Technical Notes for PMU Installation and Trouble Shooting at Bonneville Power Administration

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This document is a collection of various technical notes authored by Ken Martin sharing Bonneville Power Administration (BPA) experience during the deployment of Phasor Measurement Units (PMU). For more information please contact Ken Martin or Greg Stults at BPA.

A. PMU Installation

Purpose

This note covers general considerations for PMU installations. It is intended as a general guide for new PMU users. Please contact the PMU vendor and BPA for assistance with specific installation issues.

Input scaling

When installing PMU devices, the signal input should be set so that the maximum signal is available to the PMU without overloading the input. The reason is that all such devices use some kind of A/D input and the more bits of resolution improve accuracy and lower noise in the measurement. There should be some allowance for higher than normal signals so the input does not overload during times or high system stress. Since PMU devices are meant to serve during normal system operation including stressed conditions but not during faults, this calibration does not need to include that kind of overheads. There are no hard and fast numbers. It may be recommended to calculate to allow for a 3X-4X overload from rated on currents and a 1.5X-2X on voltages from rated. Please be very careful about boosting low signals; boosting a signal with devices that are not accurate or stable is worse than using a low signal. You may not worry about boosting signals unless they were 5X lower than the general guidelines above. Most of the PMU devices we have tested have very low noise and are rather tolerant of low signals.

When using some kind of secondary CT, like a toroid, it is recommended using the same one throughout all installations with an extra turn if you need to boost the voltage. The reason is that you have fewer components to stock and calibrate. If a particular current is real low, you can take extra turns around a toroid with practically no increase in burden. Be careful about boosting a signal that seems low simply because conditions do not bring the signal up to normal levels.

The real issue is noise. The closer you get to rated input, the more bits of resolution you get to work with, and the more accurate and consistent will be the results. As the signal gets smaller, the quantization errors increase and the random changes in the measurement are larger. This makes the signal look noisy. With a 1 amp current into an input with the standard 0.1 v/i calibration, we get .1 V rms to the PMU which is .1/1.4 or about 1/14 of full scale. That loses about 4 bits of resolution (1/16) from the maximum; 5 amps loses only about 2 bits of resolution (.5/1.4 or 1/3 of full scale--2 bits are 1/4). However going down to .66 amp (which is the minimum shown below) gives .066 V or .066/1.4 which is 1/21, less than 5 bits (1/32) below the maximum. The point here is since resolution is all by factors of 2, what appears like a big drop often has only a small effect. PMUs that only use a 12-bit A/D converter start with the best resolution 4 bits lower than those that use a 16-bit A/D on all measurements. When evaluating input levels, it is helpful to relate the measurement to the actual measurement device, and better yet, do some test runs. The processing can have several bits of influence as well.

With the Macrodyne PMUs, the current inputs are rated for a maximum of 2V peak which is 1.4V rms. An effective shunt value of 0.1 (100:0.1 with a 100 ohm load) gives a .5 V rms signal with a 5 amp current. Testing has demonstrated that the mathematical conversion actually saturates at about 1.8 Vpeak input). This setting allows continued measurement up to a little over 3X rated current. Most of our currents as observed run much below that, probably in the 1-2 amp range. Some circuits only carry rated loads during outages and run a lot lower than that. It has been noted that many installations using .014 ohm shunts (on 5 amp circuits) with reasonable results, though this gives figures in the .07 volt range and below which is getting marginal.

B. IP Configuration notes

Most phasor system devices now use IP network communications. This note briefly explains the standard routing setup.

Routing

Routing is very important for IP network communications.. Most computer devices that support IP communication will respond to the standard “route command to show the current configuration as well as change settings. To show or change routing, use the route command with an option. This command may be executed in the command line or added to one of the startup scripts,   A printout from the route command showing syntax options is shown below.

Show route
Syntax: route [-n] <command> [-net | -host] <destination> <gateway> route [-n] print
Function: Manipulate routing tables
Options:
   -n   Show addresses as numbers rather than names
   add [-net | -host] <destination> <gateway> [<netmask>] [-hopcount <num>]
         Add entry (host or network) to routing table
   delete [-net | -host] <destination> <gateway>
         Delete entry (host or network) from routing table
   print
         Print routing table

For example, the following shows a routing table printed out:

> route print
Routing tables

Internet:

Destination	Gateway	Flags	Refs	Use	Interface
default	53.16.1.2	UGS	2	4515581	enet0
53.16	53.16.130.130	U	5	3612	enet0
53.16.130.130	localhost	UHS	0	0	lo0
localhost	localhost	UH	0	0	lo0

Adding a gateway

A gateway is a device that connects to other networks. It is usually a router, but could be any device that acts as a router, even a PC so equipped. When a host (device) sends out an IP packet, it has to be sent to a device on the local network. A host will know through a discovery process the IP address of every other host on its physical and logical subnet. If a host sends a packet to a device not on its physical and logical subnet, it must go to a gateway which knows addresses on other subnets. The host routing table tells it where a gateway is for every other subnet. Since the user usually will not list every possible subnet, a default gateway is usually designated to handle all off-net traffic. In specific instances, the user may have several gateways to specific hosts or subnets, and these will be entered separately. Note that all gateway addresses must be on the host’s local subnet.

To add a default gateway for a PDC, execute the following command:

route add default <gateway IP address>

Or to add a specific host acting as a gateway to a specific subnet:

route add –net <subnet IP address> <host IP address>

Or to add a specific host acting as a gateway to a specific host:

route add –host <host IP address> <host (gateway) IP address>

For example, to add a default gateway at host address 193.66.55.2, execute:

> route add default 193.66.55.2 <ret>

To add a specific gateway at 193.66.55.2 to a subnet 47.55.103.0 execute:

> route add –net 47.55.103.0 193.66.55.2 <ret>

C. PMU and PDC output data rate summary

Introduction

This presents data rates for PMU and PDC data output for estimating purposes. There are three aspects for assessing data transmission speed. One is latency, which is the time from when the sending device actually outputs the data and the receiving device gets it. That aspect is addressed in other documents, not here. Another is port speed, which is the rate the data is passed in or out of the port. The port speed should be faster that the overall link speed, so the communication path does not have to stand idle while the device is outputting data to the communication system. Port speed also affects latency. The last aspect is the channel or communication system speed. This is the rate, usually specified in Bits Per Second (BPS) and sometimes in Baudot (BAUD) which is usually used incorrectly. This data rate is usually the limiting factor in transmitting data from one device to another. It is the rate usually specified when discussing channels, modems, etc. This is the factor discussed here.

Summary

The required data rate capability from PMU to PDC and PDC to PDC depends on the data format, the amount of information included within the given format, and the frequency of measurement. Currently in North America the most common PMU and PDC systems are operating at 30 samples/second and this rate will be used in these calculations. There some advantages to operation at 60 samples/second, so there may be some desire at a later date to increase the rate. This is not likely to happen for some time, however, probably not for at least 5-10 years.

PMU to PDC
Many current systems use the Macrodyne format, but the majority use the IEEE C37.118 format. Current systems measure 10 or fewer phasors, and up to 2 digitals, so this is used for the benchmark.
Actual data rates for 10 phasors and 2 digitals:

Macrodyne Format-   18,000 BPS
IEEE standard Format-   19,800 BPS

PDC output data streaming
Two formats are currently in common use: the PDCstream format pioneered by BPA in the WECC and the IEEE C37.118 format. The most common method is streaming over Ethernet using the UDP/IP protocol. This protocol minimizes latency and overhead, and allows simultaneous transmission to any number of users with broadcast or multicast, or a single user with unicast. TCP/IP methods require a little more bandwidth for ACK messages, but essentially use the same forward bandwidth which is used in these calculations. The estimate is based on 10 bits of transmission per byte of data which is the actual serial rate. The UDP format is more compact than that, using an actual 8 bits/byte, but it does have overhead for both Ethernet and IP framing. Since I don't know the exact amount—and it may vary—I will use 10 bits/byte as a conservative estimate. Also, a configuration packet is sent once/minute, so that additional bandwidth requirement is factored in approximately.

Estimate based on all PMUs sending 10 phasors and 2 digital values per PMU, more than typical:

Number PMUs	2	3	4	5	10	15	25	50	100
PDCstream (KBPS)	39.0	55.8	72.6	89.4	173.4	257.4	425.4	845.4	1685.4
IEEE37.118 (KBPS)	34.8	49.8	64.8	79.8	154.8	229.8	379.8	754.8	1504.8

DETAILED CALCULATIONS

PMU Output Data Rates

ASSUMPTIONS:
- All data will be in integer format
- 10 phasors and two digital words will be transmitted
- Data transmission rate is 30/sec
- Asynchronous serial data protocol (RS 232)
- 10 bit/character format (1 start, 1 stop, 8 data, no parity)

Note: Serial communications send each byte as one character framed by start and stop bits. When using network communications, there is overhead with each packet but each character is transmitted as one 8-bit byte.

Data rate for Macrodyne format

40	bytes	phasors
4	bytes	Digital
6	bytes	sample, Freq, Df/dt
10	bytes	All other
60	bytes	Message total

60 bytes/msg X 30 msg/sec = 1800 bytes/sec
1800 bytes/sec X 10 bits/byte = 18,000 bits/sec (BPS) actual data rate.

Data Rate for the IEEE C37.118 SYNCHROPHASOR Standard Format.

16	bytes	HDR, SOC, FRACSEC, PMU_ID, CRC
2	bytes	STAT
40	bytes	phasors
4	bytes	FREQ, DFDQ
4	bytes	DIG

66	bytes	Message total

66 bytes/msg X 30 msg/sec = 1980 bytes/sec
1980 bytes/sec X 10 bits/byte = 19,800 bits/sec (BPS) actual data rate.

Data rate for PDCstream (compact option)

Fixed bytes per message:	18 bytes
Bytes/PMU	
Status (chan flag, PMU stat)	8 bytes
Freq, Df/dt	4 bytes
Phasors	4 bytes X #phasors
Dig status	4 bytes X dig/2 (packed in long words)
Total/PMU	12 bytes + phasors + dig
Total/message	18 + PMU X (12 + phasors + dig)
PMU with 10 phasors, 2 digitals	56 bytes + 18 = 74

74 bytes/msg X 30 msg/sec = 2220 bytes/sec
2220 bytes/sec X 10 bits/byte = 22,200 bits/sec (BPS) actual data rate.

Note: This does not include the configuration packet sent once/minute. It only adds about 1 byte/sec on average. Note also that this format is sent only on Ethernet an dis designed for multiple PMU content which makes it more efficient.

Ethernet has much more overhead per packet, but the data is packed more compactly since each byte does not require framing. The data rates will be similar with 10 byte packets as packet overhead substitutes for framing overhead. With smaller frames the packet overhead is much more significant, but the much higher wire speed makes this somewhat insignificant.