DISTRIBUTION AUTOMATIONAT THE DFW INTERNATIONAL AIRPORT

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SUMMARY

The TU Electric facilities serving the DFW Airport were installed in the early 1970's. In 1982, premature failures of the primary cable began to occur. By 1989, the increasing cable failures at the airport had caused concern regarding the remaining life of the cable. A task force was formed in November of 1989 to study the situation and develop conceptual plans for cable replacement and other enhancement work at the DFW Airport. The purpose of this paper is to discuss the redesign decisions made to improve airport reliability and operating capabilities, with special emphasis on developing a distribution supervisory control/automation system.

I. EVOLUTION OF DFW AIRPORT ELECTRICAL SYSTEM

A. INITIAL INSTALLATION

The original design for the DFW electrical system was a total underground distribution system with the only above grade structures on airport property being the substations and various types of pad-mounted equipment. The initial system consisted of eleven radial 25 kV feeders (from two 138 to 25 kV substations), approximately 57.5 circuit-miles, installed in a duct/manhole system consisting of approximately 350 manholes and 29 miles of duct bank. (See Fig. 1) The circuits were arranged in a dual-radial configuration with two feeders and load transfer switch gear available at most locations. (See Fig. 2) A separable connector system was used down the manholes to allow feeder sectionalizing.

B. OPERATIONAL PROBLEMS

Most of the early operational problems at the airport involved the separable connector system. Recently, however, primary cable failures have become a major concern. With them have come an even greater need to quickly find and sectionalize around the problems.

1. Fault Location Difficulties - To find a fault on an underground feeder that might be several miles in length, the faulted circuit was first analyzed using the fault indicators located in the manholes to determine the general location of the fault. (To date the use of fault indicators has not proved very reliable.) Then fault location equipment would be employed to determine the more precise location. Still many of these faults had to be located by means of a time consuming manhole by manhole inspection while listening and looking for the physical evidence of the fault. Some faults even required that the feeder be re-energized repeatedly until evidence of the fault could be found. Thus a repair might take from a few hours to several days.

2. Sectionalizing Difficulties - Following a fault on a feeder circuit, most customers would be either automatically transferred (using 480 volt switch gear in the terminal vaults) or manually transferred to their alternate source (using S&C 25 kV pad-mount switch gear). Only the radially fed loads would be without power for more than a hour. Power could even be restored to these by manually transferring separable connectors from the preferred to the alternate feeder down in the manholes. Of course this required testing the manhole for dangerous gases and pumping the water out before checking for the fault or making the desired changes.

3. Cable Failures - Primary cable failures first became evident in 1982 and at first the problem did not appear to be serious. But the seven cable failures in 1989 indicated the presence of a more serious

problem. Testing demonstrated the presence of a phenomenon called "treeing" in many of the primary cables. Treeing reduces insulation values and ultimately allows the insulation to fail. Thus it was evident that the end of the XLPE cable's life was fast approaching, and it needed to be replaced.

II. CABLE REPLACEMENT

PILC type cable was selected as the replacement cable because of its proven history of high reliability, long life, and effectiveness in countering naturally wet and corrosive environments like those that exist at the DFW Airport. However, the selection of PILC cable brought with it some major challenges that needed to be overcome. The DFW Airport's existing dual radial system had been designed for XLPE type cable that used separable type connections which allowed sectionalizing in the manholes instead of requiring a major initial investment in pad-mounted or vault type switch gear. The XPLE cable also permitted the use of fault indicators down in the manholes.

The connectors or splices used in manhole applications for a PILC cable system, however, are not separable or easily disconnected. In addition, the fault indicators in the manholes that were a mainstay of fault location for the XLPE system would not work accurately when installed over lead sheathed PILC cable. The fault indicators could only be applied at PILC cable termination points such as switch gear locations. For these reasons, the dual radial design was considered unsuitable for PILC cable at the airport and a major redesign of the DFW Airport primary cable system would be required.

III. SYSTEM RECONFIGURATION (Conversion to Loop Feed)

The desire to use as much of the existing facilities as possible, to keep disruptions to a minimum, to maintain reliability during the reconfiguration, and to keep costs down clearly pointed to a loop feed system as the best redesign choice. This would basically convert a dual radial pair of feeders into a two feeder loop, with one feeder back-standing the other. (See Fig. 3) This required that all tapped laterals be incorporated into the loop or fused off the main feeders, and that, ultimately, loop feed switching capability be added at all switch gear locations. (See Fig. 4)

In the event of a fault on the new loop feed configuration, the customers with automatic transfer service would still automatically transfer to their alternate source. The manual transfer customers, however, must now wait until the fault could be located using fault indicators installed at the switch gear sites. To take advantage of the loop feed system's increased sectionalizing flexibility, the fault indicator information must be readily retrievable by operating personnel, even from the many locations that were not readily accessible such as the terminal area vaults. With this information available, power to all the other affected customers could be restored with no more than three switch operations. This would take much less time than all the manual switch gear operations and cable transfers required with the original dual radial system.

IV. NECESSITY FOR DISTRIBUTION AUTOMATION

To achieve significantly improved reliability and flexibility for the reconfigured loop feed system, the response and restoration times following any service outage had to be greatly enhanced. Significant improvement in this area demanded the ability to remotely monitor and control critical switching locations. In addition, a significant improvement in fault locating capability had to be an inherent part of any supervisory control system.

A. Communication Medium Options

Three basic options were considered for the communication medium for this system: radio, hard wire, and fiberoptic cable. Preliminary investigations indicated that the existing duct structure system would accommodate a communications cable without major modifications. Routes from the airport to the distribution operation center (DOC) were achievable utilizing existing telephone lines or installing a communications cable on existing overhead TU Electric facilities. In order to provide the highest degree of reliability, fiberoptic cable was selected as the preferred communication medium. Fiberoptic cable could greatly enhance the level of reliability possible with radio, particularly when considering difficulties associated with electromagnetic propagation at an airport the size of DFW, not to mention the tedious FCC licensing procedures. Safety considerations also favored fiberoptic cable because of close proximity to energized 25 kV cable and switch gear and the fact that fiberoptic cable is not conductive. Fiberoptic cable is immune to outside interference, small diameter, light weight, high bandwidth, low loss, very secure, and should last 40 years with minimal maintenance.

B. Concept - Supervisory Control/Distribution Automation System

The fiberoptic system will operate utilizing bi-directional polling along a fiberoptic cable loop. (See Fig. 5) The master computer will be located at the DOC. An RTU or remote terminal unit will be located at each switch gear and will directly measure AC voltage and current sensor inputs. A fiberoptic transceiver will also be located at each switch gear. The power requirements were of particular concern at the pad-mounted switch gear locations because there was no secondary voltage source available at many of these sites. The problem will be solved using S&C voltage sensors attached to the primary bus in the switch gear to serve as the power source for two battery chargers and three rechargeable batteries.

The initial system will include only 32 switch gear (of approximately 160 for the total project) located in several critical but non-terminal areas. (See Fig. 6 & 7) This preliminary system will be a SUN SPARC workstation based "stand alone" system that will not initially interface with any of TU Electric's existing computer or SCADA systems. The first phase of the project was intended to provide valuable hands on experience with a fiberoptic based supervisory control/automation system before extending control throughout the remainder of the airport.

C. Basic System Requirements

Being able to quickly determine the location of a fault and sectionalize around it were key factors in improving the service reliability to the airport and the main goal of any supervisory control/automation system. To accomplish this, current and voltage sensors were located at each sectionalizing switch along the feeder to monitor voltage and current and sense fault conditions. An RTU will accumulate and store data at each switch gear location for future downloading to the master computer. For a fault current condition, the master computer identifies each set of current sensors that have "seen" the fault. (See Fig.8) The master computer then determines the location of the fault and suggests the switching order to restore service to all possible customers. The dispatcher can then use the supervisory control to operate the appropriate switches. The system could also carry out the switching automatically with notification to the dispatcher concerning fault location and the resulting switching configuration.

V. PROJECT HARDWARE AND SOFTWARE

With the basic supervisory control/automation system conceptually determined, design efforts turned to specifying and bringing the various pieces together into a functioning system.

A. Fiber Optics Cable

A 4 fiber, tight buffer, water proof, multimode, fiberoptic cable was specified for the first phase of this project. The cable will have a 2 mm sub-unit size, outside diameter of 7 mm and capable of a bend radius of 4 inches or less. Due to economic considerations the fiber was installed directly in a spare duct. Multimode instead of singlemode fiber was chosen due to the relatively short spans between optical drivers and allowed the use of lower cost LED drivers. Approximately 57,000 feet of military tactical field cable will be installed initially. This cable was provided by Optical Cable Corporation.

In order to minimize splicing and facilitate ease in testing and replacement of a section of fiber should damage occur, the fiber was installed from switch gear to switch gear. In locations which required splicing, connectors were used to eliminate the need for fusion splices in manholes. This allows the greatest flexibility for isolating fiber related problems.

B. Fiberoptic Transceiver

The next step was to select a device to convert polling information from the master computer to pulses of light, convert the light pulses to serial ASCII data and pass this message via an EIA-232 port to the RTU and back to the master computer. The device needed to:

1. Provide a non-proprietary, open-system, networking solution for optical RTU interface.

2. Provide a high performance and high reliability data transport medium at a minimum 19.2 kbaud.

3. Require 10 watts of power or less to operate.

4. Interconnect all node transceivers via two counter-rotating fiberoptic loops (for reliability).

5. Provide an automatic reconfiguration capability to withstand single point failures involving transceivers or fiber links.

The dual ported H&L Instruments 542B Fiberoptic Transceiver was selected as ideally suited for this application. To utilize the full capability of this transceiver, two separate fibers are routed in a loop configuration beginning at one master station transceiver and ending at the second master station transceiver. The master station polls alternately clockwise and counterclockwise RTUs attached to transceivers in a multidrop configuration around the loop. The RTU's response is transmitted back to the master station on both the clockwise fiber and the counterclockwise fiber. By comparing the response arriving (or not arriving) from both directions logically the location of a fiber fault can easily be determined. Since bi-directionally, counter-rotating polling is utilized, a single point fiber fault still allows communication with all RTUs in the loop. Even the loss of a single transceiver will still allow communication with all other RTUs within the loop.

C. Remote Terminal Unit

Many RTUs suitable for distribution automation exist in the market place today; but, only a select few met all criteria for this project. In particular, to allow the system to be upgraded by anyone able to emulate the protocol the RTU had to use a non-proprietary communications architecture.

Because of the limited power available, the RTU had to be capable of accepting direct input from AC sensors without the need for a transducer interface, a device which takes AC sensor input and presents a scalable DC output for RTU processing. These interface transducers required too much power for this application. In order to effectively detect fault conditions, the RTU needed to differentiate between such occurrences as cold load pick-up and motor start inrush current and actual fault current. Additional requirements for the RTU were:

1. Ability to accumulate, store, and convert data to engineering units prior to master station downloading.

2. Measure and calculate RMS phase current, RMS voltage, power factor, direction of current flow, battery voltage.

3. 12 status inputs.

4. At least eight discrete sealed relay outputs to control pad-mounted switches.

5. Local and remote indication of fault status.

6. Communications speed of at least 9600 baud

7. Capable of operation in non-controlled climates.

The Westronic, Inc. DART was selected. This RTU can provide remote fault detection and indication or, in situations where the supervisory communication link is inoperative or doesn't exist, local detection and indication. In addition, the Westronic developed Distributed Network Protocol 3.0 was selected for this phase of the project.

D. Pad-mounted 25 kV Switch gear

The conversion to loop feed caused the total number of pad-mount switch gear sites at the airport to increase from eighty-six to one hundred and twenty-eight. In addition, thirty-two new loop feed switches are to be installed in the vault areas. Only thirty-one pad-mounted switches and one vault switch of the 160 total were included in this initial phase of the automation project.

Almost all of the existing 25 kV pad-mounted switch gear at the airport were S&C PMH manual style switch gear. This switch gear provided both switching and fusing outside of the terminal vault areas. (S&C wall mounted fuse cubicals were used in the vault areas.) This S&C PMH switch gear had performed well in the past and still fit very well with the proposed new loop feed design with the exception that each of the switch gear locations would now need to be motor operated to accommodate the supervisory control/distribution automation scheme. Space was generally available for these modifications outside of the terminal areas.

To accommodate supervisory control, S&C Type PM motor operators could have been field retrofitted onto existing manual S&C PMH switch gear. But because much of the existing PMH switch gear was now about twenty years old, the decision was made to replace the existing switch gear with new PMH switch gear factory equipped, wired, and tested with the Type PM operator, H&L Fiberoptic Transceiver, and Westronic DART. The existing PMH switch gear will be removed and, if possible, refurbished and reinstalled at other locations on the TU Electric system.

The PM operator PMH switch gear are equipped with a voltage sensor on each phase. One of these sensors will provide power for the battery charger and batteries that supply the power for the motor operators. One of the other sensors will supply power to a second charger and battery that will provide the additional power necessary to operate the RTU and fiberoptic transceiver which are mounted in a compartment on the outside of the switch gear.

E. Master Station

For this project, the decision was made to specify an operating system based on non-proprietary hardware and software. In short the system goal was flexible, user friendly software running on open systems using layered, non-proprietary communications. All software was to be written entirely in C, run under UNIX, and designed to allow migration to other hardware platforms.

The master station configuration selected will be provided by The Flood Group. It is based on the Sun SPARC workstation running the SunOS version of the UNIX operating system. The workstation continuously polls the RTUs directly over the fiberoptic network and maintains a database of current and historical values for all monitored points. The operator may access functions using a keyboard or "trackball" which provide the man-machine user interface. On-screen displays graphically represent the airport electrical grid with the same symbology that was used prior to the implementation of this automation system. The systems displays were built using a sophisticated, object-oriented graphics package designed for real-time control systems SL Systems Graphical Modeling System. This graphics package allows the operator to pan and zoom at will. By pointing at specific switch gear or vaults, then "clicking" the trackball, the display will zoom into the selected devices, displaying greater detail and allowing retrieval of database information pertinent to that device, while at the same time polling all RTUs for fault and exception conditions. Complete RTU polling of this phase of the project takes 5 or 6 seconds.

Operator displays are presented under X-Windows on a high resolution 19" color monitor. Each airport display is presented as it's own independent window, which the operator can open, close, move, resize or hide at will. The system permits several windows to be open simultaneously which allows the operator to concentrate on a specific task by keeping pertinent information in view. When the operator selects a monitored switch gear from the "overview" display of the entire airport the "detail view" immediately appears, showing detailed information on the selected switch gear. This display also presents the position of each discrete input and allows control of discrete outputs via graphical controls. As the operator makes changes in this window, either to alarm limits or switch position, the option to execute or cancel these actions is maintained. When switch operations are executed, or alarm limits exceeded these events are logged, time and date stamped, stored internally and routed to a line printer. The detail view also allows the operator to program a synchronous switching order for future execution, rather then executing the actions immediately. This switching order is stored along with notepad information for manual operations such as switch tagging and the installation of grounds. The operator can review these actions and modify them at will. The computer will store a sequence of emergency switch operations and generate a reverse order sequence to aid in switching back to normal conditions.

The master station employs a complete hot standby system as backup. It has been designed as a completely redundant system utilizing dual operating systems, dual uninterruptable power supplies (on separate feeder circuits), redundant Codex v.32 modems (which provide dial up capability) and redundant 9600 baud leased phone lines from the DOC to the airport's Southwest Substation where each end of the fiberoptic loop terminates. (See Fig. 9) In addition, as an aid to provide expedient resolution of system related problems a Telebit T2500 high speed modem will be installed. This modem allows The Flood Group, the software provider, to remotely diagnose system problems and make the required modifications or upgrades.

VI. CONCLUSION

As might be expected, a project of this magnitude and technical diversity has cut across many lines of responsibility and authority both within TU Electric and outside, and involved the cooperation and efforts of many both directly and indirectly connected with the project. The initial system should be complete by March 1993. The complete supervisory control/automation system should be in operation throughout the DFW Airport by early 1995.