<u>NASPI SCOPE OF WORK FOR PDC REQUIREMENTS</u>

- ***Goals:*** The goal of this project will be to provide a generalized reference for the PDC which could be used by industry and manufacturers to aid in the education of the function of the PDC and to aid in the creation of PDC specifications that could be used for wide area measurement systems. This reference might later be used to create a standard but that will not be addressed by at this time.

- ***Background:*** It is noted there is a complete standard for synchro-phasor measurement (C37.118) but there is no complete standard for the phasor data concentrator (PDC) which is defined as correlating data from the PMU(s) by time tag and then broadcasting the combined data for processing.

  It was identified that it would be useful to industry to provide a generalized reference document for the PDC requirements. The document scope would be defined and monitored by the sub-task team within the Performance and standards task team (PSTT) but be produced by an independent consultant. To this end, schedule, deliverables, and estimated workload is expected to be tallied by an external consultant and this sub-task team within PSTT will act as leads and owners of the final document. For the present time this document will not include IEC 61850 as other documents yet to be produced will encompass that area of integration.

- ***Task Description:*** The final document would contain a section for core requirements and also include an appendix including optional requirements, optional architectures, and future considerations. The details of the document scope are as follows:

  - <u>PDC Requirements – Core functionality</u>

    - Aligning data into a comprehensive data block
      - Ability to accept data sources with different data rates. This includes both downsampling and upsampling. In the case of downsampling, the topic of aliasing needs to be addressed and handled properly within a tolerance or error. In the case of upsampling, interpolation should be within a tolerance of error.
      - Ability to handle missing and/or corrupted input data. The PDC should specify a quality flag that data is missing (whether this flagging capability should also be a core functionality or just an option has not yet been decided).
      - Latency requirements should be defined (how long should one wait before the PDC decides the data is missing?)

- Distributing data to various users
  - Ability to distribute received data to multiple users simultaneously, each of them may have different requirements on the data
  - Ability to process and repack received data into different data rates from that of received
  - Ability to repack data with different subset of data from the received data
- Providing system management functions such as performance history and trouble alarms
  - Ability to log PMU availability statistics
  - Ability to alarm operators about PDC and other system problems
  - Ability to detect PMU lost with customer configurable delay (either absolute or relative)
  - Ability to cross trigger commands for recording/storing of events of interest

Appendix – Architecture, Hardware and Functional Considerations

- Direct connection.
- Tiered Regional Operation.
- Peered Operation.
- Data on demand.
- Different Formats other than C37.118-2005
  - Ouputs to EMS SCADA in the form of ICCP or ASCII or other formats is an option that utilities may want to explore
  - Inputs from devices that use older protocols like IEEE1344 may need to be incorporated into the PDC an is an option utilities may want to explore
- Handling of Different Data Rates
  - In applications where one is going to a State estimator down sampling may be required at the output of the PDC. Some sort of aliasing error should be defined as acceptable by the User. Utilities should consider this error when they construct their system architecture (depends of the applications). It should be also be noted that when re-sampling is done there is a need to flag that the data has been re-sampled.

        - In applications where older PMUs on their system cannot all be adjusted to a common 30 frames/second or a protection and control application that needs inputs of 60 frames/second or higher, it is useful that the PDC be capable of handling these different input rates. This is a core requirement but the utility may want, as an option, to define how they handle the combining (averaging, holding data etc.)
    - Ability to remote configure and control PMUs
    - PDC Signal Processing Requirements
        - Attached first draft included at end of this document
    - Different formats other than C37.118-2005
    - Handling Different Data Rates
    - Ability to Remote Configure and Control PMUs

        - There is the simple stopping and starting of the data stream into the PDC which is considered a core requirement.
        - There is the ability to remotely stop and restart the PMU in the field which is considered a core requirement but would require that the existing multifunction capability of the PMU not be disturbed (that is you cannot restart the PMU without sufficient permission to overide protective or recording function)
        - There is the ability to remotely configure parameters on the PMU like frames/second or phasing of voltages or line-neutral vs line to ground or perhaps filtering modes. These are not core requirements of the PDC but important for the utiility to explore as an option for their specific requirement.
        - The User should in all cases above explicitly inform the vendor what types of PMUs are on their system as the incorporation of any of these options may not be possible (ie. proprietary or simply not available).

- ***Anticipated Deliverables:*** It is expected that the final document would be in a text format (ie. White paper) and cover the scope listed.
- ***Qualifications Required:*** Consultant that are known for their expertise throughout industry in general in this area of PDCs would meet the qualifications required.
- ***Overseer of the Project:*** The project would be overseen and monitored by the sub-task team of the PSTT of NASPI.

- ***Time Required:*** The time required to complete the project is anticipated in the 6 month time frame but as noted earlier in background bullet would be estimated by the consultant.
- ***Ballpark Estimate:*** unknown

Att: PDC Signal Processing Requirements (following page)

December 14, 2008

PDC Functional Requirements

PDC Signal Processing Requirements

One of PDC's main functions is to align phasor measurements from multiple phasor data sources (or PMU), and generate consolidated data packets that can be recognized and integrated into user specified applications.

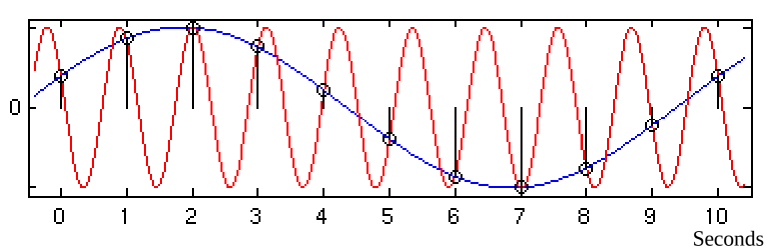
The PMU devices may measure and compute phasor data at different sampling rates such as 10, 20, 30, or 60 samples per second (sps). Phasor users may be using different technologies from PMU manufacturers or request phasor data to be computed at different data rates. Therefore, PDCs need to be flexible with their input/output data rate settings.

Consolidation of phasor data with various data rates to a specific output data rate involves re-sampling of the data. This document examines the issues associated with re-sampling as it may cause aliasing in the final phasor datasets. Both down-sampling and up-sampling are presented below followed with a general definition of aliasing.

Aliasing

Numerical devices use signal processing to calculate secondary quantities used for a variety of power system monitoring, recording, and protection and control applications. In signal processing, aliasing refers to the effect of sampling a high frequency signal at a low rate. Reconstructed signal with the low-rate samples would make the original high frequency signal appear to be a low frequency signal. An example is shown in the figure below. The original 0.9 Hz signal (red trace) appears to be of 0.1 Hz (blue trace) with 1 sps sampling rate.

The Nyquist–Shannon sampling theorem requires the sampling rate higher than twice of the highest frequency in the signal in order to avoid the aliasing phenomenon. If the sampling rate does not meet the requirement, then higher frequencies will alias to lower frequencies. More aliasing examples can be found at the following web site: http://www.dsptutor.freeuk.com/aliasing/AD102.html.



Down-sampling

A PDC may receive phasor data at various rates. According to IEEE Synchrophasor Standard, phasor data rates can be 10, 20, 30 or 60 sps for 60 Hz fundamental frequency, or 12.5, 25, or 50 sps for 50 Hz fundamental frequency. Down-sampling is needed when the PDC output rate is lower than the input phasor rate. Aliasing may occur if the down-sampling is not properly done.

As an example, let's assume the input rate is 30 sps and the output rate is 10 sps. If the input signal does not contain any frequency components higher than 5 Hz, then simple interpolation would be adequate for down-sampling the 30 sps signal to 10 sps as it meets the Nyquist–Shannon sampling theorem requirement. However, in reality, the 30 sps signal would very likely have frequency components in the range of 5-15 Hz. The 15 Hz is the highest frequency a 30 sps signal can effectively capture according to the Nyquist–Shannon sampling theorem.

In a power system, generator torsional modes are well in this range, and many control devices can also generate oscillations in this range. For example, if there is a 9.75 Hz oscillation in the 30 sps signal. Down-sampling to 10 sps would make it appear to be 0.25 Hz oscillation. This aliasing occurs as the 5-15 Hz spectrum of the 30 sps signal is folded over into the 0-5 Hz spectrum of the 10 sps signal. The 0.25 Hz oscillation can be mistakenly interpreted as inter-area oscillations. Therefore, prior to down-sampling, the 30 sps signal needs to be pre-filtered so that any frequency components of greater than 5 Hz will be attenuated. This, of course, means that a real 9.75 Hz oscillation will not be captured in the 10 sps signal. The appropriate sampling for this example would have been at least 20 sps commercially available product if the 9.75 Hz oscillation is of interest.

In general, a PDC should have anti-aliasing filters to handle aliasing issues. The user should be able to select the filter based on the frequency range desired.

Some PMU vendors may use oversampling to move the Nyquist frequency to something much higher than the frequency of interest and thus simplify filtering. this avoids filter delays and may result in space savings. A PDC can consider this approach for down-sampling a signal. It is noted that all sampling processes require anti-alias filtering. The advantage of an oversampling approach is it moves the Nyquist frequency to something much higher than the frequency of interest which simplifies filtering. If it can be ascertained that there are no signal components higher than the Nyquist frequency, no filtering is needed. This is true for any situation, not just in oversampling.

Up-sampling

Up-sampling occurs when input rates are lower than the output rate. Up-sampling could be accomplished by interpolation with sinusoidal or linear or 2nd/higher-order functions. With up-sampling, you will not be aliasing signals but could create new frequency components in the up-sampled signal. If you can visualize a sine wave with a sparse number of dots and then insert a new dot between each old dot but alternatively slightly below and then slightly above the curve, it is pretty easy to see you have created a new frequency component at about ¼ of the sample rate. That is an exaggerated example, but it illustrates that up-sampling can create artifacts.

A better way to up-sample a signal is to apply a low-pass filter to the interpolated signal to remove all the higher frequency artifacts and then re-sample the filtered signal at the output rate. . This will ensure the resulting signal will not contain any frequency components of higher frequency than those in the original signal. For example, up-sampling a 10 sps signal to 30 sps can be done by interpolating the 10 sps signal to 30 sps, applying a 5 Hz low-pass filter, and re-sampling the filtered signal at 30 sps. To perfectly remove the artifacts higher than 5 Hz, it would require a perfect 5 Hz low-pass filter with a sharp cut-off at 5 Hz. A real low-pass filter will have to have a transition band.   It is noted that iIf a standard filtering process is used, the filtered signal will be at the output rate and no re-sampling is needed.

Applying filters always cause delays. The benefit of the low-pass filter should be evaluated with respect to the artifacts caused by the interpolation. A PDC should specify how much error would be introduced due to its up-sampling mechanism.