SCADA UPGRADE AND INTEGRATION WITH ENTERPRISE NETWORK INFRASTRUCTURE: A CASE STUDY

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ABSTRACT

The city of Fort Worth Rolling Hills water treatment plant underwent a series of upgrades and expansions from early 2001 to 2005. The work was divided into four phases and included new ozonation facilities, a new elevated storage tank for backwash water supply, upgrades to the 20 existing filters, and a new high-service pump station. It was recognized early in the planning process that a major upgrade of the existing supervisory control and data acquisition system (SCADA) would be required. Major upgrades to the plant and enterprise information technology (IT) infrastructure would also be needed. Traditionally, SCADA design considerations had been separate from IT design considerations. However, the convergence of similar hardware and standard practices in both areas offered an opportunity for better functionality and less duplication of effort. The Rolling Hills projects were the first for the city of Fort Worth to combine the engineering of both SCADA and IT infrastructure improvements into a single integrated design package that could be bid competitively.

During construction of the first phase, the 9/11 attacks forced consideration of a higher level of security monitoring than had been anticipated. Modifications to the SCADA and IT system design were required to address the need for more extensive real-time monitoring of facilities.

The paper will discuss approaches taken to achieve the successful integration of the SCADA and IT infrastructure. Items covered will include system architecture, communications technologies, failure modes, maintenance of plant operations, adjustments due to 9/11 attacks, conversion of a proprietary SCADA to an "open" system, division of responsibility for SCADA versus IT components, procurement

approaches, and startup. The innovative practices developed in this project are being followed on subsequent projects involving SCADA and IT improvements or expansion.

KEYWORDS

SCADA, IT infrastructure, Programmable Logic Controllers (PLC), Supervisory Control and Data Acquisition (SCADA)

INTRODUCTION

The Rolling Hills water treatment plant (RHWTP) was originally constructed as a conventional water treatment facility located in the southeast portion of the city of Fort Worth. Its capacity prior to summer of 2005 was 160 million gallons per day (mgd). A facilities upgrade and 40-mgd expansion project was conducted in four phases starting in 2001 with completion in the fall of 2005.

Phase 1 involved construction of a new ozone treatment facility. Phase 1 expanded the existing SCADA system with addition of PLCs and workstations to support the new facility. A fiber optic backbone was added to the west side of the plant to help accommodate future installation of security systems.

Phase 2 involved construction of a new elevated storage tank for backwash water storage. Phase 2 included addition of one PLC at the storage tank to control tank filling and backwash operations. The fiber optic backbone was extended to the east side of the plant. Separately, the city began design and construction of a network room at RHWTP.

Phase 3 involved rehabilitation and upgrade of the plant filter systems, improvements to water settling systems, and improvements to washwater recovery systems. The filter upgrades were divided over two separate seasons in order to keep the plant operational. Phase 3 included replacement of the proprietary remote telemetry units (RTUs) used for filter control. The RTUs were replaced with two hot-standby PLCs and remote I/O at the individual filters. The filter control consoles (FCC) were completely removed. An additional PLC was added for the washwater recovery basin operations. The RHWTP SCADA server was upgraded to a redundant server. The capability to route process information electronically to the water production reports server was added.

Phase 3 also included integration of the SCADA network infrastructure into the enterprise network infrastructure utilizing virtual local area networks (VLANs) and dedicated firewalls for separation of the two. The network room layout was modified to provide for the additional enterprise equipment being installed under Phase 3.

Phase 4 involved construction of a high-service pump station. Phase 4 also included addition of a separate PLC for high-service pump station control and extension of the fiber optic backbone from the east communications hub to the laboratory.

Table 1 summarizes the improvements completed over the four phases:

Construction Phase	Facility Improvement	SCADA or IT Improvement
1	New Ozone Treatment Facility	Additions to existing SCADA Construction of fiber optic backbone on west side of RHWTP
2	Elevated Storage Tank for Backwash Water	Additions to existing SCADA Construction of fiber optic backbone on east side of RHWTP
3	Filter, Settled Water, Washwater Recovery Improvements	Upgrade of SCADA Elimination of filter control consoles Integration of SCADA into Enterprise network
4	New High Service Pump Station	Additions to upgraded SCADA Extension of fiber optic backbone to laboratory

APPROACH

The SCADA upgrade approach included a study, preliminary design, final design, procurement, construction, and testing / commissioning effort. The 9/11 attacks occurred after the study effort but prior to preliminary design and forced reconsideration of the SCADA design.

An earlier study effort had identified the major needs and design approaches for the various water plants at Fort Worth. In terms of SCADA, the recommendations of the study pointed to migration to a more “open” systems architecture approach, but still kept the SCADA network infrastructure separate from the enterprise network architecture. Preliminary design of the RHWTP SCADA upgrade began near the end of the first phase (ozone treatment facility).

The preliminary design included three separate workshops dedicated to controls and SCADA “vision” topics in which all known design issues (site conditions, instrumentation, controls philosophy, human-machine interface (HMI) selection, and IT infrastructure) were discussed. Meeting minutes and technical memoranda documented the discussions and decisions, and were validated by city staff. The technical memoranda served as the guidelines for the design effort. Four innovative guidelines were included in the preliminary design:

Elimination of the FCCs. The electrical and instrumentation staff requested that the PLC controls be placed in easily accessible free standing panels rather than the traditional FCCs, which were awkward to service.

Coordinated design of SCADA and IT. The design of the IT infrastructure upgrade would be coordinated with the SCADA upgrade design. Enterprise and SCADA networks would be separated using VLAN techniques but would utilize common hardware. The practice of designing a separate SCADA network was discontinued.

Enhanced testing. Multiple testing milestones were included due to the seasonal sequencing required by the project. The witnessed factory test (WFT) of the SCADA system components would include participation by engineer, owner, and contractor. The goal was to minimize risk of software problems during the field commissioning effort, and to provide the owner the opportunity to validate and "fine tune" the control algorithms. It was recognized this testing effort required a larger commitment of engineer and city staff time than had been normal practice in previous projects.

Network equipment included in construction contract. Network equipment for the network infrastructure upgrade would be included in the construction project. In previous projects, network equipment was owner-furnished and installed when the space was available for occupancy. For the RHWTP improvements, network equipment and services supply were made part of the general contractor's scope using a minimum of three pre-qualified suppliers from which to solicit bids.

Incorporation of the enterprise network equipment under Phase 3 continued the steps taken in earlier phases to address concerns generated by the 9/11 attacks. It was recognized that some form of security system having video surveillance would be needed and was under study in a separate project. In order to be prepared for it, a western communications hub was added during the Phase 1 construction by change order. The hub would provide fiber optic infrastructure for present and future use. Trenching and construction of manholes were integrated into the Phase 1 effort successfully, taking advantage of the scheduled plant disruption. Phase 2 extended the communications hub concept to the east side of the plant. By Phase 3, RHWTP was ready for the new networking equipment and had a fully installed and tested fiber optic backbone to support it. The infrastructure and equipment improvements were intended to support the ultimate configuration of the video surveillance system, not just be limited to SCADA and enterprise uses.

DESIGN FEATURES

FCC touch screens.

The FCC PLC hardware was placed in free-standing panels installed on the walls opposite to where the FCCs had been. The manual control devices of multiple FCCs were replaced with a portable touch screen that could be moved from filter to filter and plugged into a connection to the filter control PLC.

SCADA hardware and software

Figure 1 shows the RHWTP SCADA architecture prior to the upgrades. Figure 2 shows the upgraded RHWTP SCADA system architecture at completion of Phase 4.

Pre-upgrade PLCs and RTUs. The original system featured proprietary RTUs for the filters and three International Electrotechnical Commission (IEC) Standard 1131-compliant PLCs for the chemical systems, chlorine / ammonia systems, and surface washwater pumping systems. The proprietary RTUs communicated to the host computer with an RS-485 serial link, and the IEC-compliant PLCs communicated over ethernet.

Post-upgrade PLCs. The upgraded system architecture is based on IEC-compliant PLCs and the existing SCADA HMI. PLCs were added to monitor or control the ozone facility, north filters, south filters, the elevated storage tank, washwater recovery basins, and the high-service pump station. Additional I/O was added to one of the existing PLCs for pump control. The existing PLCs were already IEC-compliant and were not modified. The filter PLCs and ozone system PLCs were specified to be redundant in hot standby configuration. All other PLCs were single processors.

SCADA network and workstation. The SCADA system was and continues to be distributed between the RHWTP and the Fort Worth Holly plant (Holly). Prior to the upgrade, the Rolling Hills SCADA segment system had a single Alpha server hosting the Rolling Hills PLCs and containing the Rolling Hills data base segment. The Rolling Hills server communicated to the Holly Alpha server over a dedicated ISDN line. Operator workstations at Rolling Hills were standard office personal computers that communicated to the Holly server over the enterprise network. Access to the Holly server was limited to those workstations with a special X-window communication package and appropriate password authentication. The communications path utilized the physical media of the enterprise network which included a dedicated T-1 link to Holly. The workstations did not log into the local server. The enterprise network and the SCADA network were kept physically separate, although the Holly server resided on both networks.

RHWTP SCADA server upgrades. A second Alpha server was paired with the existing Alpha server at RHWTP in a redundant configuration. The Rolling Hills server pair hosted RHWTP operator workstations as well as all PLCs. All SCADA devices were connected to the plant enterprise router in a “Star” configuration with local switches at the filters and ozone areas. The separate ISDN line to the Holly plants was eliminated, and all SCADA communications utilized the upgraded enterprise infrastructure with VLANs.

Enterprise network modifications

Figure 3 shows the major differences between the RHWTP network infrastructure before and after the improvements projects.

Prior to the upgrades, the plant enterprise network consisted of a single switch, workstations connected to the switch, and a T-1 link to the Holly plant. After the upgrades, identical routers had been installed at both Holly and RHWTP and handled all network traffic between them. A second T-1 link provided additional communications bandwidth to service the enterprise and SCADA VLANs. The city specified a router that provides multi-service capability for data, voice, and video, in conformance with the long term direction being taken for IT infrastructure development.

The network room layout was modified and it was outfitted with router, power backup, cable trays, additional patch panels, and furniture.

Remote communications hubs at the ends of a fiber optic backbone were established at the western and eastern areas of the plant in Phases 1 and 2, respectively. The backbone was extended to the laboratory during Phase 4. Switches with UPS power backup are installed in the hub areas and communicate to the network room over the fiber optic backbone. The remote hubs have made subsequent additions of IP addressable equipment very easy to integrate into the overall plant network architecture.

Network Components Specification

An important innovation of the RHWTP Phase 3 was to include procurement and installation of all IT equipment in the construction contract. Previous projects had kept procurement of sophisticated IT equipment as an owner-furnished item. The approach taken during the RHWTP upgrades was to prequalify three equipment suppliers that had previously done business satisfactorily with the city. Once prequalified, city staff worked with each vendor separately to fashion a design and list of equipment and services that met the needs of the project. The list, description, and scope were incorporated as a specification section in the bid documents. The three prequalified suppliers each submitted bids to the general contractor, and the general contractor selected a supplier to include in his overall project bid.

All prequalified vendors were enthusiastic about submitting bids for supplying equipment and services. However, they had never participated in the role of direct subcontractor to a general construction contractor or the associated bid process. Misunderstandings of scope and bidding process led to a mistake in the bid for network equipment that had to be addressed with a change order to the contract. It was verified that all three suppliers made exactly the same mistake due to similar misunderstandings. It was therefore considered to be a legitimate bid error, and it was not felt that the successful bidder had obtained an unfair advantage.

Overall, installation and commissioning of the network equipment went well, and the process was considered to be a success. A subsequent project at the city’s Eagle Mountain water treatment plant addressed the cause of the vendor misunderstanding and no bid errors occurred.

Definition of Responsibility

In order to successfully integrate the enterprise equipment and SCADA equipment into the same network, clear definition of skills and responsibility were required. These focused on furnishing, installation, testing, operation, and maintenance of the network and SCADA components. For the general contractor, the plans and specifications held these definitions. For the city, skill sets and individuals that possessed them were identified early in the design process. Subsequent development of the overall design defined the areas of responsibility for equipment acceptance, commissioning, and operation. Consensus was generated during design, and all commitments were met harmoniously during construction. The clear definition of responsibility and follow-through on the part of the city staff was a major contributor to the success of the joint design, installation, and commissioning of the IT and SCADA upgrades.

Submittals and Testing Philosophy

Detailed submittals of schedules, execution plans, bills of material, layout drawings, and detailed design drawings were required from the various subcontractors supplying SCADA or IT components or services. The specifications also required several testing milestones and conclusive documentation that the milestones had been met. Testing protocols were described in the specification, and provisions were included for additional “free form” testing if deemed necessary by the city or engineer. The protocols were more in-depth than typical water treatment projects, and included use of a simulator for RHWTP processes. From the beginning, it was planned to have significantly more involvement in test witnessing on the part of city staff and the engineer than on previous similar projects.

CONSTRUCTION AND STARTUP

The submittal review process for the SCADA and IT components started quickly after notice to proceed. Three specialized coordination meetings dedicated strictly to the SCADA and IT upgrades helped resolve questions and conflicts and kept the these parts of the project on schedule. There were more than 30 separate submittals that were unique to process instrumentation, SCADA system, IT equipment, or SCADA testing. The detail and specialized nature of these submittals required a significant effort on the part of the reviewer. This included confirmation that specified equipment was being provided, and verification that the components of the SCADA and IT system were being properly coordinated by the suppliers.

After approval of the appropriate submittals, fabrication of the SCADA panels and programming began. Each of the phases included provisions for a witnessed factory test (WFT) once the panels and programming were ready. The most extensive factory testing was performed on the filter and washwater recovery PLCs in Phase III. This level of intense testing was necessary because the filters were completely refitted with new media, flow control equipment, and air scour, and because there would be a very narrow window between completion of construction and startup. The settling basins and washwater tank controls were also upgraded, and there was a need to test interactions between all settled water, filter, backwash, and washwater systems prior to actual commissioning.

The Phase 3 SCADA WFT included representatives from the system integrator, engineer, owner, and construction manager. The settled water operation, filter operation, polymer injection operation, chemical backwash operation, and washwater operation were extensively tested using a simulator. During the testing process several flaws were discovered and fixed immediately. Viewing the operation with a simulator also revealed that some minor changes in control strategy were needed. These changes were documented by the system integrator, reviewed by testing team, implemented, re-tested, and approved. Once the specified testing milestone was completed, known failure modes (loss of flow signal, loss of level, etc.) were tested in a free-form format. Programs were modified if necessary to bring equipment to a “safe” condition after the reaction to these failure modes was observed. The extensive testing generated confidence in the product by the city witnesses who would later be responsible for their operation through SCADA.

The SCADA testing effort conducted in the factory was attended by experienced operations, technician, and engineering personnel. Once the system was shipped to the field, the testing was repeated with less senior personnel as witnesses. This field testing not only validated the correct operation of the system, it provided an opportunity for personnel involved in the checkout to obtain some preliminary training and familiarization with the new system.

Similar planning and testing was conducted on the main router, except that it was done onsite prior to total system integration.

The results of the design, submittal, and testing efforts were a very smooth startup and transition to the new fully integrated SCADA and IT system. There was no unscheduled downtime that occurred as a result of startup activities.

CONCLUSIONS / LESSONS LEARNED

Several lessons were learned from the RHWTP SCADA and IT improvements design, construction, and startup efforts:

Filter consoles are not needed. There was full acceptance on the part of the plant operations staff of the roll-around touch screens. Placing all filter controls in free-standing panels facilitates easy maintenance.

Extra testing was valuable. The testing effort was an added cost to owner above what is typically provided in water plant upgrade projects. However, inclusion of IT and operations staff during the testing provided some training, eliminated the need for later program changes, and helped to expedite project completion.

Define responsibility early. The SCADA / IT / operations areas of responsibility were defined during design and commitments obtained. Because of the early discussion and resolution of differences, all groups worked well during the project and fulfilled all commitments. This was a key contributor to the success of the upgrades.

Network equipment suppliers need some coaching in general construction contracts. The specialized suppliers of IT equipment were willing and able to compete with bids. However, they were not accustomed to providing bids to a general contractor and made legitimate errors. Network equipment suppliers require some coaching to make sure they understand both their part of the job and how they fit into the bigger picture when bidding directly to a general contractor.

Communications link modifications have subtle requirements that can affect a project's critical path. When existing communications links are being modified in a project, the sequencing may conflict with other tasks that are critical path to meet overall project schedule. The communications tasks are often subtle, but should be carefully reviewed so that equipment and labor is available to meet narrow installation windows not obvious in an overall project schedule.

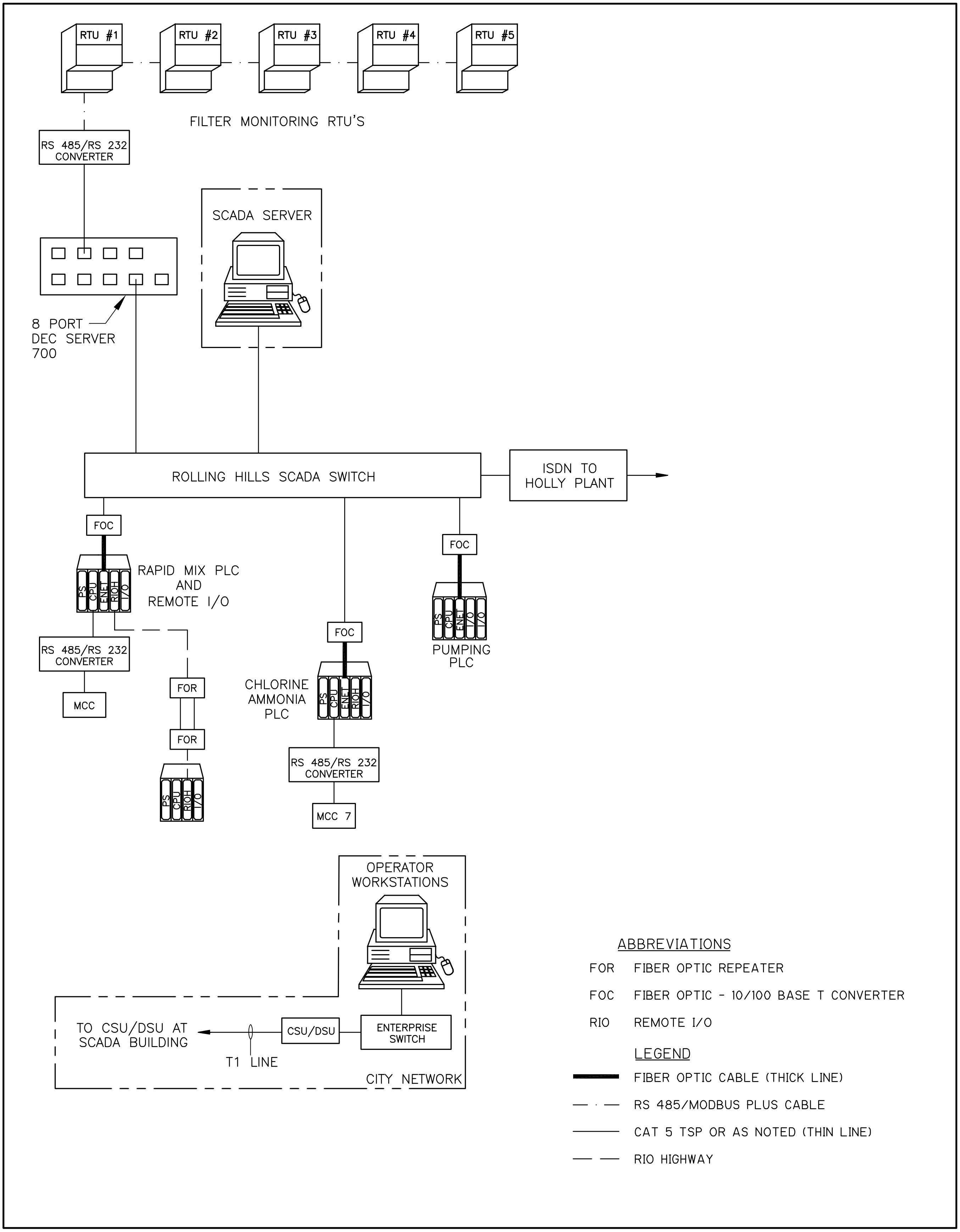


FIGURE 1
ROLLING HILLS SCADA
PRIOR TO UPGRADES

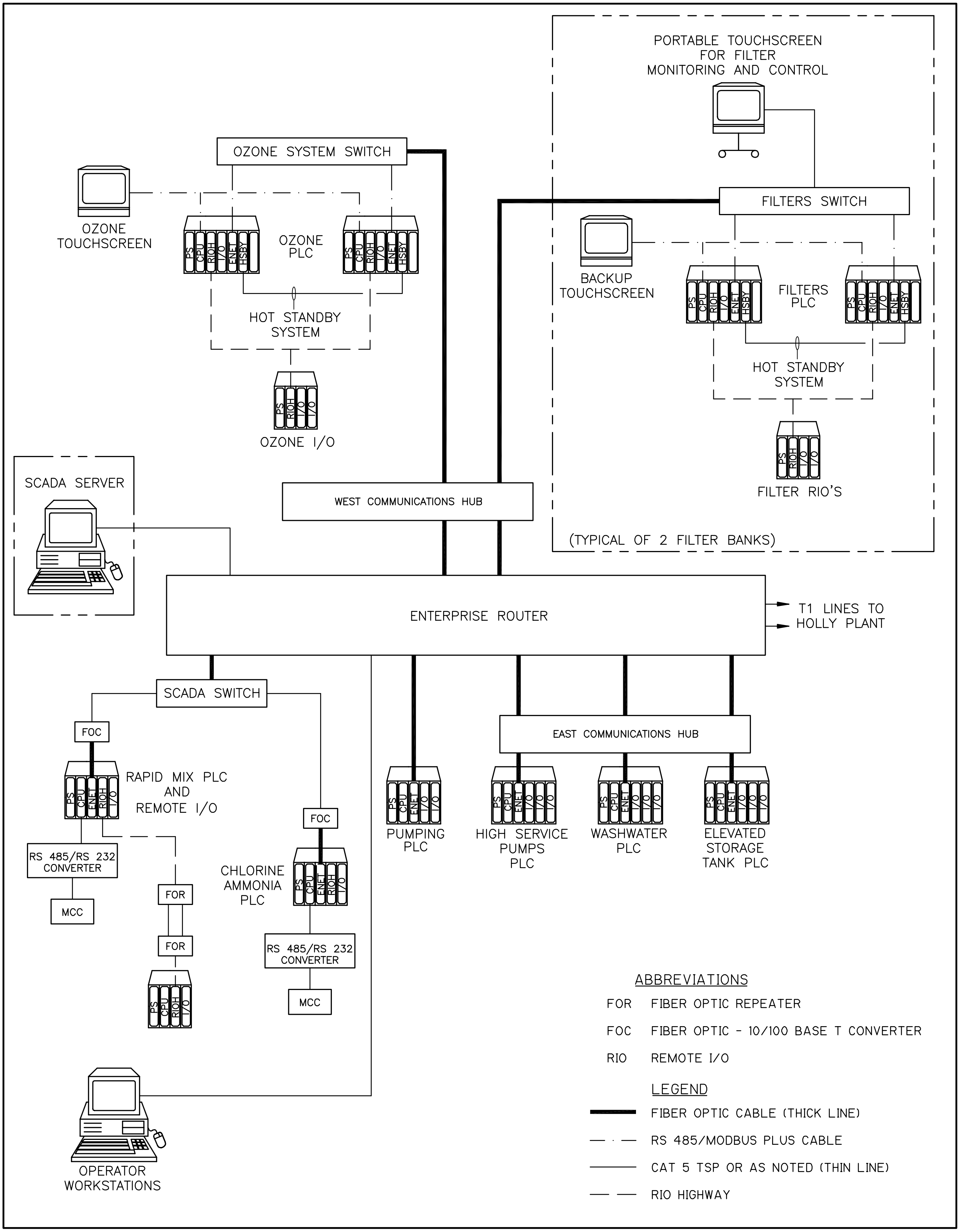
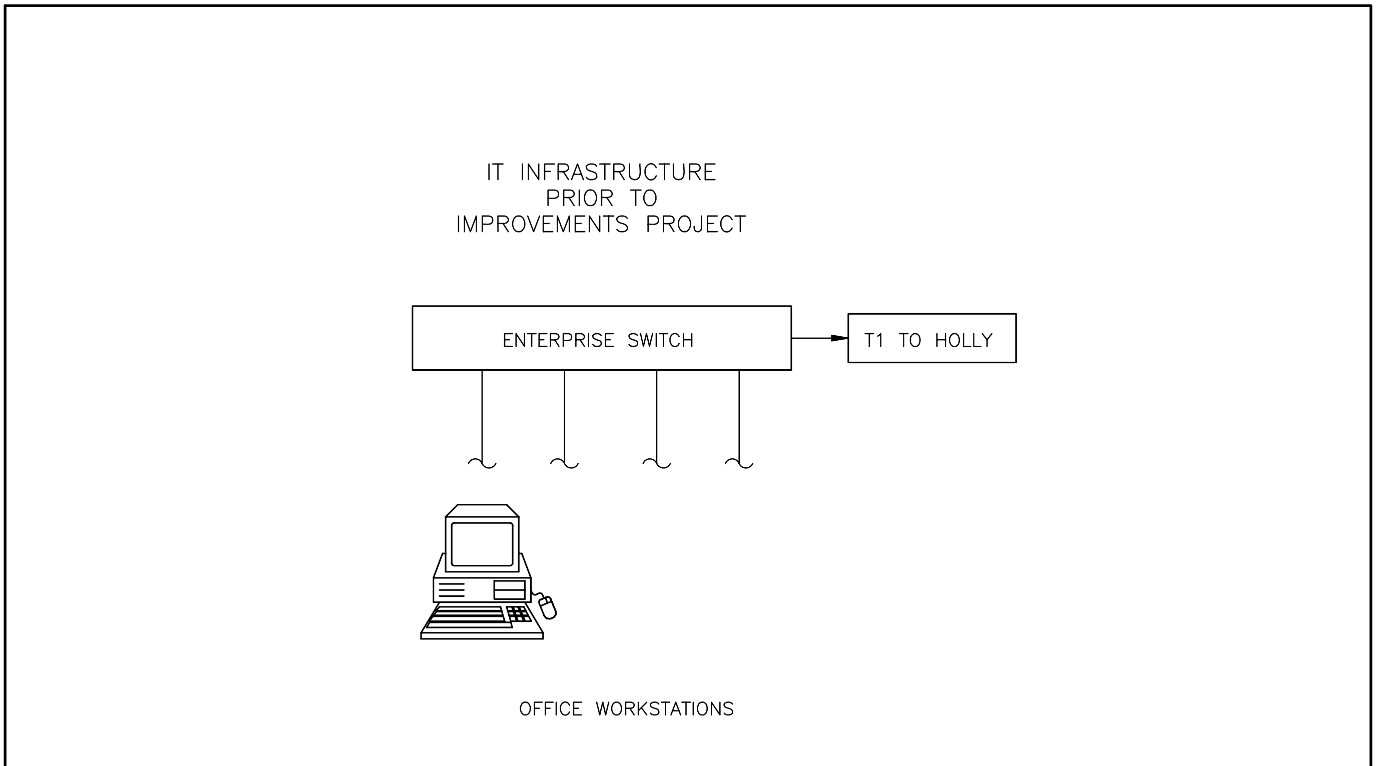


FIGURE 2
ROLLING HILLS SCADA
AFTER UPGRADES



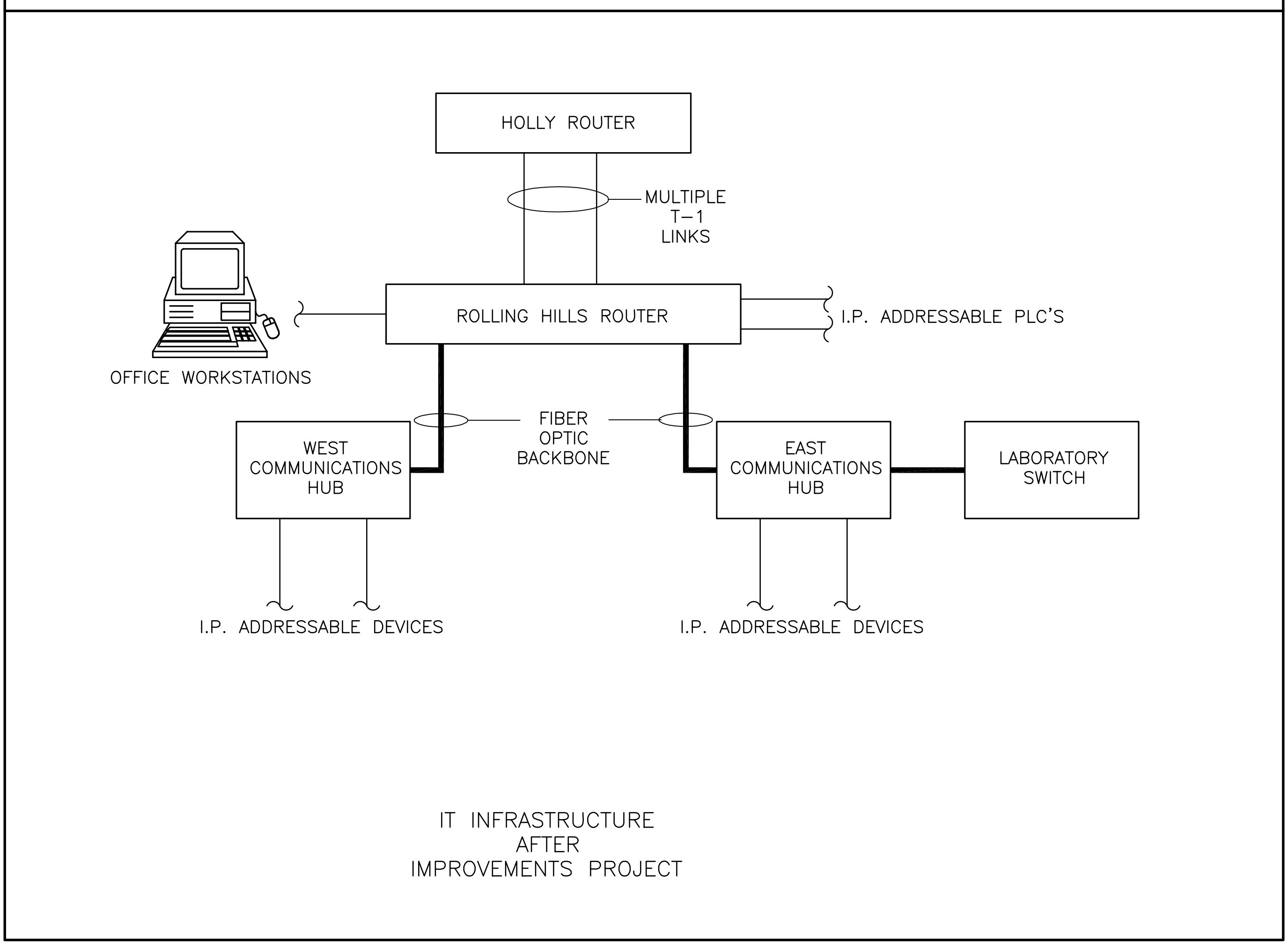


FIGURE 3
IT INFRASTUCTURE
IMPROVEMENTS