PAC Time Synchronization Applied To Power System Relaying

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Abstract

Many power system processes rely on efficient and effective distribution of a clock reference to time. Today, it is possible to send data with a time stamp, providing more accurate and useful information. Precise timing is available at the programmable automation controller (PAC) level. This allows for PAC applications in the power system, especially for high speed data acquisition. This work demonstrates the use of synchronization protocols to evaluate protection scheme delays via a PAC.

Comparison of Time Protocols

Three timing protocols were evaluated during this investigation: GPS, Precision Timing Protocol (PTP), and IRIG. Fig. 1 shows a comparison of these protocols. Within a substation, GPS is most commonly distributed to intelligent electronic devices (IEDs) via IRIG-B. IEEE 1588 is a viable synchronization solution to a distributed network of IEDs and meets the process bus requirements presented by IEC 61850. This work distributes IRIG-B via a GPS clock to IEDs in the system. The PAC is synchronized to the same GPS clock via IRIG-B, and distributed to the PAC modules via PTP over an EtherNet/IP network.

TABLE I. COMPARISON OF TIMING PROTOCOLS

Protocol	Global Positioning System (GPS)	IEEE 1588 - Precise Time Protocol (PTP)	Inter-Range Instrumentation Group (IRIG)
Manged By	United States D.o.D.	IEEE/IEC	Inter-Range Instrumentations Group
Distribution Media	Coaxial Cable, Fiber, USB	Twisted Pair Copper, Fiber	Coaxial Cable
Accuracy	+/- 10 ns	+/- 100 ns	Modulated: +/- 1 ms Un-modualted: +/- 1 us
Sync Algorithm	Value/Phase	Frequency & Value/Phase	Value/ Phase
Re-sync Frequency	Top of Second	Once Every Second	Once Every Second
Ultimate Time Source	GPS Satellite	Grandmaster Clock	Primary Time Source
Compensation for Master Loss	No	Yes	No
Master Clock Determination	GPS Satellite	Best Master Clock Algorithm	Primary Time Source
Master Override	No	Yes	No

Power System Monitoring & Protection

The test system constructed uses PMU measurements from key locations in the system, and decision trees implemented in a PDC, to classify the operating state of system. During stressed conditions, the relays perform voting while for safe conditions the relays perform normal operation. A PAC was used to perform logic based on the classified state of the system from the PDC. Using a PAC in this scheme has additional benefits besides performing voting logic.

A PAC implementation allows for ease of data acquisition, interfacing to other protection devices within a substation network, and simplified software changes to protection logic. In addition, a synchronized PAC can apply accurate sub-µs time stamps to discrete input transitions. Using a PAC between the relay 52A and the circuit breaker 52TC will inject delays; it is critical in power system protection and wide-area measurement to minimize these delays to acceptable levels.

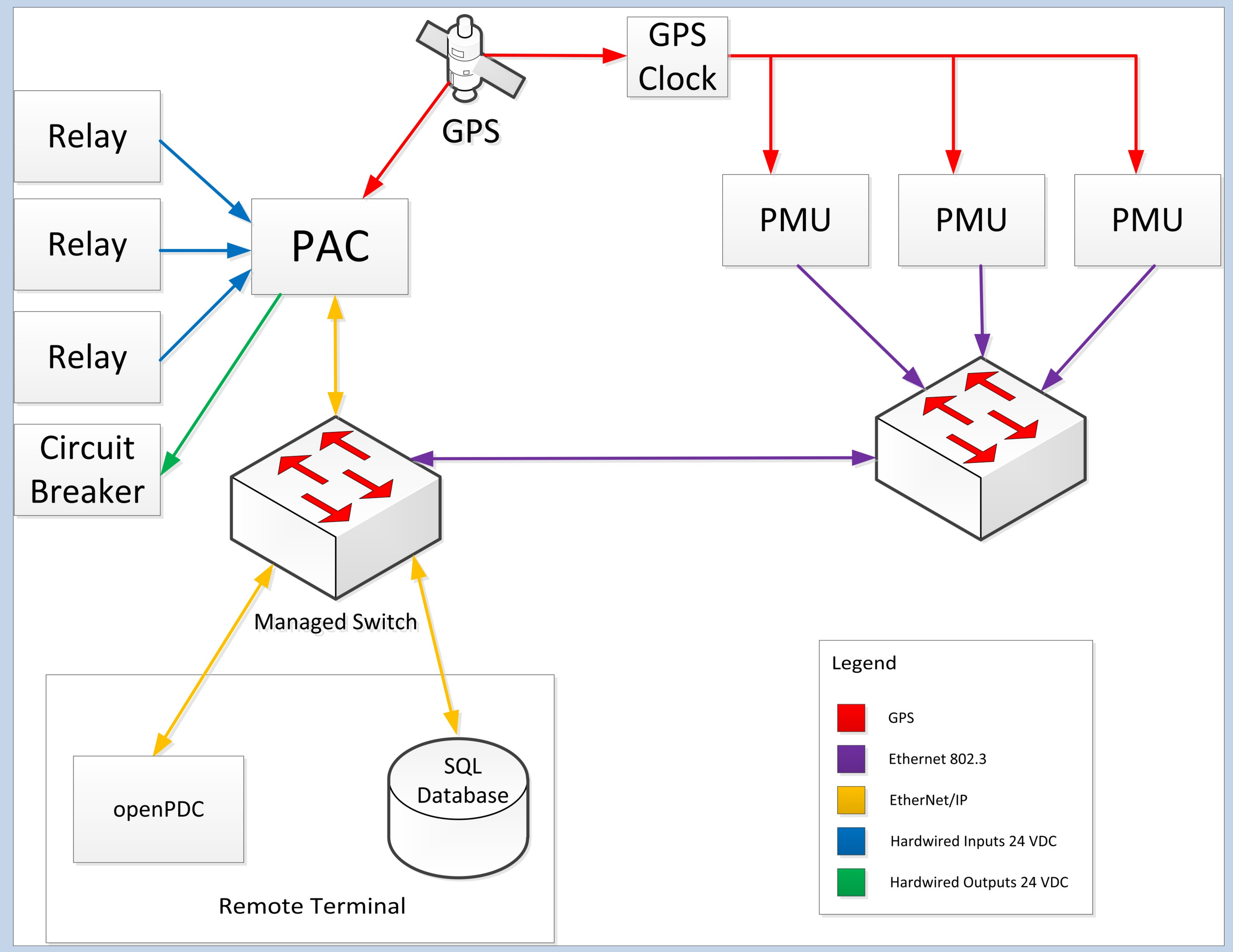

Figure 1. System Diagram

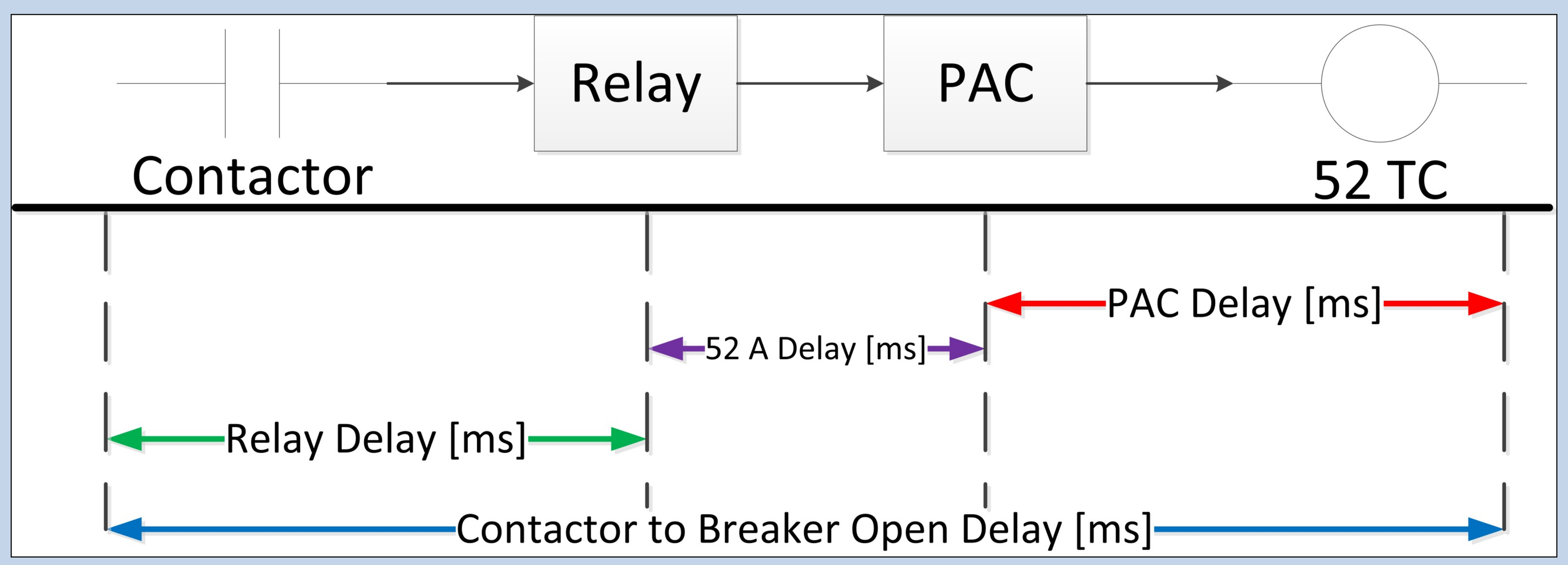

Figure 2. System Delays

Sequence of Events (SOE) Architecture

The system architecture was broken up into two area: wide-area inputs consisting of PMUs, and local inputs consisting of instantaneous overcurrent relays. The 52A contacts of the local relays were hard-wired to PAC SOE inputs. Off→On transitions at these SOE inputs trigger a 64-bit UTC timestamp obtained from the PAC timing module. A PAC output is wired to a circuit breaker 52TC in order to simulate corrective action. This output was also paralleled to an additional SOE input, providing a timestamp of when the breaker trip signal was applied. Fig. 1 shows a high-level system architecture.

Post-mortem analysis of power system events requires a common timing reference such that wide-area events can be pieced together. The PAC was time synchronized to the same clock reference as the relays, which allowed for comparison of internal event records to applied PAC timestamps. The measured delays in the test setup are shown in Fig. 2. The contactor closure was initiated by the time-synchronized PAC. The relay trip times were recorded using internal SOE records and PAC timestamps.

Table II. Test Results

	Non Voting			Voting		
	Min[ms]	Avg[ms]	Max[ms]	Min[ms]	Avg[ms]	Max[ms]
Overall Trip Time	8.3250	10.6516	13.0250	10.4220	12.3773	15.5490
PAC Delay	0.3200	1.1870	2.1990	0.8750	1.9561	3.1755
Max Relay Op Diff	0.0000	0.5075	2.0260	0.0000	0.8997	2.2250
R1: Contactor Delay	4.0540	4.3369	4.2060	4.6500	4.3058	4.3320
R2: Contactor Delay	4.3910	4.4089	4.3230	4.7940	4.5287	4.5370
R3: Contactor Delay	4.3960	4.1620	4.0280	3.7750	4.2241	4.3170
R1 Tripping Time	3.0470	5.8682	8.1440	4.8260	6.6730	8.4920
R2 Tripping Time	3.0090	5.5316	7.5520	4.3790	6.3370	9.0880
R3 Tripping Time	3.0790	5.6016	7.6620	4.4490	6.3403	9.1580

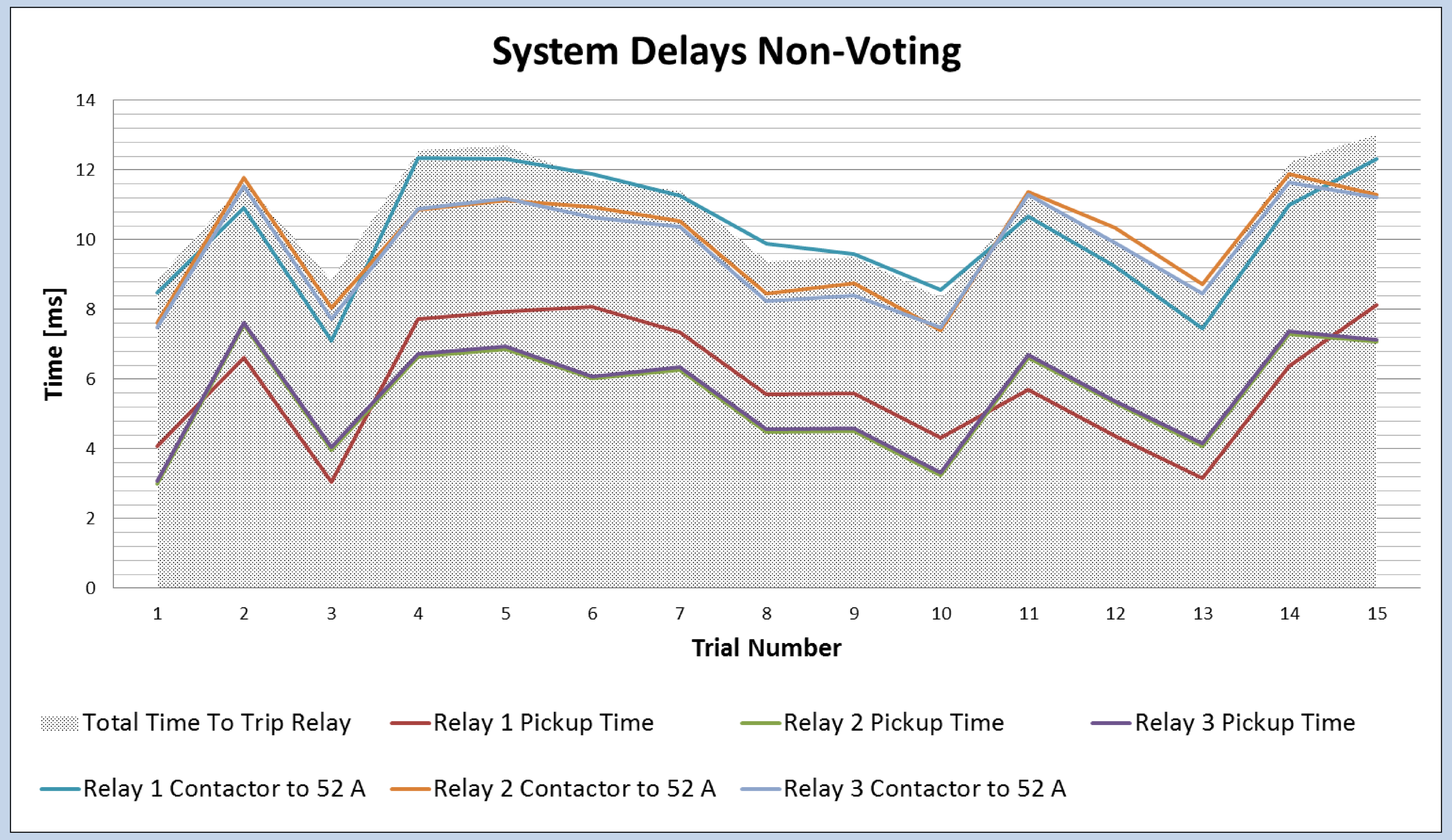

Figure 3. Graphical Results

Conclusions

GPS time was efficiently and effectively distributed via IRIG-B and PTP protocols simultaneously over a distributed network. The PAC was used to record accurate UTC timestamps of events, including relay assertions and breaker trips. The synchronized event times were compared against each other to determine system delays. Table II and Fig. 3 show results from testing. The incurred time delay between the applied overcurrent step signal and overcurrent element assertion was 9.15 ms maximum. The relay 52A delays were 4.3 ms on average. The maximum added delay from implementing a PAC between the relays and breaker was 3.18 ms. The PAC provides a viable SOE recorder solution while producing acceptable delays.

References

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