generation and transmission requires routine delivery, with the shortest achievable update intervals, of transmission line real and reactive power values from substations to the

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utility EMS/SCADA system with concurrent transfer in the reverse direction of generator control commands. This EMS application is the most demanding in respect of update interval. It presents a continuous load to the external communication facilities of transmission substations that is a substantial fraction of the combined communication traffic of all other EMS functions.

B.5 Planning and maintenance applications

Communication services required to support non-real-time engineering and planning applications primarily consist of periodic and/or event-driven collection of local data by a substation IED followed by on-demand low-speed transfers of stored files of processed data to an external IED. These external transfers are uncritical, can use the lowest available priority, and can have essentially unlimited delivery times. There are no special requirements for data security and integrity as all of these transfers can be repeated to eliminate any detected errors.

Examples of such applications include high-speed collection and subsequent analysis of sequence-of-events and digital fault recorder data and low-speed collection of long-term load profiles for feeders and major customers. The resulting data files may range in size from a few kilobytes to several megabytes. For most substations, such file transfers are infrequent, e.g., less than one per month.

Some maintenance applications have similar data communication requirements. For example, breaker health monitoring requires low-speed collection and storage of breaker operations and loading data followed by its on-demand (e.g., quarterly) transfer to a remote IED.

Other maintenance applications require bi-directional transfers between a substation and external IEDs of program and data files. Such applications include remote loading and testing of protective relay functions and setpoints and remote loading and execution of power system device diagnostics. The total communication traffic and throughput demands of these applications are limited, but the highest available levels of data security and integrity are required.

The substation communication facilities are also required to support the work of maintenance personnel at the substation by providing local access to both local and remote IEDs and their databases. These accesses include interactive operation of a local workstation(s) to collect and display current operating conditions and recent events, to display and modify local (and possibly remote) power system device operating parameters, and to display and update substation inventory, engineering documentation and operating instructions.

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