Synchro Phasor

1 Descriptions of Function

All prior work (intellectual property of the company or individual) or proprietary (non-publicly available) work should be so noted.

1.1 Function Name

Synchro-Phasors

1.2 Function ID

IECSA identification number of the function

T-4.3

1.3 Brief Description

This system provides synchronized and time-tagged voltage and current phasor measurements to any protection, control, or monitoring function that requires measurements taken from several locations, whose phase angles are measured against a common, system wide reference. This is an extension of simple phasor measurements, commonly made with respect to a local reference. Present day implementation of many protection, control, or monitoring functions are hobbled by not having access to the phase angles between local and remote measurements. With system wide phase angle information, they can be improved and extended. The essential concept behind this system is the system wide synchronization of measurement sampling clocks to a common time reference.

In addition to providing synchronized measurements, the synchro-phasor system distributes the measurements. Voltages and currents are measured at many nodes throughout the power grid. Any protection, control, or monitoring function can access measurements from several nodes, either by subscribing to continuous streams of data, or requesting snapshots as needed. In principle, any function could request measurements from any node, though in practice most functions require data from only a few nodes.

1.4 Narrative

The following is an example of how synchro-phasors can be used to perform digital current differential fault protection for a two terminal transmission line. There are two intelligent electronic devices, one at each terminal, taking samples of currents from all three phases. Physically, the two terminals might be any distance at all apart, ranging from a few miles to a thousand miles, for example. It is wished to provide fault protection for the transmission line by summing the phasor values of currents to determine differential current. In order to do that, the two intelligent electronic devices need to measure the phasor values against the same time reference, and exchange the data with each other. This can be done with synchro-phasors.

Each intelligent device in this example is both a client and a server of synchro-phasors. As a server, it provides synchro-phasors to its partner. As a client, it requires synchro-phasors from its partner. It is a completely symmetric situation. We will examine the example mostly from the point of view of one of the terminals, call it A.

Terminal A requires a steady stream of phasors for three phase currents from terminal B. In this particular case, it is decided to compute phasors every ½ cycle of the power system frequency, and to transmit them once per ½ cycle. To simplify things, it is decided not to perform frequency tracking, but rather to base the sampling frequency on absolute time. For this particular case, it is decided that synchronization between any pair of measurements must be within 10 microseconds in steady state, even though there are other applications that require tighter synchronization, such as to within 1 microsecond. Transiently, much larger synchronization errors are permitted, but each terminal requires an estimate of the least upper bound of the synchronization error if it exceeds 10 microseconds.

For correct transient tracking, it is decided that the sampling windows must be aligned. That is, the set of sampling times for each phasor window must be the same at each terminal: overlapping is not allowed. It is understood that there may be some latency involved in the exchange of information, but it should not exceed 24 milliseconds, for example. It is also recognized that some data might get lost or corrupted. A certain amount of lost data is acceptable. The amount is somewhat arbitrary, but experience has shown that 2.5% lost data can be tolerated. For this application, it is not necessary to retransmit the lost data, since more, up-to-date data will be arriving shortly anyway. However, it is necessary to inform the protection application, so that it can move on to the next time slot. It is also recognized that sometimes, communications might be down altogether.

The possibility of corrupted data is a fact of life in this arena. Without even considering abnormal events such as electrical interference from faults, many types of communications are considered to be operating normally with a low, but non-zero bit error rate. Unless some steps are taken, it is possible for bit errors to corrupt the data being exchanged. For this application, corrupted data must be detected and ignored, since incorrect data could very well cause a false de-energization of a transmission line, and move one step closer to a black out. Bad data is worse than no data at all. To that end, protection engineers would either want to see at 32 bit cyclic redundancy code protecting against corrupted data, or have some other assurances that under a credible worst scenario, it would not be expected that a corrupted phasor would sneak through more often than once every 300 years.

During installation of the differential protection scheme, the two terminals are identified to each other, and various parameters are selected, including those that impact the exchange of synchro-phasors. There are GPS receivers at both substations that can be used for sampling synchronization, so the intelligent devices are configured to synchronize to the GPS clock. (That is not always the case.) In this case, the GPS receivers are not deemed reliable enough, so a backup strategy is required in which the intelligent devices can synchronize to other clocks in the network using the network time protocol. Also, the system engineers do not completely trust digital communications, so they insist on two physically independent communications channels between the pair of terminals. That way, the system can continue to provide protection if only one of the communications channels fails.

During commissioning, the two intelligent devices are connected to their GPS clocks and checked out. Various tests are run successfully off-line. The devices are then re-initialized in an on-line mode.

During re-initialization of terminal A, the synchro-phasor service synchronizes the local sampling clock to the GPS clock, and turns on the calculation of synchronized phasors. Terminal A then attempts to connect with terminal B, which in this scenario, has not been initialized yet, so terminal A waits. Finally, both terminals are ready, and begin to exchange synchro-phasor data, and begin to provide digital current differential protection of the transmission line.

Because of the communications latency, the synchro-phasor also provides an alignment service. That is, it matches local phasors with remote phasors that arise from the same time window. This is a non-trivial task, because of the possibility of lost data or data that arrives out of sequence under normal operation.

During normal operation, the synchro-phasor exchange service attempts to exchange phasors redundantly. That is, two copies of the data are transmitted over physically independent paths. That way, if one path fails, data is likely available over the other.

Occasionally the communications network may switch the physical path between the two terminals, thereby changing the latency. In the case of a switch to a shorter path, it is possible to receive data out of order. In that case, it is permissible to throw some data away, on the theory that more will be arriving shortly.

On rare occasions, the GPS clock at one or both of the terminals may become unavailable. In that case, it is desired to automatically throw over to the use of the communications network to maintain the synchronization of the sampling clock(s), although the protection function will need to be informed of the loss of the GPS clock, and will need an estimate of the synchronization error. In the case of loss of clock synchronization altogether, the protection function also needs to be notified.

On resumption of clock synchronization following a loss of synchronization, there are two options: a step reset of the sampling clock, or a gradual ramping. As far as the protection function is concerned, either approach is acceptable, but protection is turned off until complete resynchronization is attained.

1.5 Actor (Stakeholder) Roles

Actor groupings include applications that use synchro-phasor measurements, and services that this function is built on. Applications receive time-tagged, synchronized phasor measurements, both phase quantities and sequence quantities, as well as estimates of the actual frequency.

Grouping (Community) '		*Group Description*
Synchro-phasor Client		Any monitoring, control, or protection function that requires remote measurements.
Actor Name	*Actor Type (person, device, system etc.)*	*Actor Description*
General phasor client	function	Any monitoring, control, or protection function that could request phasor measurements.
Synchro-phasor subscriber	function	Any client that subscribes to a continuous stream of synchronized, time-tagged phasor measurements.
Synchro-phasor requestor	function	Any client that requests a single snapshot of synchronized, time-tagged phasor measurements.

Grouping(Community)		*Group Description*
Synchro-phasor Supporting Service		Services that support the synchro-phasor system
Actor Role Name	*Actor Type (person, device, system etc.)*	*Role Description*
host device	device	The gathering of data generally requires a host device to provide the basic hardware functions for supporting the measurements, such as sensors, filters, A/D converters, etc.
TimeSynchronizationDevice	function	A globally synchronized local clock that is used to control the timing of data sampling and the time-tagging of phasors. Usually provided by the host device.
SamplingDevice	device	A device such as a variable frequency oscillator (VCO), delta-sigma A/D converter, or simple A/D converter, for converting analog information into digital form. Usually provided by the host device.
Communications interface	device	The interface to the wide area communications network. Usually provided by the host device.
Clock monitor	function	A function that monitors the sampling clock to ensure synchronization.
PhasorMeasurementUnit	device	Phasor measurement unit

Replicate this table for each logic group.

1.6 Information exchanged

Describe any information exchanged in this template.

Information Object Name	*Information Object Description*

1.7 Activities/Services

Describe or list the activities and services involved in this Function (in the context of this Function). An activity or service can be provided by a computer system, a set of applications, or manual procedures. These activities/services should be described at an appropriate level, with the understanding that sub-activities and services should be described if they are important for operational issues, automation needs, and implementation reasons. Other sub-activities/services could be left for later analysis.

Activity/Service Name	*Activities/Services Provided*
Phasor computation	Compute and provide the synchronized, time-tagged, fundamental power frequency components of voltages and currents for each phase. The theoretical basis for the calculation is providing a least mean square error fit of a sine wave to the samples over a given time window, using a fixed sampling frequency. Corrections should be made for errors caused by off-nominal frequency.
Total vector error estimation	Many clients of this function will find it useful to have some estimate of how well (or poorly) the data samples fit a sine wave. This can be provided by a total vector error estimate.
Sequence components computation	Compute and provide positive, negative, and zero sequence components of voltages and currents.
Frequency estimation	Estimate and provide the actual frequency of the power system at that node from the data samples. Of course, each node may be at a different frequency.
Subscription alignment and validation	A client will usually subscribe to data streams from several nodes, which will not necessarily arrive at the same time, because of variations in communications latencies. Nearly all client calculations require a set of phasors collected at the same time. For this reason, it is necessary to provide an alignment function, that packages the separate, unaligned node subscriptions into a

Activity/Service Name	*Activities/Services Provided*
	coherent picture, keeping in mind that individual phasors may be lost, corrupted, or arrive out of order.
Measurement identification	Clients of synchro phasors will need a way to find out what measurements are available from a measurement node, and to be able to identify the measurements with physical locations in the power gird.
Self description	Clients of synchro phasors will need a way to find out the values of various parameters used in the computation of particular phasors, since it may turn out that they are not the same throughout the system. Parameters are described in the next section.

1.8 Contracts/Regulations

There are several key performance parameters that are relevant to the application of synchro-phasors, that can be derived from an analysis of the requirements of the applications that use synchro-phasors. Standards are beginning to emerge, such as the proposed IEEE standard, C37.118, "IEEE Standard for Synchrophasors for Power Systems". However, several issues are still being debated and remain to be resolved. It is hoped that analysis of synchro-phasors with respect to control applications will shed some light and resolve some issues.

There are three technical areas to be considered: phasor measurement, synchronization, and communications. Phasor measurement is concerned with estimating the fundamental power system frequency component. Synchronization is concerned with taking measurements in a wide area at the same time. Communications is concerned with transporting the measurement from the location where it is made to the location where it is used.

Contract/Regulation	*Impact of Contract/Regulation on Function*
IEEE 1344-1995	Integrating measurement systems into substation environments, specifying data output formats, and assuring that the measurement processes are producing comparable results
Draft C37.118	The SYNCHROPHASOR standard defines the synchronizing input and the data output for phasor measurements made by substation computer systems. It also discusses the processes involved in computing phasors from sampled data. It is hoped that this standard will be of considerable value to the developers and users of digital computer based substation systems.

Policy	From Actor	May	Shall Not	Shall	Description (verb)	To Actor

Constraint	Type	Description	Applies to

2 Step by Step Analysis of Function

Describe steps that implement the function. If there is more than one set of steps that are relevant, make a copy of the following section grouping (Preconditions and Assumptions, Steps normal sequence, and Steps alternate or exceptional sequence, Post conditions)

2.1 Steps to implement function

Name of this sequence.

2.1.1 Preconditions and Assumptions

Describe conditions that must exist prior to the initiation of the Function, such as prior state of the actors and activities

Identify any assumptions, such as what systems already exist, what contractual relations exist, and what configurations of systems are probably in place

Identify any initial states of information exchanged in the steps in the next section. For example, if a purchase order is exchanged in an activity, its precondition to the activity might be 'filled in but unapproved'.

Actor/System/Information/Contract	***Preconditions or Assumptions***
TimeSynchronizationDevice	Prior to publication of synchro-phasors, the underlying sampling clock shall be synchronized to the other clocks in the system.
communication interface	Prior to publication of synchro-phasors, the communication interface must be initialized.
Phasor publication enabled	Phasor publication is enabled after the sampling clock is synchronized and the communication interface is ready.

2.1.2 Steps – Normal Sequence

Describe the normal sequence of events, focusing on steps that identify new types of information or new information exchanges or new interface issues to address. Should the sequence require detailed steps that are also used by other functions, consider creating a new "sub" function, then referring to that "subroutine" in this function. Remember that the focus should be less on the algorithms of the applications and more on the interactions and information flows between "entities", e.g. people, systems, applications, data bases, etc. There should be a direct link between the narrative and these steps.

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot '.'. Within a level, the sequence number comprises an optional letter and an integer number. The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

Sequence 1:

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1.1 - Do step 1
1.2A.1 - In parallel to activity 2 B do step 1
1.2A.2 - In parallel to activity 2 B do step 2
1.2B.1 - In parallel to activity 2 A do step 1
1.2B.2 - In parallel to activity 2 A do step 2
1.3 - Do step 3
1.3.1 - nested step 3.1
1.3.2 - nested step 3.2
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Sequence 2:

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2.1 - Do step 1
2.2 – Do step 2
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#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
#	*Triggering event? Identify the name of the event.*[1]	*What other actors are primarily responsible for the Process/Activity? Actors are defined in section0.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information? Actors are defined in section0.*	*What other actors are primarily responsible for Receiving the information? Actors are defined in section0.* *(Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 1.6*	*Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.*	*Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.*
1.1	Phasor computation	PhasorMeasurementUnit	Compute phasor	Local phasor measurements are handed off for publication.					NA
1.2A.1	Request for subscription	General phasor client	Request phasor subscription	Request that local phasor measurements be transmitted to a remote client	General phasor client	Communications interface			Intra-Control Center
1.2A.2	Cancellation of subscription	Synchro-phasor subscriber	Cancel phasor subscription	Cancellation of a previous subscription request	Synchro-phasor subscriber	Communications interface			Intra-Control Center
1.2B	Request for phasor	Synchro-phasor requestor	Request local phasor measurement	Request that a single local phasor measurement be transmitted to a local client	Synchro-phasor requestor	Communications interface			Intra-Control Center

2.1.3 Steps – Alternative / Exception Sequences

Describe any alternative or exception sequences that may be required that deviate from the normal course of activities. Note instructions are found in previous table.

[1] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environments
2.1	Loss of clock synchronization		Censor phasor data	Loss of synchronization triggers either censoring of phasor data, or indication that the phasors are not synchronized, or an estimate of the synch error.	Clock monitor	Communications interface			NA
2.2	Clock recovery		Resume normal operation	Normal operation is resumed.	Clock monitor	Communications interface			NA

2.1.4 Post-conditions and Significant Results

Describe conditions that must exist at the conclusion of the Function. Identify significant items similar to that in the preconditions section.

Describe any significant results from the Function

Actor/Activity	***Post-conditions Description and Results***

2.2 Architectural Issues in Interactions

Elaborate on all architectural issues in each of the steps outlined in each of the sequences above. Reference the Step by number.

Microsoft Excel
Worksheet

2.3 Diagram

For clarification, draw (by hand, by Power Point, by UML diagram) the interactions, identifying the Steps where possible.

3 Auxiliary Issues

3.1 References and contacts

Documents and individuals or organizations used as background to the function described; other functions referenced by this function, or acting as "sub" functions; or other documentation that clarifies the requirements or activities described. All prior work (intellectual property of the company or individual) or proprietary (non-publicly available) work must be so noted.

ID	Title or contact	Reference or contact information
[1]		
[2]		

3.2 Action Item List

As the function is developed, identify issues that still need clarification, resolution, or other notice taken of them. This can act as an Action Item list.

ID	Description	Status
[1]		
[2]		

3.3 Revision History

For reference and tracking purposes, indicate who worked on describing this function, and what aspect they undertook.

No	Date	Author	Description
0.			