Functional Requirements for Synchrophasor Communications via IEC 61850

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1 Introduction

Synchrophasors are measurements of the instantaneous state of the power system that are comprised of a magnitude, an angle, a time stamp of when the measurement was taken, a measurement of the time quality, and an indication of Leap Second pending or active. These measurements have application in several power system applications. This document discusses the various application domains and the related functional requirements through a Use Case format

2 Synchrophasor Use Cases

A Use Case is a text narrative that describes how a particular application functions. Below are a set of preliminary narratives describing the application and functional requirements for the communication of Synchrophasors.

3 Intra-Substation Communication

In a given substation, any number of devices may be computing synchrophasors. One application of these measurements is Check Sync Reclosing. In this application, the reclosing relay needs to know the phase angle difference between the voltage on the line and the voltage on the bus. If the voltage magnitudes, voltage difference angle, the slip frequency between the two measurements are within a "setting range", the reclose is enabled. To effect this application, synchronized voltage phasors, with their time stamp and time quality, need to be communicated from a line source and a bus source to the device performing the reclose function. It can be assumed that the involved devices are on the same station bus. Measurements are needed at a rate of at least 4 measurements per second as reclose times of ¼ to ½ a second are common for high-speed reclose applications. Upon receipt of the measurements, the voltage magnitudes need to fall within the set ranges, the angle difference must be with the set range, the slip frequency between the two angles must be less than the set value, ***and*** the Time Quality values from both measurements must fall within the range of acceptable error. For example, if one of the synchronizing sources had recently failed but the Time Quality indicated only a 100 μsec error and a 5° error margin was set on the reclose function, reclose would still be enabled. If, however, the Time Quality indicated as much as a 1ms error, the reclose operation would fail as at 60 Hz, a 1ms error translates to 22.6° error.

Observation: the mapping of Synchrophasor values and time stamps into a GOOSE message can achieve this required functionality.

4 Inter-Substation Communication

There are several functions that require measurements among multiple substations, specifically, Wide Area Out of Step protection, Double Ended Fault Location, and Black Start Line Synchronization. The functional requirements for each of these is outlined below:

4.1 Wide Area Out of Step

In this application, synchronized measurements from multiple different substations must be communicated either between selected substations or among several substations communicating a common location. Whereas in check sync reclosing, an angle difference of less than a setting was required, in Wide Area Out of Step, large angle differences and their acceleration are measured against settings. Magnitude of the phasor is not a major concern but may be used as a blocking/enabling function. The primary difference between Wide Area Out of Step is the speed of performance. In order to maintain stability in a swing condition, decisions need to be made in the 20 to 50 ms time frame. To meet this criteria, inter-substation communication rates from 30 to 120 synchrophasor data sets per second are required. Similar to check sync, before an action is taken, the application must validate the accuracy of the measured angles through the Time Quality parameter on each measurement.

4.2 Backup Protection

Backup protection on a power line is always installed for the case when a primary protection fails to perform its function. In the past, one popular form of backup protection was a distance element (known as Zone 3) that looked some electrical distance past the end of the protected line. Given the availability of high-speed synchrophasor measurements, it is now possible to perform synchrophasor-based backup protection. Synchronized measurements can be streamed from one location to a Protection PDC (PPDC) at a data rate of 25 to 60 synchrophasor datasets/sec. The PPDC, receiving the multiple synchronized datasets, would have pre-formulated backup zones of protection where backup current differential calculations could be performed and surgical backup protection effected.

4.3 Black Start

Black Start is the situation where the power system has collapsed and must be restarted from reliable sources such as gas turbines, battery storage, and hydro generation. When bringing these generation sources on-line and creating a synchronized system, synchronization must often occur between different islands of power. By measuring the absolute voltage angles, a Wide Area Check Sync function can be performed. The functionality of the reclose operation is the same as that described for intra-substation Check Sync with a similar synchrophasor reporting rate of 4 datasets/sec.

4.4 Double Ended Fault Location

For a fault on a line, datasets of synchronized voltages and currents at the time of the fault can be captured from all line terminals (typically 2 or 3) and used in multi-terminal fault location calculations. Synchronized measurements used in this manner enable greater accuracy in the fault calculation as measurement errors due to fault impedance and terminal voltage angle differences can be compensated. The captured datasets are to be communicated either among the involved relays or between the involved relays and a central repository (e.g. – a Phasor Data Concentrator). A calculation is made and the results shared – either as a client-server message or broadcast via GOOSE to any involved subscribers. There is no streaming required in this application, only the sharing of the fault dataset after the event. Note that there should be multiple storage buffers in order to accommodate fault-reclose-fault-reclose-fault-lockout scenarios.

5 Power System Oscillation Detection

Inter-area oscillations fall into 2 frequency ranges, specifically, .1 to 5 Hz and 15 to 45 Hz. Each of these applications has different reporting rate requirements.

5.1 3.1 Inter-area Small Signal Oscillations

There has been an emergence of new unstable swing modes in power systems [4]. Unlike the focus of conventional stability "equal-area" analysis, the new swing modes have to do with the small signal behavior of the power system in which the interaction of the system with the generator controls can lead to a gradually increasing low frequency oscillation. It was found in the case of the western power system, modulating the power of the Pacific HVDC intertie could damp the low frequency oscillations [1, 2, 3]. One of the tools to measure these oscillations is a small signal oscillation extraction of synchrophasor measurements captured over a wide area. For the small signal oscillation detection, synchrophasor measurements are needed from hundreds of PMUs in an area. As the frequencies of interest can span up to 5 Hz, a reporting rate of at least 10 synchrophasor datasets per second is needed (per the Nyquist sampling criteria). Some degree of data delivery reliability is desired (up for discussion). Options for delivery reliability include message repeat (similar to GOOSE) or re-transmission through TCP. From a given substation, there could be 2-3 sets of synchronized voltages and as many as 30 sets of synchronized currents. In addition to the aforementioned data items, the dataset could also include 30 measurements of Watts and Vars as well as status information of all 30 breakers in the substation.

5.2 Sub-synchronous Oscillation Detection

A second oscillatory phenomenon is that of sub-synchronous oscillations. These oscillations are typically the result of interactions between the power system and series capacitors. There are two major differences between the small signal oscillations and the sub-synchronous oscillations:

1. The oscillation frequency ranges between 15 and 45 Hz

2. The oscillation magnitude can be significant (10% to 50% of the fundamental frequency – reference?)

With the expanded frequency range, there is an associated increase in the required reporting range. On 60Hz systems, reporting rate of 120 phasor datasets per second are required. On 50Hz systems, a reporting rate of at least 100 Phasor datasets per second is required. In these scenarios, data repeat, although desirable, cannot result in network congestion and should not impose overly large buffer requirements in the PMUs.

5.3 PDC to PDC Communication

A Phasor Data Concentrator (PDC) is a device that captures data from multiple PMUs in a substation, concentrates the multiple PMU data into a single stream, and then transmits the concentrated data stream to one or more other PDCs. Each remote PDC could request a different dataset from the transmitting PDC and the reporting data rates could vary from as little as 1 dataset every 10 seconds to as many as 240 datasets per second. The input/output latency of the PDC is to be measured and made available as a data item. Note that PDC to PDC communication could be both Intra and Inter Utility. As such, security of the data is a critical issue.

6 Operator Interface

In a given installation, either a PMU or a PDC will be required to support a user display. The display will most likely be an amalgamation of synchrophasors from multiple devices and multiple locations. The PMU or PDC must time-align the received datasets (based on the UTC time stamp) and then release datasets to clients as requested. Client request rates from one every 10 seconds to 4 times per second are expected.

7 Crosscutting Requirements

The following are general requirements for the reporting of Synchrophasors:

7.1 User-configurable datasets shall be available

7.2 Data in a dataset must be “coherent”, that is, all data is synchronized to the same point in time

7.3 The PMU and PDC shall have support for multiple clients

7.4 The Time Stamp shall be based on the Second of Century – starting Jan 1, 1970 and shall provide support for a modulo-based fraction of second, support for Time Quality as defined in IEEE C37.118, and shall be able to identify and account for leap seconds

7.5 A mechanism shall be provided to map the Status word from C37.118 into IEC 61850 semantics

7.6 A mechanism for detecting/reporting missing data shall be provided

7.7 The implementation shall be capable of providing a high degree of data integrity

7.8 An option for tamper detection and data confidentiality shall be provided

7.9 Control capability from the PDC to the PMU shall be provided

7.10 Synchrophasor files shall be named per the IEEE C37.232 File Naming Convention

7.11 Synchrophasor file output shall be formatted per the recommendation in the appendix of COMTRADE

8 References

[1] R. L. Cresap and W. A. Mittelstadt, "Small-signal modulation of the Pacific HVDC intertie", IEEE Transactions on PAS, Vol. PAS-95, No. 2, March/April 1976.

[2] R. L. Cresap, D. N. Scott, W. A. Mittelstadt, and C. W. Taylor, "Operating experience with modulation of the Pacific HVDC intertie", IEEE Transactions on PAS, Vol. PAS-97, No. 4, July/Aug 1978.

[3] J. F. Hauer and R. L. Cresap, "Measurement and modeling of Pacific AC intertie response to random load switching", IEEE Transactions on PAS, Vol. PAS-100, No. 1, January 1981.

[4] R. L. Cresap and J. F. Hauer, "Emergence of a new swing mode in the western power system", IEEE Transactions on PAS, Vol. PAS-100, No. 4, April 1981.