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THE DOE WIDE AREA MEASUREMENT SYSTEM (WAMS) PROJECT – DEMONSTRATION OF DYNAMIC INFORMATION TECHNOLOGY FOR THE FUTURE POWER SYSTEM

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Abstract

In 1989 the Bonneville Power Administration **(BPA)** and the Western Area Power Administration **(WAPA)** joined the US Department of Energy **(DOE)** in an assessment of longer-term research and development needs for future electric power system operation. The effort produced a progressively sharper vision of a future power system in which enhanced control and operation are the primary means for serving new customer demands, in an environment where increased competition, a wider range of services and vendors, and much narrower operating margins all contribute to increased system efficiencies and capacity. Technology and infrastructure for real time access to wide area dynamic information were identified as critical path elements in realizing that vision. In 1995 the DOE accordingly launched the Wide Area Measurement System **(WAMS)** Project jointly with the two Power Marketing Administrations **(PMAs)** to address these issues in a practical operating environment– the western North America power system. The Project draws upon many years of PMA effort and related collaboration among the western utilities, plus an expanding infrastructure that includes regionally involved contractors, universities, and National Laboratories plus linkages to the Electric Power Research Institute **(EPRI)**.

The WAMS project also brings added focus and resources to the evolving Western System Dynamic Information Network, or **WesDINet**. This is a collective response of the Western Systems Coordinating Council **(WSCC)** member utilities to their shared needs for direct information about power system characteristics, model fidelity, and operational performance. The WAMS project is a key source of the technology and backbone communications needed to make WesDINet a well integrated, cost effective enterprise network demonstrating the role of dynamic information technology in the emerging utility environment.

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Introduction

Many strategic visions of the future power system are in circulation among energy strategists. Broadly described, all visions agree that more "intelligent" design, control, and operation of system assets will be a primary tool for meeting energy demands. This expectation, reinforced by emerging market forces, argues that the future power system will be very information intensive. By contrast, in many respects the existing power system is better characterized as information starved. Closing the gap calls for a rapid upgrade of the real-time information infrastructure, supported by major deployments of better and cheaper information technology.

In the Fall of 1989 BPA and WAPA joined the US Department of Energy's Office of Energy Storage and Distribution in an assessment of longer-term research and development needs for future electric power system operation. Three workshops developed a progressively sharper vision of a future power system in which enhanced control and operation will be the primary means for serving new customer demands (1-5). These alternatives can be much more cost effective than constructing new facilities for power generation and delivery. It is also much more compatible with the changes associated with utility restructuring. The future utility will almost certainly operate in an environment that is characterized by much narrower operating margins, increased competition, a larger number of independent power producers, and a much wider range of electrical services and providers (6,7).

Two thrust areas were chosen for Joint DOE/BPA/WAPA Research Initiatives: real-time control and operation, and high capacity transmission (primarily high voltage dc). BPA and WAPA, the two western PMAs, have done pioneering work in both areas and are sharply aware of the implicit challenges. Presentations in 1992 by their chief engineers (8) highlighted the following steps to success in the Initiatives:

- Collaborative programs for effective utilization of R&D investments.
- Rapid development and demonstration.
- Early implementation of results.
- Federal sponsorship of longer-term R&D, especially during the transition to a deregulated industry.

These were also viewed as indicators of success. The overall joint initiative were rooted in concerns that the PMAs, and electrical utilities in general, might be faced with long term technology needs that they could neither anticipate nor deal with in a timely manner. Circumstances have been forcing the utilities to scale back their new technology deployment for many years. The cumulative effects of this may be slow to overcome. There is a massive backlog of unassessed technology for which utilities need value engineering guidelines. The vendors, in turn, need product evaluation by the utilities to justify and focus the next development cycle. Both utilities and vendors are reluctant to proceed without clearer rules for conducting business in the new marketplace that utility restructuring will produce.

Overview Of The WAMS Project

The WAMS Project accelerates and expands interrelated BPA and WAPA efforts to

- Evaluate leading edge technology applicable to wide area measurements.
- Develop instrumentation and siting requirements for relevant power system applications.
- Deploy and test advanced-technology information network facilities.
- Identify future research needs related to power system measurement and control.

The Project draws upon many years of PMA effort and related collaboration among the western utilities, plus an expanding infrastructure that includes regionally involved contractors, universities, and National Laboratories plus linkages to EPRI.
The WAMS project also brings added focus and resources to a much broader effort. In recent years the member utilities of the Western North America power system have made significant progress in the development of monitor facilities for examining system behavior. This development, coordinated through the WSCC with strong BPA and WAPA participation, is a collective response to the utilities' shared needs for direct information about system characteristics, model fidelity, and operational performance. The emerging result can be usefully termed the Western System Dynamic Information Network, or **WesDINet**.

Existing and planned WSCC monitors are sparsely located, and many are based upon technology that is either obsolescent or immature. These shortcomings reduce the likelihood that critical events will be adequately recorded, and they increase the staff costs associated with translating acquired data into useful information. Furthermore, present facilities do not provide the comprehensive data access and real time integration that is necessary for full use of wide area control (9,10).

The next phase of WesDINet evolution should close the major gaps in monitor coverage, upgrade measurement system performance through network based technologies, and reinforce the general infrastructure through which the WSCC utilities collaborate in their use of these facilities. This is proceeding along three paths:

The DOE/BPA/WAPA WAMS Project, funded under the DOE Initiative for Real Time Control and Operation of Electric Power Systems.

EPRI Project RP3717, for refinement of phasor measurement technology. Cofunded as a Tailored Collaboration by BPA and five other WSCC utilities.

Actions of the WSCC member utilities, both individual and collective.

These efforts are complementary and mutually supporting, with much of the coordination provided by WSCC technical groups or the participating utilities themselves (11,12).

WAMS provides key source technology plus backbone communications and infrastructure necessary for further evolving WesDINet as a well integrated, cost effective information network. Parallel efforts lead by BPA include developing mathematical software for extracting information from measurements, designing the wide area measurement tests, and projecting information requirements for the emerging utility environment (9-13).

Restructuring is now carrying BPA, WAPA, and the other utilities toward the future very quickly. WAMS and WesDINet started in response to technical needs in a cost based business environment. Their value in the new price/performance based environment is likely to be much higher. The growing participation by EPRI and the DOE National Laboratories open many opportunities to enhance technology transfers, information sharing, and collective support for this full-scale testbed of the future dynamic information system.

Architecture Of The BPA/WAPA Monitor Nets

Like WesDINet, overall monitor facilities for BPA and WAPA are evolving as a "network of networks." This is not just a result of multiple ownership. Diversity in the lower level networks also reflects the use of different base technologies to serve different information needs under different security constraints.

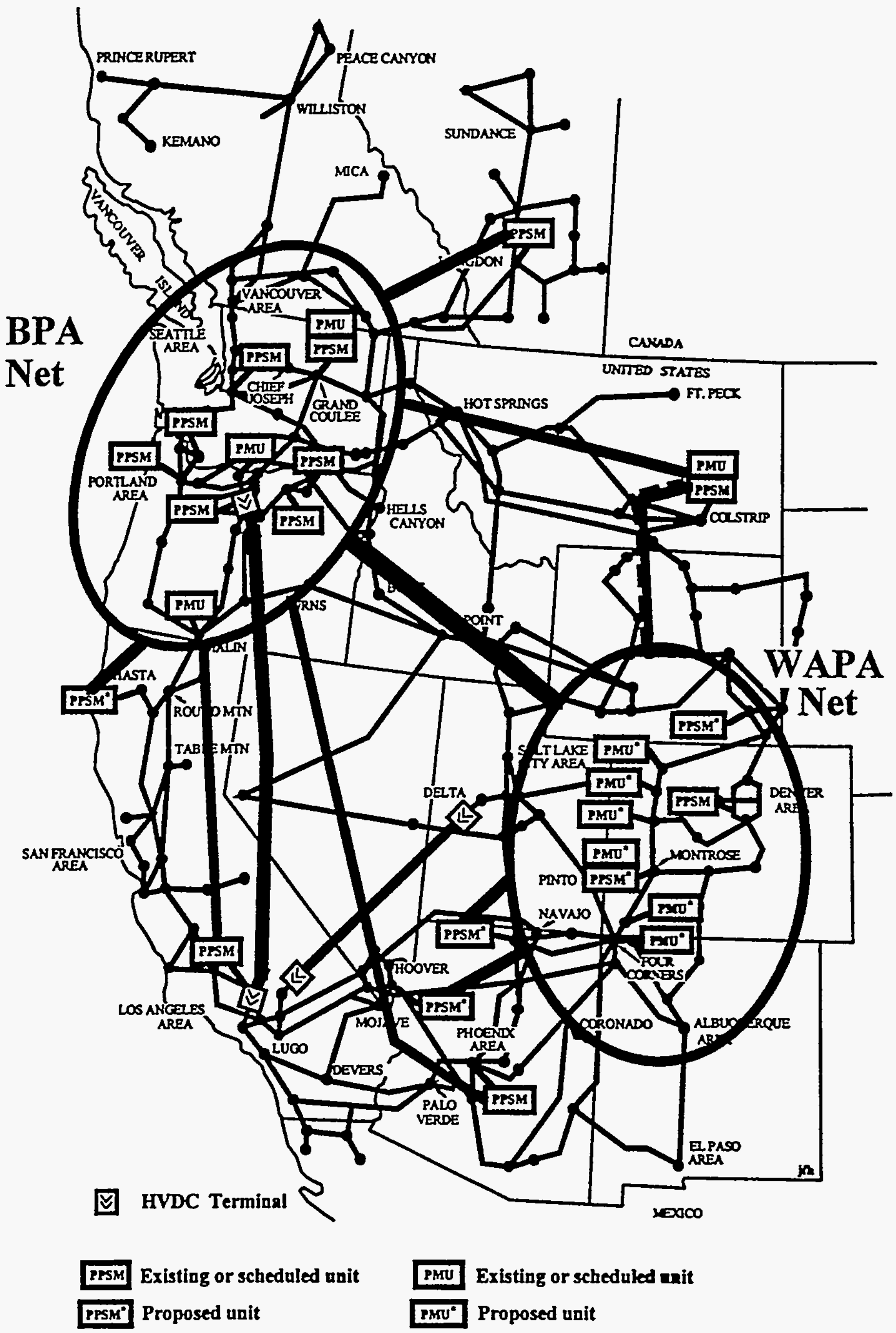

Figure 1
Projected geography for the BPA and WAPA monitor nets (1996)

The general architecture for these facilities is shown in Figure 1, from a geographical perspective. The BPA monitor network **(BPA Net)**, based at the Dittmer Control Center, extends over most of the BPA service area and includes key sites well beyond it. It reflects BPA's long involvement in dynamic stability and control issues associated with the Pacific AC Intertie (14-17). Deployment of the WAPA monitor network **(WAPA Net)** is in its early stages. This network will be based at the Montrose or the Loveland Control Center, in Colorado. For WAPA dynamic stability is a less immediate problem, dominated by that of inadvertent loop flow (18-20). Appropriate technologies for instrumentation and control of the underlying power flow are just now becoming available (21-24). BPA Net and WAPA Net will also link with generation plant monitors operated by the US. Bureau of Reclamation **(USBR)**, and perhaps by the US. Corps of Engineers **(USCoE)**.

The PMA networks will be connected by communication links providing high performance support for functions such as

- Real-time communication of special signals.
- Selective cross-triggering of monitor units and accessory recording devices.
- Sharing of reference signals for wide area correlation.
- Interactive "workteam" assistance, from remote locations, during measurement operations and analysis.
- Automatic posting of disturbance directories on computer "bulletin boards."
- Exchanges of data records.

Where appropriate, the technical approach will facilitate progressive replacement of point-to-point communications by general network services. These may be either commercial or private.

WAMS Technical Objectives

The technical objectives of the WAMS project are summarized in the five component tasks stated below.

Task 1: Laboratory Evaluation of Information Technology

Leading edge technology applicable to wide area information systems will be examined and closely evaluated under controlled laboratory conditions. A full range of value engineering factors will be identified and examined. Most, though not all, of the technology considered is digital. Specific subtasks address the issues below.

1.1 Advanced Transducers for Stability Control

Thoroughly test and evaluate signal processing quality of leading edge transducers for bus angle, bus frequency, and rms quantities. Focus issues are high performance measurement and control of interarea "swing" dynamics, with assured protection against parasitic interactions with network or machine resonances.

1.2 Virtual Instrumentation

Review and report BPA experience with virtual instrumentation technology. The Report will include documentation of the Portable Power System Monitor **(PPSM)**. Focus issues include development time, user level programming, choice of computer platforms, tradeoffs between virtual and "hard" instrumentation, and training requirements.

1.3 Network Methods and Technology

Develop and test PPSM-based local area network (**LAN**) interfaces to the Macrodyne phasor measurement unit (**PMU**), the PTI/Hathaway dynamic system monitor (**DSM**), leading edge dynamic signal analyzers (**DSAs**) and digital fault recorders (**DFRs**). Test and evaluate technology for interactive control of remote LANs, integration of LANs into regional and wide area networks. Focus issues include hardware based assurance of power system and network security, value engineering, and projection of emerging technologies.

Task 2: Definition of WAPA Measurement System Requirements

The western Colorado area of the WAPA transmission system is well suited for testing wide area measurement technology. Monitors there can record the slow power changes associated with loop flow and automatic generation control, as well as fast dynamics associated with power surges and system swings. This provides new information, along the eastern side of the WSCC system, for validation of planning models and assumptions. This task will involve identifying instrumentation and siting requirements for test application of wide area measurement technology.

Task 3: Deployment and Evaluation of WAPA Measurement Systems

Install, demonstrate, test, and evaluate the WAPA Net. Collectively, these measurement systems will support both monitoring and direct tests of controllable system dynamics. It is expected that the technology will also be used in a wide range of future power system applications.

3.1 WAPA Monitor Net Additions

Install integrated PMU and PPSM networks based at WAPA's Montrose or Loveland control center. Focus on a dense regional PMU network for centralized phasor measurement of ac powerflow. The PPSM network supports instrument integration, remote interactive control and analysis of measurements, and regional dynamics monitoring. This includes regional USBR generation sites.

3.2 Real Time Measurement of Powerflow State

Use the WAPA PMU network for direct measurement of powerflow on the regional 230 kV or 345 kV transmission system. Evaluate performance against state estimation, including estimators which accept phase angle data. Focus applications are remedial action control, direct dispatch and control of ac powerflow within a FACTS environment.

3.3 Measurement System Testing and Evaluation

Test all aspects of the WAPA Net in place. Evaluate performance against both technical specifications and an updated requirements list based upon operational experience. Evaluation factors include adequacy of signals measured or computed, data storage and retrieval, communication requirements and performance, information displays, staffing costs, and compatibility with pre-existing technologies.

Task 4: Demonstration of Network Integration Technologies and Performance

Integrate the BPA and WAPA Nets to demonstrate and test this aspect of wide area measurements. This may involve some extensions to the BPA Net at Dittmer, to acquire representative hydroplant signals and for selective data exchanges with other utilities.

4.1 Dittmer Monitor Net Additions

Extend the PMU and PPSM networks based at BPA's Dittmer control center to key network and generation sites. Focus on a PPSM network for wide area measurements, monitoring, and analysis. A sparse PMU network presently provides phasor data for centralized measurement of ac powerflow.

4.2 Integration of BPA and WAPA Monitor Nets

Develop a high performance link between the BPA and WAPA monitor nets. This link will support selective cross-triggering of monitor facilities, data exchanges, and workteam communications. It may also include selective sublinks to the USBR, the USCoE, and other utilities.

Task 5: Identification of Future Research

Recommend approaches for technology enhancements, and refinement of guidelines for deployment of existing technology. Identify research issues related to data management, analysis, and exchange of wide area measurements.

Focus Technologies For The BPA Monitor Net

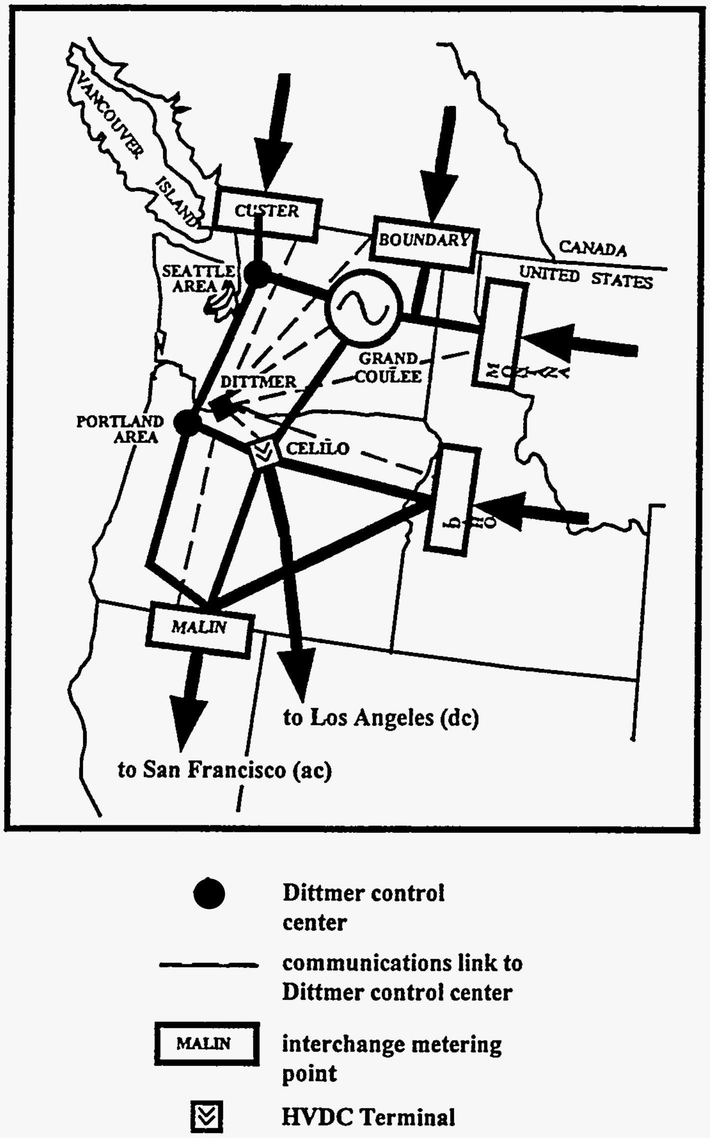

Figure 2
Central monitoring of BPA regional interchanges

BPA operates a centralized monitor system, based at the Dittmer control center, that is interlaced with an expanding network of remote monitors and secondary recording devices. Many of the remote monitors provide local or regional surveillance over a major control system. The general approach is to collect essential signals (including alarms) from such sites on the central monitors, at modest data rates, and to perform comprehensive high speed monitoring locally. The high speed data is immediately available to site operators, but selectively forwarded to the control center or to system analysts.

The cost and availability of supporting communications is a key factor in determining monitor network architecture. At present the central monitors (indicated in Figure 2) have access to several hundred analog signals that, for the most part, represent power flowing on the system and contain useful information at frequencies up to perhaps 2 Hz. Signals associated with control projects are an increasingly common exception to this. They ordinarily use 20 Hz channels and the corresponding transducers, if any, tend to be conventional electronic units modified for either 12 Hz or 20 Hz bandwidth.

In this arrangement the 2 Hz signals present a comprehensive view of interarea "swing" dynamics visible in BPA interchanges, plus information about voltages, reactive flow, important loads, and AGC. The 20 Hz signals convey a necessary minimum of essential information about controller behavior. They also facilitate alignment and cross analysis of central monitor records with more comprehensive local recordings. The total communications burden for this mixture of central plus distributed monitoring is much less than for a fully centralized monitor system. Furthermore, much of the data can be moved with adequate speed and reliability with general purpose computer networking technology. The value engineering implications of this are discussed in (10,13).

This deployment of remote monitors on a general network represents an evolutionary step in the gradual transition from analog technology to digital. Direct replacement of BPA's present point-to-point analog communications by digital channels of comparable bandwidth and resolution (about 14 bits, after filtering) would be needlessly expensive. Best use of digital technology will call for new architectures, which should readily accommodate the rapid product enhancements so characteristic of the "information age."

BPA, in association with vendors and contractors, is both refining and deploying two digital systems that, together, represent a considerable cross section of the issues implicit in the transition to digital instrumentation and networks. These are

The Portable Power System Monitor. This is an interactive measurements workstation, with extensive networking capabilities that include "real-time" data sharing. It was expressly developed for tests and monitoring to support wide area control. PPSM code modifications are facilitated by use of LabVIEW virtual instrumentation technology, and integration of multiple-site data is facilitated by optional use of satellite-synchronized precise time measurements.

The Macrodyne Phasor Measurement Unit. This is an advanced digital transducer package with local recording features, using satellite-synchronized precise time measurements to accurately determine phase angle and other quantities at multiple sites . It is normally operated in a centralized monitor configuration with selective two-way serial communications.

These two devices have complementary characteristics and BPA will usually install them as pairs (Figure 3). This places the PMU on a substation network where the PPSM provides a coordinating local intelligence for overall data recording, archiving, forwarding, display, and analysis. Analogous to a DFR, the PMU is thus freed to perform the high priority but narrowly defined functions characteristic of control applications, while the PPSM serves a wider range of functions outside the control loop. This also provides PMU access through the general computer network on which PPSM units share data and support workteam operations.

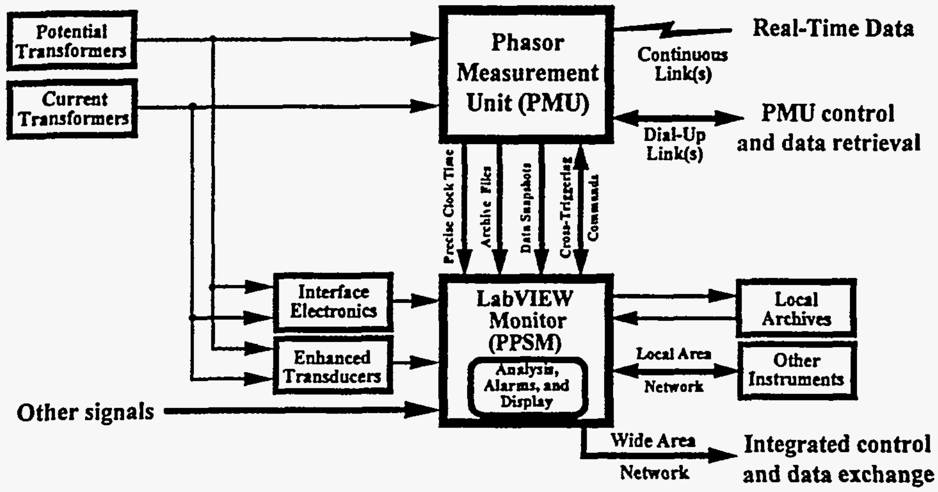

Figure 3
Task sharing in PMU/PPSM pair

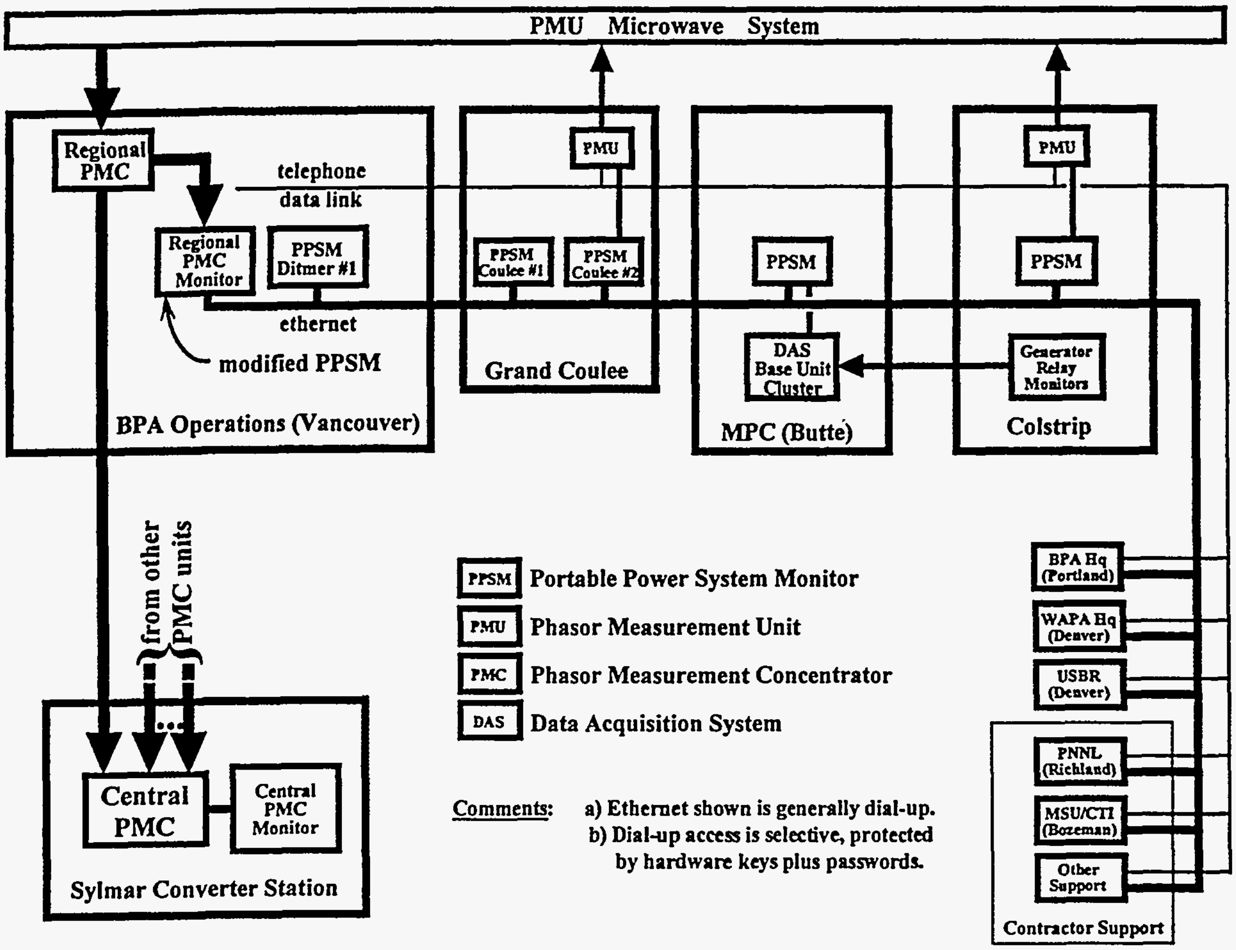

Figure 4

General integration of Coulee/Colstrip monitor net

A typical configuration for wide area networking is shown in Figure 4. This represents a likely architecture for BPA monitor additions associated with the EPRI RP3717 Project.

A defining requirement for the BPA Net, and for much of WesDINet, is wide area correlation analysis (16,25). This requires long high-resolution signal recordings, in compatible formats, collected at key measurement points across the power system. For staged tests a necessary minimum of these signals must be available at the test control site, in real time, and necessary information must be extracted from them in real time. Utility restructuring is producing similar needs at the control centers, where prompt access to dynamic information may be needed to estimate network transfer capacity.

Focus Technologies For The WAPA Monitor Net

The western power system has an underlying loop structure, with important radial extensions into British Columbia, Alberta, and eastern Montana (see Figure 1). Remote imports into the Los Angeles area are nearly 10% of system capacity. Power flow along the western side of the loop is concentrated on a few major interties. Along the east side of the loop power flow is diffused across a web of more numerous and weaker lines, eventually concentrating along a major transmission corridor that approaches Los Angeles from the east.

Loss of any major transmission path toward Los Angeles produces a "power surge" that may overload the remaining paths and cause the system to separate into several islands. Assessing and mitigating this risk is a major concern of utilities operating the major interties. The WAPA Net will assist in this effort, but the dominant concerns are somewhat different.

The east side contains a number of transfer path constrictions, or bottlenecks, that each involve several transmission lines. One of these is the system of lines connecting eastern and western Colorado across the continental divide (Figure 5). Another is the connective path between the Colorado-Utah and the New Mexico-Arizona regions. WAPA is interested in real time assessment of actual power flows and dynamic capacity across these paths (which planning engineers refer to as "totals"), and in assessing possibilities for extending capacity through direct powerflow control.

Overloading of these weak links during power surges is a serious but infrequent problem. Their limited capacity is also an onerous and persistent constraint during daily operation, through inadvertent "loop" flows that can readily consume all available transmission capacity across them (19,20).

WAPA has operational responsibility for a number of control devices that have been installed to relieve the loopflow problem. These include phase shifting transformers (**PST**'s) along the Colorado-Utah and the New Mexican-Colorado borders, plus an advanced series compensation (**ASC**) device at Kayenta substation in the Four Corners area (26). The ASC, in conjunction with USBR hydro generators at Glen Canyon Dam, might also be useful for stability enhancement and for damping or avoiding subsynchronous oscillations on nearby thermal plants (27).

So, while WAPA Net will provide basic capabilities in all aspects of dynamic measurements, its focus application is powerflow measurement and control. Unlike the BPA Net, where key measurement points are well defined and fairly concentrated, the WAPA Net must cover a very dispersed transmission network for which the key measurement points are not obvious. It must also seek a different kind of information. The natural "state variables" for the BPA Net are, for the most part, associated with generator and control system dynamics. Fairly good signals for these quantities are available from enhanced conventional transducers for power, frequency, and voltage magnitude. The natural state variables for powerflow dynamics are complex voltage and current. Competent instrumentation for the associated angle determinations requires precise time synchronization technology that has just recently become available (22).

Thus the defining requirement for the WAPA Net is the use of phase angle measurements in real time powerflow estimation. For best results, WAPA's PMU network will communicate directly with PMU networks operated by BPA and other WSCC utilities, and draw upon other data sources for accessory information. The development of these resources will necessarily interact with that of information tools for estimating network topology, parameters, and powerflow.

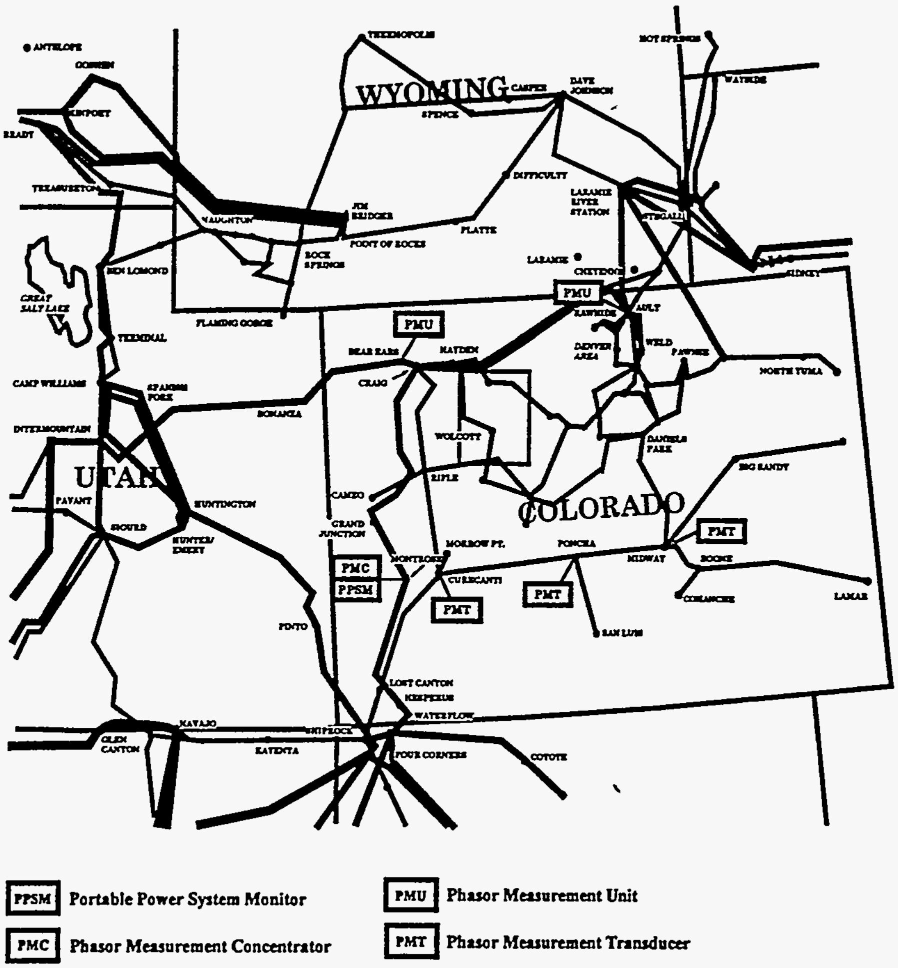

Figure 5
Initial Architecture for WAPA Monitor Net

Conclusions

The WAMS Project will expedite progress toward a future power system in which intelligent design, control, and operation of system assets is a primary tool for serving increased demands for quality power, lower cost energy, and flexibility of supply. Narrower operating margins, increased utility competition, and more generation from independent power producers are the driving forces in the need for more advanced power system information technology and control. The Project will address this need through a comprehensive testing of dynamic information technology across the western North America power system, where long involvement with stability problems has anticipated the information and infrastructure requirements that characterize the envisioned "intelligent energy system." Utility restructuring is expected to intensify these needs, while extending them to all aspects of utility operation.

Acknowledgments

The WAMS Project derives from and reinforces a collective response to future information needs in the nation's energy system. The pace of utility restructuring indicates that these needs are arriving rather sooner than expected, and that managing the information technology investments will at the same time be more difficult and more critical. The architects of this Project, of which their are many, are recognized for their vision in providing the industry with an early start in dealing with these important issues. Chief among these are Steinar Dale (formerly with ORNL), Tom Weaver (formerly with WAPA), and Chuck Clark (formerly with BPA).

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