PLC BASED SUBSTATION AUTOMATION AND SCADA SYSTEMS And Selecting a Control System Integrator

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1) Introduction

Much attention has been given to the use of PLCs (Programmable Logic Controllers) in substation and distribution automation applications in recent years. Innovative engineers and technicians have been actively seeking new applications for PLCs in substations and SCADA (Supevisory Control And Data Acquisition) systems. The manufacturers of PLCs have responded by developing new products that meet the unique requirements of substation automation and SCADA applications. PLCs are very cost competitive with traditional RTUs and have many benefits in substation automation applications. PLCs have an important place in substation automation and their use in substation applications will grow.

As the use of PLCs in substation automation applications increases, and the demand for substation and distribution automation increases, utility engineers are seeking ways to implement applications. With deregulation, utilities are decreasing engineering staff levels. Utility engineers are required to field more projects with fewer available resources. The services of outside control system integrators, engineering firms or consultants are often called upon to meet the needs of the utilities. Selection of an outside firm is an important task of the utility engineer and the selection of the particular outside firm can determine the success or failure of a project.

2) History of PLC use in substations

The Hydramatic Division of General Motors Corporation specified the design criteria for the first programmable controller in 1968. The first PLCs only offered control relay functionality and were programmed in RLL (Relay Ladder Logic). PLCs offered the automobile industry quick change for year to year model changes. In addition, PLCs were modular and easily understood by plant floor personnel.

The first programmable controllers were known as PCs; the acronym PLC for programmable logic controller, was actually a trade name used by Allen-Bradley. With the introduction of personal computers known as PCs the term PLC became the common term to avoid confusion.

By 1971 PLCs were coming into wide spread use in industries outside the automotive industry. Still providing control relay replacement only, they were found in industries such as food and beverage, pharmaceutical, metals, manufacturing and pulp and paper.

The introduction of microprocessors changed the PLC industry. PLCs have been reduced in size from the size of an apple crate to smaller than a loaf of bread. Some PLCs are smaller than a deck of cards. Processing power increased and PLCs are now capable of the most complex program algorithms. Originally PLCs were programmed only in RLL; they can now be programmed in several styles and types of programming languages such as SFC (sequential function chart), state language, control block languages and statement languages such as Basic. With the growth in technology, PLCs are now capable of advanced data manipulation, communications and process control.

PLCs were first used by the utility industry in generating stations. This is undoubtedly because of the similarity of generating station applications to industrial applications in which PLCs were already being applied. My first knowledge of an application of a PLC in an electric utility substations was when John Holt of Pacific Gas and Electric told me there were considering the application of a PLC in a substation in San Francisco. This was in 1987. Private industry has been applying PLCs in substations for many years. Exxon has applied

PLCs in refinery substations for load shedding and load restoration (called re-acceleration because of the connected motor loads) since the early 1980s. PLCs have been used in emergency power systems in commercial buildings and hospitals for many years for switching, load shedding and restoration and emergency generator control.

3) Applications for PLCs in substation automation and SCADA

There are many applications for PLCs in substation automation, distribution automation and SCADA systems. As utility engineers become more familiar with the capability of PLCs and PLC manufactures develop new substation specific products, the number and type of potential applications continues to increase.

- RTU (Remote Terminal Unit) emulation and replacement
  - Alarm reduction and intelligent messaging
  - Utilize existing SCADA protocols
  - Ethernet, TCP/IP
  - Multiple protocols, DNP 3.0, Modbus, Modbus Plus, AB DF1, ControlNet
  - Analog and Discrete I/O
  - Data Concentration from IEDs
  - Metering and station information management
  - Parameter monitoring, logging and trending
  - Integration of IEDs
- Protection and control
  - Circuit breaker lockout
  - Protective relay interface/interaction
  - Dynamic protective relay setting for dynamic station topology
- Automatic switching
  - Emergency Load Shedding
  - Re-routing services for station maintenance
  - Automatic transfer schemes
  - Load sectionalizing
  - Custom, automatic reclosing schemes
  - Automatic service restoration
  - Circuit breaker control and interlocking
  - Feeder automation and fault recovery
- Voltage regulation management
  - LTC (Load Tap Changer) Control
  - Voltage regulator control
  - Capacitor control
- Transformer management
  - Parameter monitoring and alarming
  - Real-time modeling
  - Interface to existing transformer monitors
- Automation System diagnostics
  - Power apparatus health monitoring
  - PLC and communications self monitoring
  - Report and Alarm on IED self diagnostics
- Maintenance and Safety
  - Kirk-key interlock management

    - Maintenance “Lock-out/Tag-out” management
    - Automatic circuit isolation control
- Station HMIs – Graphical User Interface (GUI)
    - Interactive real-time single line displays
    - Interactive real-time breaker and switch control display
    - On-line operations and maintenance logs
    - Sequence of events recording
    - IED detail displays
    - Parameter trending displays
    - Oscillography
- Remote Control
- Demand Control
- Synch check and generator synchronization.

4) Benefits of using PLCs in substation automation

Reliability, a large installed base, extensive support resources and low costs are some of the benefits of using PLCs as a basis for substation automation and SCADA systems.

PLCs are extremely reliable. They have been developed for application in harsh industrial environments. They are designed to operate correctly over wide temperature ranges and in very high electromagnetic noise and high vibration environments. They can operate in dusty or humid environments as well. The number of PLCs (in the millions) which have been applied in various environments has allowed the designers of PLCs to perfect the resistance to the negative effects of harsh environments.

The large installed base of PLCs offers the advantages of reduced costs, readily available and low cost spare parts and trained personnel to work on PLCs. The large installed base also allows the manufactures more opportunity to improve design and offer new products for more varied applications.

PLCs have extensive support throughout the US and most of the world. PLC manufactures have extensive of field offices, distributors and authorized control system integrators. Most technical schools and colleges offer courses in PLC application, programming and maintenance.

In many, if not all, applications PLCs offer lower cost solutions than traditional RTUs for SCADA systems. They offer lower cost solutions than traditional electromechanical control relay systems for automated substation applications. With the lower cost solutions PLC based systems offer in substation and distribution automation applications along with the other benefits, it is no surprise that there is so much interest in the application of PLCs in substation.

5) Selecting a Control System Integrator

When applying a PLC in a substation automation or SCADA project, a utility engineer has a number of options for implementing the project. One option for implementation is to do the project “in-house.” With the restricted manpower resources in the competitive deregulated utility environment, doing a project “in-house” is seldom feasible, especially if the project is large.

Therefore, selecting a control systems integrator, an engineering firm or a consultant becomes an important task in the application of a PLC based substation automation or SCADA project. There are many factors to consider in selection including technical expertise, business management practices, financial strength and project management methodologies.

It may not be clear just what the differences between a control system integrator, an engineering firm and a consultant are. There are many similarities between them and often they do perform the same work, but there are significant differences, primarily in the end product offered. Consultants and engineering firms offer an end product of engineering studies, specifications and plans. Control system integrators offer a final product, such as a delivered operational system. They often provide an operational system based on plans and specifications provided by and engineering firm or consultant or they just as frequently deliver a system based on their own design. Many control system integrators have shop facilities where panels and computer systems are fabricated and tested prior to delivery. Most often engineering firms and consultants do not ally themselves with a particular manufacturer of PLCs. In general, control system integrators have definite preferences for a particular manufacturer of PLC and in many cases have formed working definite partnerships and teaming relationships with specific PLC manufacturers and suppliers. In general, a control system integrator is oriented toward integration of systems, software solutions and to project management and delivery of systems. Control system integrators most often work under fixed price contracts or variations of fixed price contracts.

When evaluating the selection of a control systems integrator, an engineering firm or a consultant for a PLC based substation automation or SCADA project there are several criteria that should be used. To assure the success of the project the utility engineer should assure that the control system integrator has:

- A record of successful projects
- Financial stability
- Strong business practices including:
  - General management
  - Human resources and professional development
  - A proven project management methodology which encompasses:
    - Project management
    - Quality management
  - Financial management
  - Business development (sales)
- Adequate insurance including:
  - General business insurance
  - E&O Insurance
- Up-to-date technical knowledge including:
  - Current in applications of PLC systems
  - Current in trends in substation automation
  - Knowledgeable about utility and electric power applications

Some questions that can help the utility engineer evaluate the potential control system integrator include:

- Is the control system integrator or the engineering firm offering control system integration services a member of CSIA (Control System Integrators Association)? The CSIA, founded in 1993, is an affiliate of NEMA (National Electrical Manufactures Association. The objectives of the CSIA include developing standards for sound business practices and promoting professionalism in the control system integration industry.

- Does the potential control systems integrator hold any PLC manufacturer authorizations or certifications? These can be an indication of technical expertise in PLC applications.
- Is the control system integrator active in organizations such as IEEE (Institute of Electrical and Electronic Engineers), ISA (Instrument Society of America) or other professional organizations?
- Does the control system integrator participate in organizations such as the Western Electric Power Institute (WEPI) or the Northwest Public Power Association (NWPPA)?
- How many registered professional engineers does the control system integrator have on its staff?
- What do the references provided for past projects say about the performance of the control system integrator?

The control system integrator's proposal dollar amount should be one of the last criteria evaluated. Of course, the PLC based substation automation or SCADA project must be completed within the budget. But often, when the dollar amount is the only criteria or the primary criteria the project does not end in success for either the utility or the control system integrator.

6) A Case History

The Public Utility District No. 1 of Klickitat County (KPUD) headquartered in Goldendale, Washington provides electric, water, and sewer services to the nine thousand plus customers within the county, spread across approximately 1,500 square miles. KPUD's electrical power system includes fourteen substations. Eight of the fourteen substations are points of delivery (P.O.D.) – also called task 1 substations. Five of the remaining six distribute power to certain regions of the county and are called task 2 substations. One substation (Darland) is functionally equivalent to a task 2 substation but also has remote equipment operation capabilities and is called the task 3 substation. The substations contain equipment of various vintages ranging from 1940s to 1980s. KPUD also has a fifty percent share of a ten megawatt hydroelectric plant on the McNary Dam. In 1997, KPUD contracted with Chelan PUD (Wenatchee, WA) to manage their power acquisition.

KPUD realized that Chelan PUD would need to monitor KPUD loads and resources on a real time basis in order to make purchasing decisions. The existing KPUD system did not have the data collecting capabilities required to address this need, having only standard metering devices. To remove these deficiencies, KPUD undertook a capital project to implement SCADA (Supervisory Control And Data Acquisition) county-wide for their power system.

KPUD prepared a complete specification for the SCADA system based on the following goals:

- Real-time data collection (four second update)
- Fail-safe, robust, long term operation
- Established equipment manufacturer and support network
- Timely and cost-effective implementation

Using this specification, KPUD conducted a search and evaluation of SCADA systems equipment providers and control systems integrators. Many candidates were reviewed, with proposed systems ranging from traditional RTU's to custom hardware and software. After studying the proposals, KPUD chose Programmable Control Services, Inc.; (PCS) a control systems integrator based in Spokane, Washington.

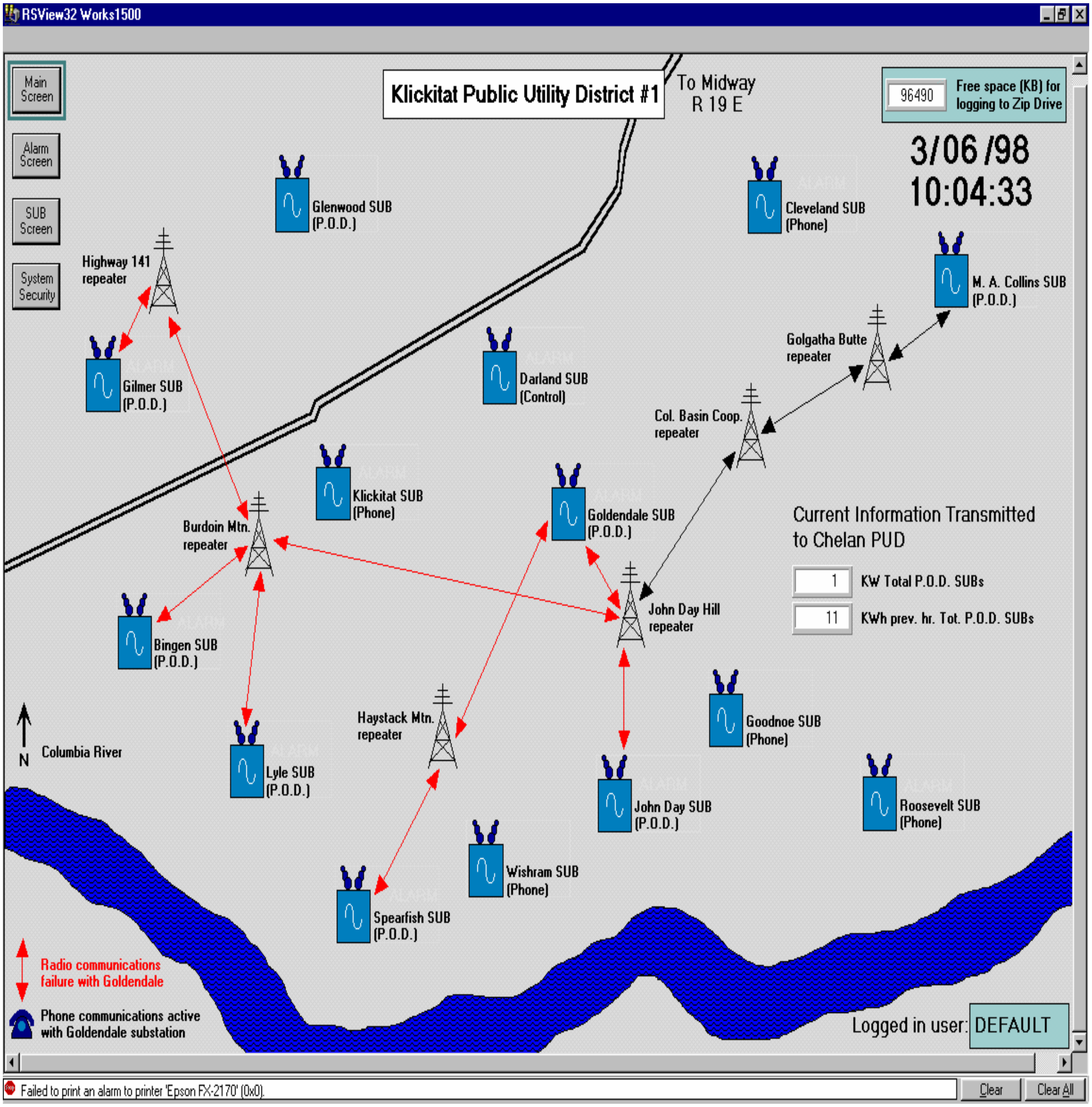
The SCADA system acquired by KPUD was commissioned in April 1998 and consists of a PLC at each substation, and a master station at KPUD's service center in Goldendale. The master station is a PLC with a data link to a Personal Computer (PC) running an operator interface terminal (OIT) application in the Windows NT operating system. The substations are linked to the master station by a main radio network and a backup telephone network. The main radio network consists of a radio at the master station, radios at point of delivery substation PLCs, and radio repeaters at various locations. The backup telephone network consists of a modem server at the master station, modems at each substation, and is facilitated by a software application running on the master PC. The master PLC gathers load data from all of the substations on a polled by exception basis via the main radio modem link (using store & forward packet burst technology) or by backup telephone modem link in the event of a radio communications failure.

Each substation PLC is tied to a power monitoring device through the PLC's remote I/O system. The load data from all point of delivery substations is logged by the OIT application to a file that Chelan PUD accesses at regular intervals. A module in the master PLC has been programmed to provide a modem interface that will transfer data directly from the master PLC to Chelan PUD at a four second update rate. Chelan PUD is planning to use this interface at a future date.

Current process data is displayed by the OIT application, and also logged to disk and/or printer. The process data includes items such as phase/line voltages and currents, KW, KVA, KVAR, power factor, and equipment status like recloser position. Data is displayed in both instantaneous and demand/peak forms. In addition, KPUD is utilizing logged data to generate substation load profiles and power factor profiles. The OIT application provides an interface for KPUD to operate equipment at substations as far away as seventy miles. This functionality includes operation of reclosers, and remote voltage reduction to avoid demand levels.

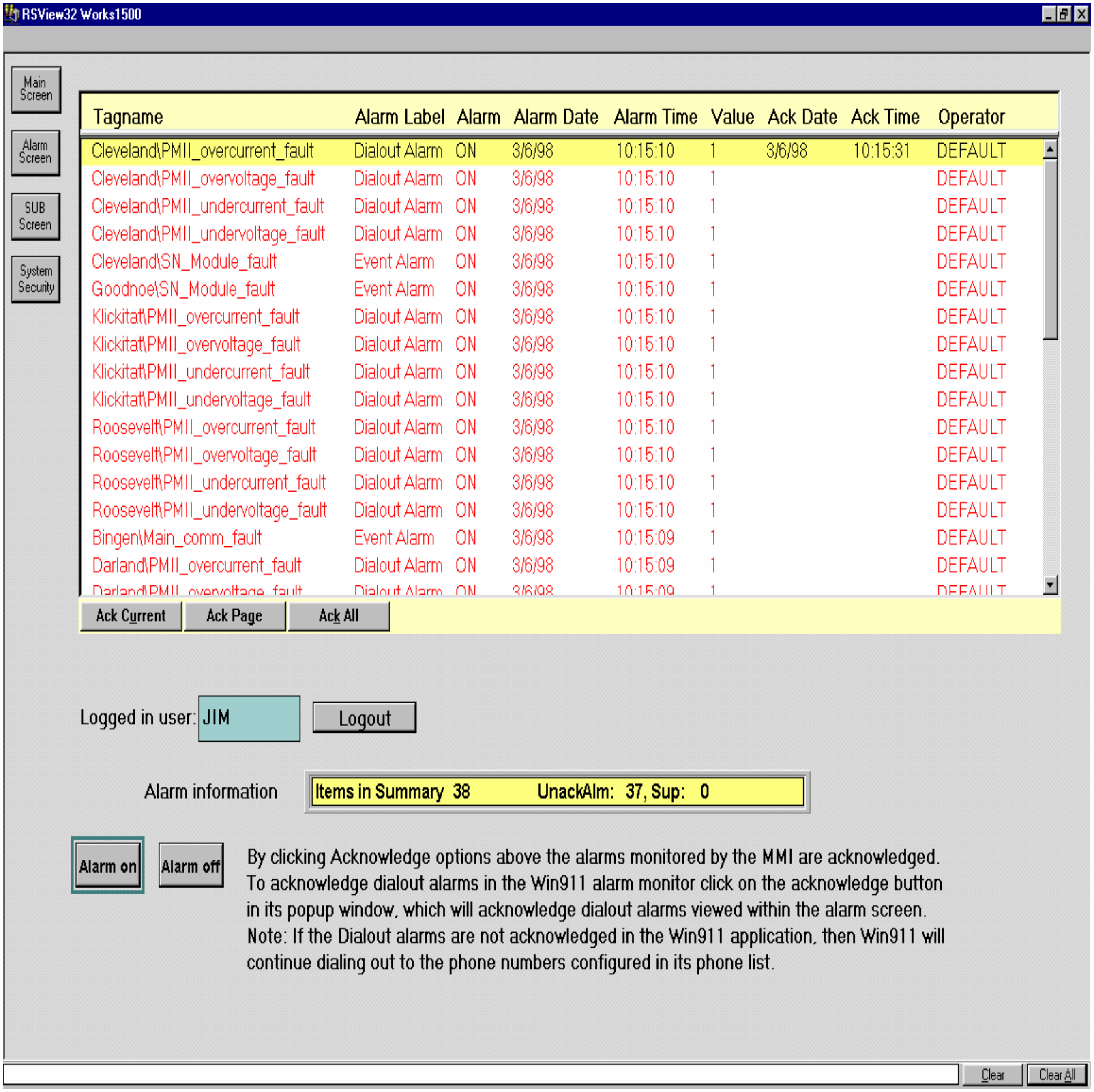
The system provides complete alarm information that is displayed on the OIT, voice enunciated through the OIT's sound card and/or an external P.A. system, and logged to disk and/or printer. Alarms include items like over/under voltage, over/under current, equipment condition (i.e. transformer over-temperature, regulator position). The system can page operations personnel in the event of an alarm. A touch-tone telephone interface is available for operator retrieval/acknowledgement of alarms, and remote operation of the system.

The OIT application is the main interface between the operator and the KPUD SCADA system. Through this application the operator is able to monitor the current status of the KPUD power system, make changes to operating parameters within the system, monitor and acknowledge system alarms, and remotely operate equipment within the system. The following pages show some of the typical operator interface screens.

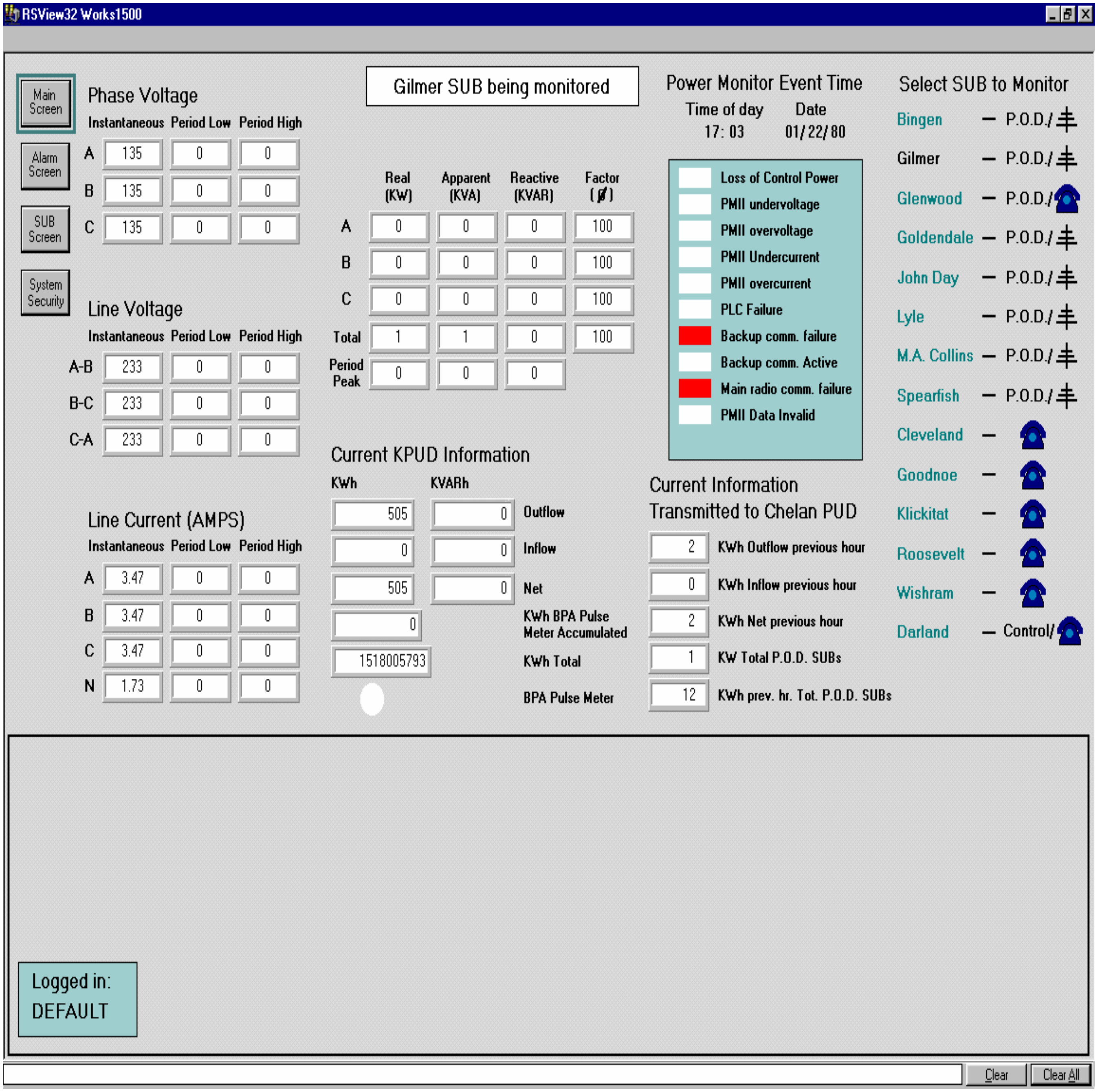


KPUD Main Status Screen

(Importing the screens into the document has distorted the aspect ratio.)

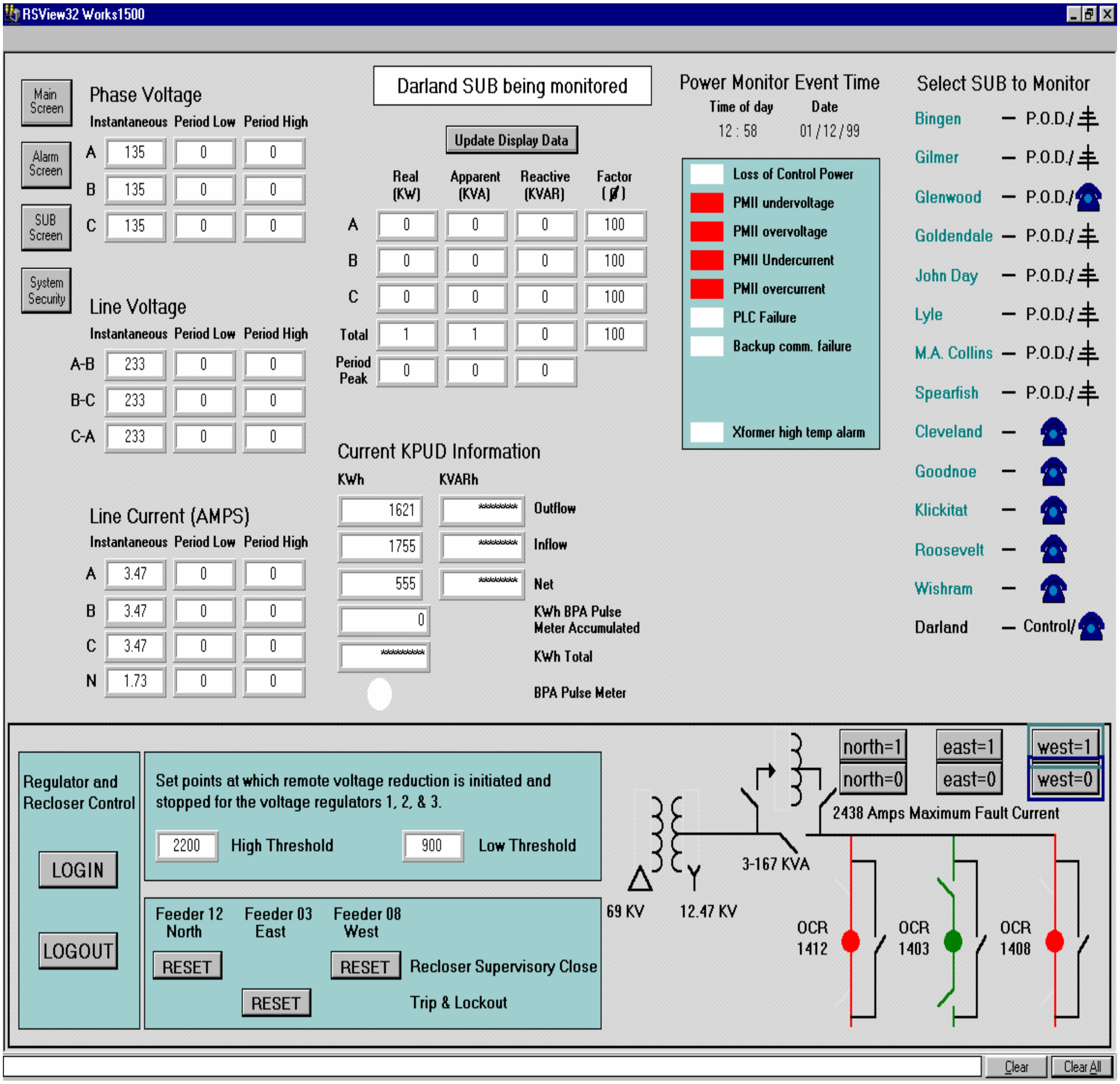


KPUD Alarm Summary Screen
(Importing the screens into the document has distorted the aspect ratio.)



A Typical KPUD Substation Screen

(Importing the screens into the document has distorted the aspect ratio.)



KPUD Task3 Substation (Darland)

(Importing the screens into the document has distorted the aspect ratio.)

Since system commissioning in April 1998, KPUD has learned many things about their system operation with the help of the SCADA system. For example, the SCADA system provided KVAR profile data at the Bingen substation indicating that the load was lagging during the week and leading on the weekends. Further investigation determined that an industrial customer with a highly inductive load did not have enough capacitor banks to compensate and was leaving the banks on line on the weekend when the inductive load was offline. KPUD used the data to calculate the size of the capacitor banks needed and is currently installing the banks to compensate for the weekday load. They are also working with the industrial customer to coordinate their capacitor banks for the weekend load. The new capacitor banks will be switched on and off automatically by the SCADA system based on the KVAR reading. With these changes to the Bingen substation, KPUD will avoid costly penalties levied by Bonneville Power Administration for poor a power factor.

The commercial environment for electric utilities today is very different from what it has been in the past and it continues to change. Such changes are requiring electric utilities to manage their power distribution systems with quicker response and greater efficiency. KPUD's PLC based SCADA and substation automation system is an excellent tool for efficient power system operation and management. The system provides quicker notification of substation alarms allowing for fast response and repair. Having mobilized the necessary resources to create a world class power distribution PLC based SCADA and substation automation system, KPUD is well positioned for efficient and cost effective operations in the face of industry change.

7) Fourteen Phase Project Management System

Programmable Control Services, Inc. (PCS) used a fourteen-phase system to ensure KPUD's PLC based SCADA and substation automation system project was fielded on time, in scope, and within budget. The individual project phases with highlights and the benefits to KPUD are:

- **Phase 1 – Automation Plan -** This phase embodied all the activities leading up to and including the handoff of KPUD's PLC based SCADA and substation automation project to the PCS project team. This phase established the tone for the project through the initial definition of the project.
- **Phase 2 – Project Kickoff Meeting -** Especially critical to the KPUD project was the kickoff meeting with the customer. The goals of this meeting included introduction of the team, establishment of goals, discussion of project scope and gathering design, safety and standards documentation required. Mail and documentation were also discussed. This meeting marked the formation of the KPUD/PCS project team.
- **Phase 3 – Field Survey -** The field survey was conducted after the project kickoff meeting. The team observed current operations, obtained input from maintenance and operations personnel and learned all it could about the operating environment of the project. This survey was particularly important as it gave PCS personnel understanding of the physical, safety and operational issues that were crucial in fielding a properly designed system.
- **Phase 4 – Scope Description -** Drawing on information gained to this point, PCS drafted a scope of work description for review by KPUD. The scope description highlighted deliverables, services to be performed, system input and output definitions, and project responsibilities of PCS, KPUD and third parties. KPUD's review and concurrence with this document was important as it established the understanding of the services that PCS would perform.

- **Phase 5 – Implementation Plan -** This plan described how each of the items in the scope were to be fielded to meet KPUD's requirements. It included the project timeline with milestones, identified the project team with points of contact, and detailed KPUD project acceptance criteria. KPUD reviewed the implementation plan when complete. This phase filled in details not included in phase four and provided a reality check to minimize surprises later in the project.
- **Phase 6 – Acceptance Test Plan and Procedures -** The acceptance test plan and procedures defined what tests would be conducted through development and fielding, how and when they would be done, and identified the expected results. The objective of this plan was to ensure the project was tested and that the factory and commission acceptance tests demonstrated the functionality KPUD required to accept the project.
- **Phase 7 – Technology Validation Test -** PCS validated communications, interface, programming capabilities and requirements of all hardware and software that were to be implemented in a new fashion on the KPUD project.
- **Phase 8 – System Development –Hardware -** The hardware development phase included hardware design, development of project drawings, panel fabrication services and preliminary testing.
- **Phase 9 – System Development – Software -** During software development, a functional description of the system or software functional specification was developed which described the software functionality of the PLC based SCADA and substation automation system. The software functional specification also included sketches of operator interface screens. This document, again submitted to KPUD for review, provided an advance view of how the system would work. Any misunderstandings were resolved at this point to avoid rework and fielding a system that functioned differently than expected. Once the software functional specification was reviewed, actual software development took place.
- **Phase 10 – System Integration -** This phase encompassed the PCS in-house activities to put the system together and make sure all the parts worked as expected. Communications, data handling, component coordination and hardware functions were critical items tested. Once these tasks were completed, the project was ready for KPUD to come to the PCS facilities to conduct the factory acceptance test.
- **Phase 11 – Factory Acceptance Test -** The factory acceptance test was a critical verification of system functionality before shipment. A punch list was developed and corrections were made before shipment. A thorough checkout of all I/O wiring and software functions prior to shipment simplified on-site startup.
- **Phase 12 – On-Site Services -** This phase included all services PCS provided from shipment of the system through training. These services included shipment, installation supervision, hardware and software checkout, system commissioning, and training.
- **Phase 13 – Commission Acceptance Test -** The commission acceptance test was conducted at the conclusion of on-site services. The test fully demonstrated specified system functionality, as defined and approved in the implementation plan, to the satisfaction of KPUD.
- **Phase 14 – Project Completion -** PCS provided complete documentation at the beginning of startup. PCS provided as-built system documentation as soon as possible after the commission acceptance test. Typical project documentation included complete PLC program listings with cross-references, operator interface user's manual with database listings and system drawings with the files provided on magnetic media. This phase also included internal PCS time for wrapping up the project, and preparing final project reports.

8) Conclusion

The use of PLCs (Programmable Logic Controllers) in substation and distribution automation applications has grown in recent years. The economics of PLC based solutions mean that substation automation and SCADA solutions can be applied even more widely. This will help the utilities respond to the challenges presented by deregulation.

As the use of PLCs in substations increases, the criteria for selection of control system integrators, engineering firms and consultants will become an extremely important factor in the success of PLC substation automation and SCADA projects. One of the most important criteria is that the control system integrator, the engineering firm or the consultant has sound business practices in place. They should also have a project management methodology in place to assure the success of these projects.