Distribution Automation and Video Surveillance Systems Improve Electric Cooperative Service and Security

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Abstract—**Taylor Electric Cooperative, Inc. (TEC) has taken an aggressive approach to improve the reliability of power delivery to their customers. TEC has undertaken a project to install a robust fiber-optic-based synchronous optical network (SONET) communications system. The system provides reliable communications between the control center and key substations for a new distribution automation system that improves service reliability. The communications system is also used to support a substation video surveillance system, allowing operators to continuously monitor substation activity, improving security.**

The distribution automation system provides automatic service restoration to customers in the event of a delivery interruption and gives control room operators visibility of distribution system operating parameters. Distribution feeder reclosers controlled by the distribution automation system provide isolation of faulted line segments and the ability to restore power delivery to customers.

The substation video surveillance system uses multiple Ethernet-capable video cameras with pan, tilt, and zoom capabilities at each substation to provide control room operators with the ability to monitor substation activity at any hour, improving the security of the substation assets and safety for field personnel. A networked video recorder is also used to provide several months of storage of video and images captured by the cameras.

This paper discusses the design and implementation of the communications, distribution automation, and video surveillance systems.

I. Introduction

Taylor Electric Cooperative, Inc. (TEC) is based in Merkel, Texas, and is a distribution cooperative that serves approximately 2,250 square miles with approximately 4,577 miles of energized line. TEC is a member of the Golden Spread Electric Cooperative, Inc. (GSEC), a consumer-owned public utility with 16 members. TEC undertook a project to install a robust fiber-optic-based synchronous optical network (SONET) communications system, providing reliable communications between the control center and key substations. The SONET communications system also provides the foundation for a distribution automation (DA) control system to improve service reliability for TEC customers. The DA system provides automatic service restoration, when possible, to customers in the event of a delivery interruption and gives control room operators the ability to monitor distribution system operating parameters.

The communications system also supports a substation video surveillance system that allows TEC operators to continuously monitor substation activity. The substation video surveillance system uses multiple Ethernet Internet Protocol-capable (IP-capable) cameras with pan, tilt, and zoom capabilities at each substation to provide control room operators with the ability to monitor substation activity at any hour, improving the security of the substation assets and safety for field personnel.

This paper discusses the design and implementation of the SONET communications, DA, and video surveillance systems for TEC.

II. Project Drivers

Because the main goal of TEC is to increase service reliability and minimize the impact of an outage to their customers, TEC previously considered DA systems for their electrical distribution network as a method to increase power delivery reliability. TEC already used a radio communications network to monitor substations and some distribution system assets; however, it was limited in bandwidth and capabilities and not suitable for the desired improvements. Through a GSEC smart grid grant from the U.S. Department of Energy, TEC was able to find a solution to achieve their goals. Using their existing microprocessor-based protective relays with a new communications system and DA system software would allow TEC to implement a cost-effective system that would improve electric service reliability to their customers. A new fiber-optic-based communications network was planned to provide a foundation for implementing a new DA control system as well as to provide other features and capabilities to help TEC achieve their goals.

A suitably configured fiber-optic network would provide a self-healing communications path from the TEC supervisory control and data acquisition (SCADA) system at their control room to the substations and to the reclosers and other devices on the distribution feeders in the TEC distribution system. The network would also provide the ability to install equipment to monitor substations to enhance safety for TEC personnel and provide security and loss prevention for key substation assets.

The new communications and DA systems would provide other benefits for operations at TEC. The systems would provide the ability to conveniently and quickly retrieve Sequential Events Recorder (SER) data and oscillographic waveform files from the protective relays installed on the feeders and in the TEC substations. By transferring some of

the existing SCADA-to-device communications from the radio network to the new fiber-optic network, bandwidth would become available on the radio network, improving the communications performance of other devices not transferred to the fiber-optic network. The DA system software would also allow for future expansion to other feeders and substations, further improving service and reliability for TEC customers.

III. SONET COMMUNICATIONS

Providing a reliable communications network for the DA and surveillance systems was a critical project requirement. The communications network had to incorporate flexibility, remote access, ease of operation, remote upgrades, alarm and event reporting, channel provisioning, and automatic fault restoration. A SONET-based communications network using a dedicated fiber-optic medium met all of these requirements. Additional advantages provided by the SONET network include the following:

- Automation of all operations, administration, maintenance, and provisioning required by the communications network.
- Reduced cost of operation.
- Elimination of manual operations.
- Protection for cable cuts and node failures.
- Faster, more reliable, and less expensive service.

Fiber-optic communications were selected over a copper medium or radio. Optical fiber provides immunity from ground potential rise as well as from electromagnetic and radio frequency interference.

The lowest data rate defined in the SONET standard is a DS1, or T1, signal. A DS1 signal can carry 24 voice channels. From there, as defined in the standard, optical carrier (OC) level capacity increases. Table I lists some of the standard OC rates.

TABLE I
SONET SYNCHRONOUS RATES

OC Level	Bit Rate (Mbps)	Number of Voice Channels	Number of DS1 Signals
OC-1	51.84	672	28
OC-3	155.52	2,016	84
OC-12	622.08	8,064	336
OC-48	2,488.32	32,256	1,344
OC-192	9,953.328	129,024	5,376

The SONET network used for this project operates at an OC-48 level over a pair of single-mode fiber-optic cables routed between five substations and the TEC control center. This routing forms a fiber-optic ring providing both primary and backup communications paths and uses a protection technique referred to as a unidirectional path-switched ring (UPSR). In a UPSR network, data are transmitted in both directions around the ring. When a communications failure is detected, the receiver switches to accept traffic from the backup direction. Fig. 1 shows normal UPSR data flows.
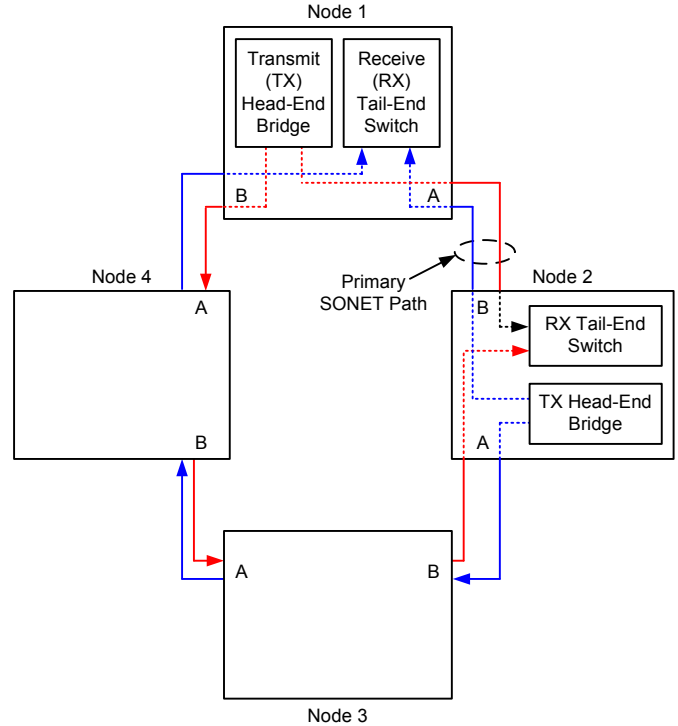

Fig. 1. Primary communications path. (Note the normal data flow between Node 1 and Node 2. Data flow in both directions around the ring.)

As shown in Fig. 1, data enter the SONET network at a head-end bridge and are sent as part of the SONET payload on both the left and right SONET paths around the ring. The receive tail-end switch detects the data from both paths and is provisioned with a primary and backup path priority. The switch routes the data to the receiver from the primary path and switches to the backup path in the event the primary path fails. When the receiver switches to the backup path, a message is sent to the remote receiver, forcing it to also switch to its backup path. Requiring both receivers to operate on the same path eliminates the concern for asymmetrical channel delay conditions.

Because switching is performed at the path (channel) level, only the affected channels are switched. The remaining channels on the network, which have their primary path located on another portion of the ring, are not affected by a fiber break or the channel switching operation. Fig. 2 shows the backup communications path when there is a fiber cable break.

The SONET standard allows 10 milliseconds to sense a failure and 50 milliseconds to switch and restore the channel. The SONET equipment chosen for this project provides a channel restoration time of less than 5 milliseconds. One potential problem with UPSR is that in the event of a single fiber break, it is possible for one node to be receiving data on the primary path and the remote node to be receiving data on the backup path. This condition results in different channel delay times between the nodes. This is not a desirable condition for protective relaying communications because they have time-critical requirements. This condition is

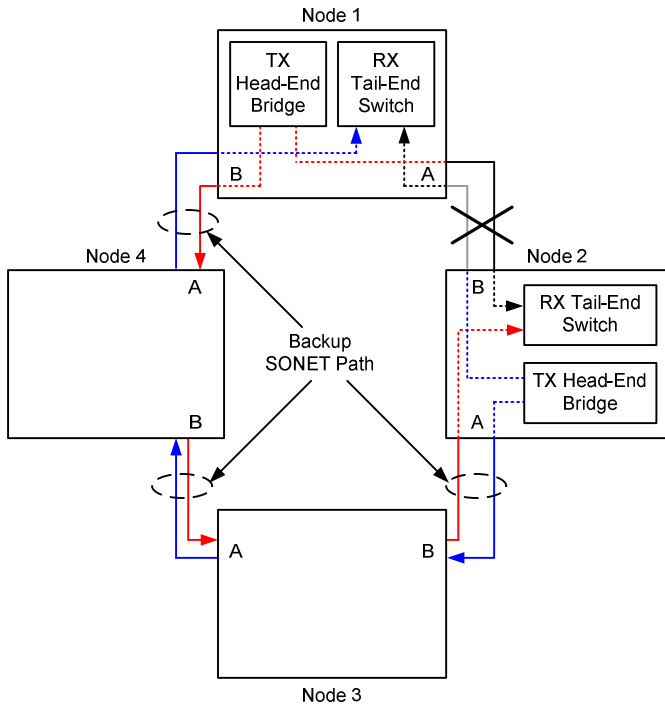corrected by forcing the remote node to switch to the backup path.

Fig. 2. Backup communications path. (Note the broken communications path between Node 1 and Node 2. Data flow in only one direction around the ring.)

A main requirement incorporated in the SONET standard was eliminating the need to interrupt traffic on the network. Reserving a large amount of the SONET bandwidth for a network management system (NMS) increases reliability, reduces maintenance, allows automatic restoration from fiber cuts, and provides remote software upgrades. NMS programs run in the SONET overhead, do not consume channel bandwidth, and provide complete network management access to any node in the network from any other node in the network. NMS programs allow operators to add channels to the network, generate accurately time-stamped alarm and event reports, and monitor the health of the network.

Hardware redundancies, such as dual power supplies and line modules with redundant optical components further increase the network reliability.

IV. PROJECT BACKGROUND

The TEC distribution network consists of 11 substations and 36 feeders; however, the area where the DA control system was implemented includes 5 substations and 12 feeders. Fig. 3 illustrates the connectivity between these five TEC substations.
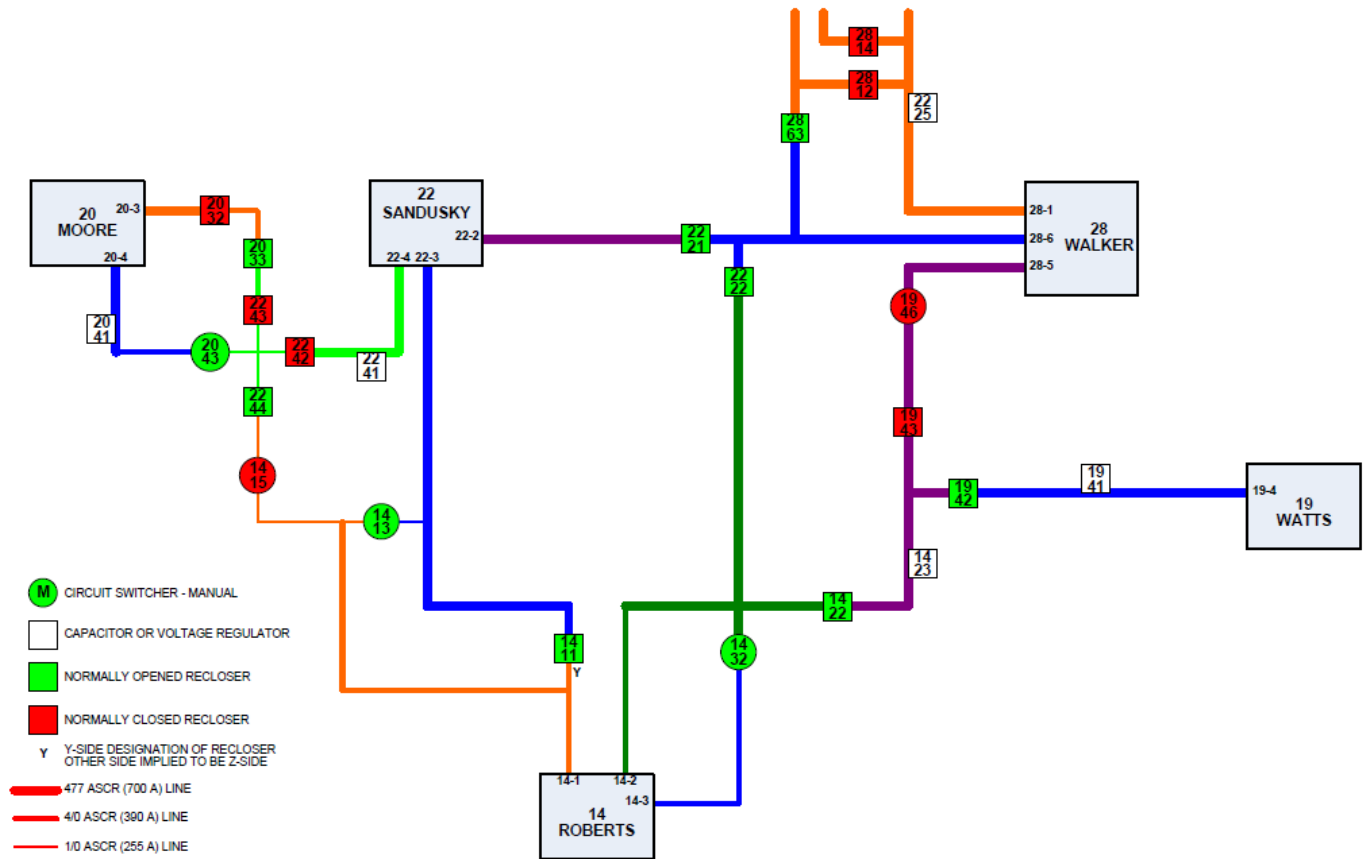

Fig. 3. TEC distribution network feeder interconnections used in DA control system.
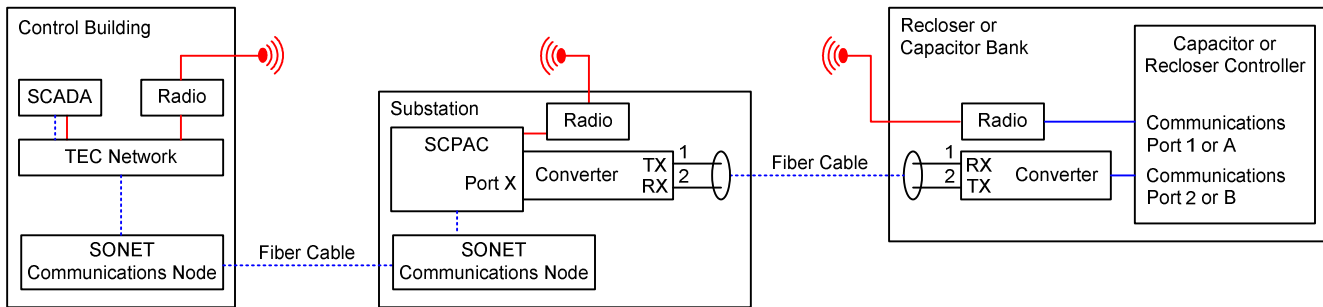
Fig. 4. Primary communications path using fiber-optic cabling (shown by the blue dashed lines) and backup communications path using radio communications network (shown by the red lines) from the TEC SCADA system to distribution system devices.

The Walker substation is under construction and scheduled for completion by June 2014. Presently, the distribution circuits that will be fed from Walker substation Feeders 1, 5, and 6 are being fed from Sandusky substation Feeder 2. In this configuration, the Walker feeders are connected, Circuit Switcher 1946 is open, and Recloser 2221 is closed. While the discussion and illustrations in this paper include the Walker substation, the present communications and DA control systems do not include Walker equipment. The fiber-optic network and DA control system will be modified in conjunction with the Walker substation commissioning.

V. PROJECT DETAILS

Prior to this project, a substation communications process automation controller (SCPAC) was installed at each substation. Using the existing radio communications network, the SCPACs collected and transmitted substation device data (such as breaker statuses, relay trip information, and bus voltages and breaker currents) to the TEC SCADA system and received commands (such as breaker trip or close) from the SCADA system. The SCPACs, with the radio communications network and the TEC SCADA system, allow TEC operators to monitor and control the distribution system assets. The SCPACs continue to provide information to the SCADA system and allow TEC operators to control the substation devices; however, the primary communications path is now via the SONET fiber-optic network. The older radio communications network is a backup communications link between the SCPACs and the SCADA system.

Similarly, field devices (such as reclosers and capacitors) on the distribution circuits outside of the substations also used the radio communications network. With the new fiber-optic communications network, field devices now provide data and control capability via the fiber-optic cables to the SCPACs in the substations and then via the SONET fiber-optic network to the SCADA system. The radio communications network was also retained as a backup communications link between the field devices and the SCPACs and SCADA system.

Fig. 4 illustrates the primary and backup communications paths.

The design of the routing and the connections for the fiber-optic cabling used for the SONET network and to the field devices was completed for the project partially based on the details shown in Fig. 5. The design used splice boxes at various points throughout the fiber-optic cable route to connect fibers from the main trunk cables to the reclosers, capacitors, and other devices located along the distribution circuits. Some devices, however, were not included in the fiber-optic cable routing and continue to communicate with the SCPACs and SCADA system via the radio communications network.

A communications node was used at each substation and at the TEC control center for the SONET fiber-optic network. Each communications node includes four Ethernet ports and provides a seamless Ethernet network from the control center to each substation. At each substation, the SCPAC and three IP video cameras (one to monitor inside the substation control building and two to monitor the switchyard at the substation) were connected to the communications node Ethernet ports. Each IP video camera supports pan, tilt, and zoom capabilities, giving SCADA system operators the ability to view the entire substation or control building and to zoom in on a particular object in the area. Additionally, a network video recorder was installed at the TEC control center to record the images from each of the substation cameras.

Fig. 6 illustrates the communications node, SCPAC, camera, and field device connections.

At each substation, the existing SCPAC application programs were modified to collect and transmit data from the field reclosers and capacitor banks to the TEC SCADA system. The programs were also modified to send control signals from the TEC SCADA system to the field reclosers and capacitor banks.

To implement the DA control system, the Sandusky substation SCPAC was selected to be the centralized DA controller. This SCPAC was upgraded to allow the added functionality, and a computer program library of object-oriented function blocks for the DA control system was installed on this SCPAC. The other SCPACs were modified to transmit data (such as substation breaker statuses and metering data as well as field recloser data) and receive commands (such as trip and close) transmitted from the Sandusky SCPAC DA controller. These data are transmitted using networked global variable lists (NGVLs) via the SONET fiber-optic network.

The DA control system was programmed using a previously developed library of DA function blocks based on object-oriented programming constructs. Fig. 7 illustrates how

the DA control system function block objects are connected. The theory and operation of DA control systems are extensively described in [1], [2], and [3] and will not be duplicated here.

The DA control system library includes function block objects that are required to implement the DA functionality, such as a scheme manager, communications channels, and object joins. The library also includes other function block objects that mimic real-world devices and equipment, such as switches, reclosers, substation feeder breakers, transformers, and transmission lines. These objects were placed in a project model, and connections were created between the objects to represent the real-world connection of the devices. Inputs to the objects were used to set the operating constraints (such as constants and operating modes), the commands from TEC operators, and the actual status values (such as voltages and currents measured by the system intelligent electronic devices) in the DA control system. Outputs from the objects were used to provide the status of the DA control system to the TEC SCADA system and the commands to the reclosers, breakers, and switches.

New human-machine interface (HMI) screens were created to display operational status details for the substation and field devices, to display DA control system information and operator controls, and to link to the IP video cameras at the substations. Samples of the HMI screens that were created are shown in Fig. 8 through Fig. 12.

A video system image similar to those available from the IP video cameras is shown in Fig. 13. Operators can pan and tilt the video cameras and zoom into a particular area in the substation control building or, with the exterior-mounted cameras, a particular area of the substation control yard. The network video recorder records these images for future analysis or review.

Prior to deployment, the DA control and substation video surveillance systems were fully tested using a combination of devices similar to those installed, actual devices that would be installed, or simulated devices. Validation testing helped ensure that complete and fully functional systems were put into service, and it helped minimize the system commissioning and startup period.
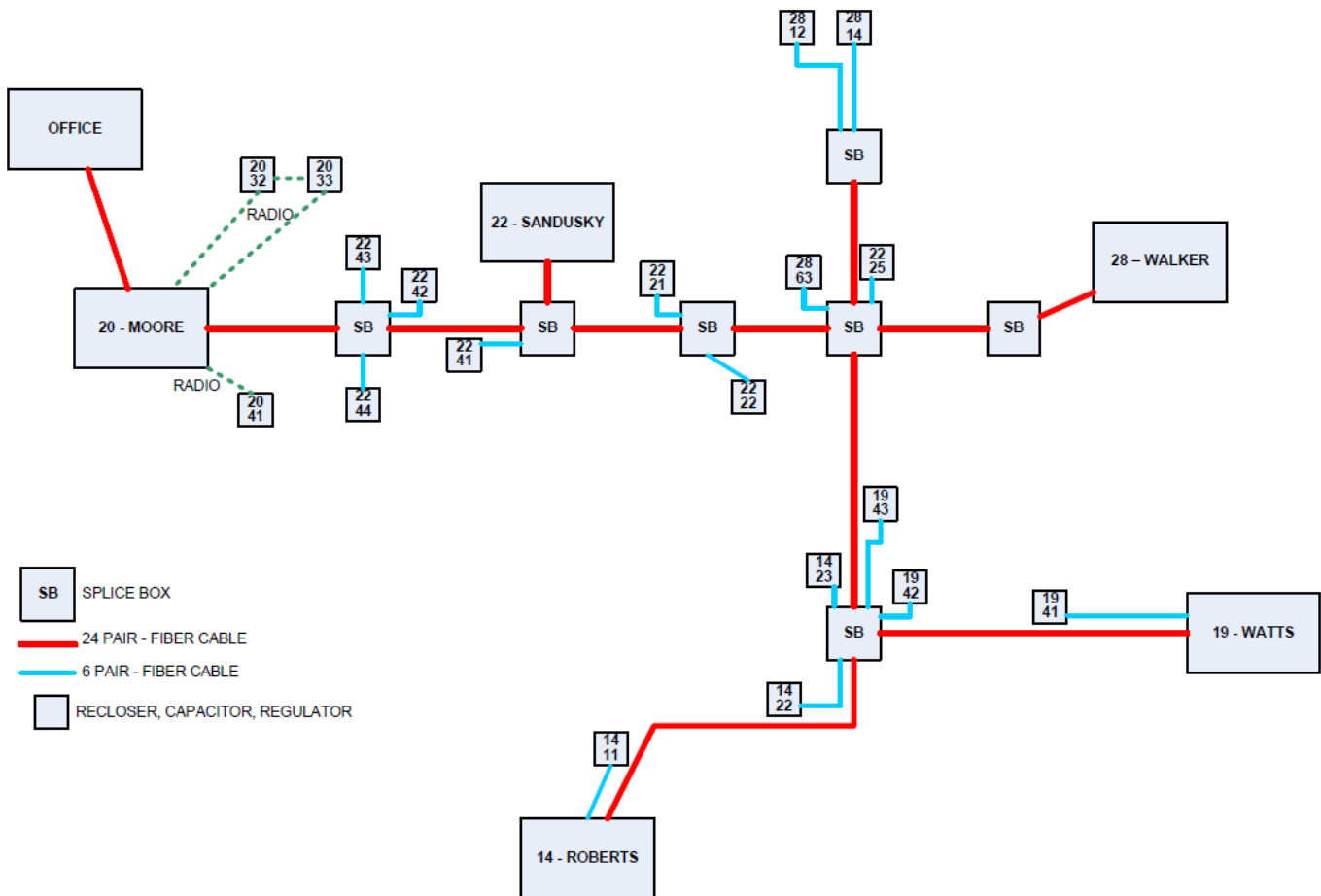

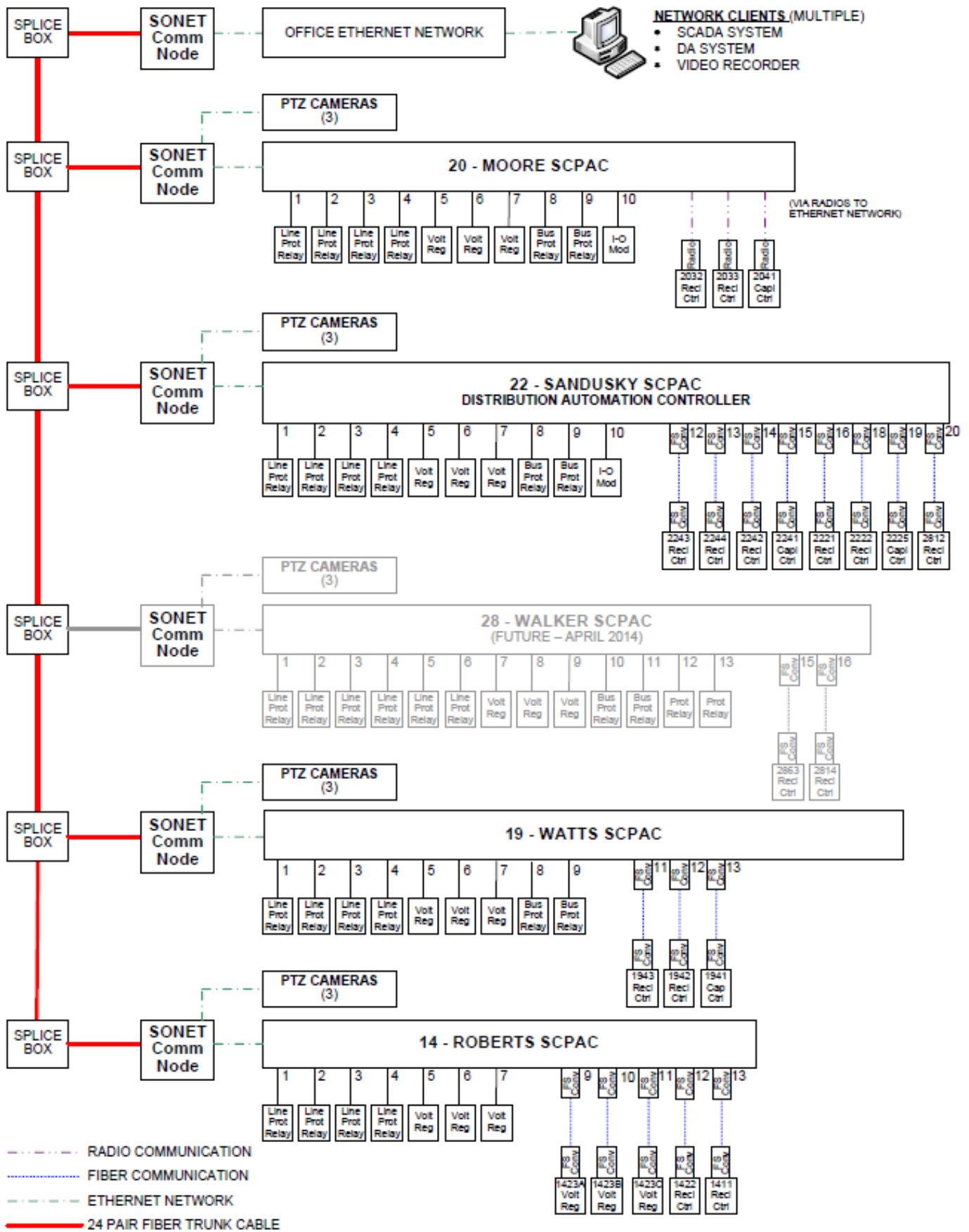Fig. 5. TEC fiber-optic cable routing design.

Fig. 6.   System communications diagram.

AREA_CONTROL [0]

WALKER SUBSTATION "IN SERVICE"
AREA MODEL

SEE THE "DAC_INPUTS" AND THE
"DAC_OUTPUTS" PROGRAM BLOCKS
FOR INPUT AND OUTPUT ASSIGNMENTS
FOR THESE PROGRAM BLOCKS

SUB_20_MOORE [3]
F_203
F_204

L_2031 [13]   RECL_2032 [14]   L_2032 [15]   RECL_2033 [16]   R_2033 IS N.O.

JOIN1 [17]
DA_JOIN
A1
A2

L_2041 [18]   L_2042 [19]   SWI_2043 [20]   S_2043 IS N.O.

JOIN3 [21]
DA_JOIN
A1
A2

DIFFERENT WIRE SIZES

SUB_22_SANDUSKY [9]
F_222
F_223
F_224

L_2221 [22]   RECL_2221 [23]   R_2221 IS N.O.

JOIN9 [24]
DA_JOIN
A1
A2

L_2231 [25]   L_2232 [26]

L_2233 [28]

L_2241 [30]   RECL_2242 [31]   L_2242 [32]   L_2243 [33]   RECL_2244 [34]   R_2244 IS N.O.

JOIN5 [35]
DA_JOIN
A1
A2

L_2244 [36]

L_2245 [37]   RECL_2243 [38]   L_2246 [39]

SUB_28_WALKER [10]
F_281
F_285
F_286

L_2811 [40]   L_2816 [41]   L_2817 [42]   RECL_2814 [43]   L_2818 [44]

L_2819 [45]

L_2812 [46]   RECL_2812 [47]   L_2813 [48]   L_2815 [49]

L_2814 [50]

L_2851 [52]   SWI_1946 [53]   L_2851_2 [54]   RECL_1943 [55]   L_2852 [56]   L_2853 [57]

L_2854 [59]

L_2861 [61]   L_2862 [62]   RECL_2863 [63]   R_2863 IS N.O.

JOIN5 [51]
DA_JOIN
A1
A2

L_2863 [64]   L_2865 [65]

L_2864 [66]   RECL_2222 [67]   R_2222 IS N.O.

JOIN9 [68]
DA_JOIN
A1
A2

SUB_14_ROBERTS [11]
F_141
F_142
F_143

L_1411 [69]   L_1412 [70]   RECL_1411 [71]   R_1411 IS N.O.

JOIN4 [29]
DA_JOIN
A1
A2

L_1413 [72]   L_1414 [73]   SWI_1413 [74]   S_1413 IS N.O.

JOIN2 [27]
DA_JOIN
A1
A2

L_1415 [75]   SWI_1415 [76]   L_1416 [77]

L_1421 [78]   L_1422 [79]   L_1425 [84]

DIFFERENT WIRE SIZES

L_1424 [82]   RECL_1422 [83]   R_1422 IS N.O.

JOIN7 [69]
DA_JOIN
A1
A2

L_1423 [80]

L_1431 [85]   SWI_1432 [86]   S_1432 IS N.O.

JOIN6 [81]
DA_JOIN
A1
A2

SUB_19_WATTS [12]
F_194

L_1941 [87]   RECL_1942 [88]   R_1942 IS N.O.
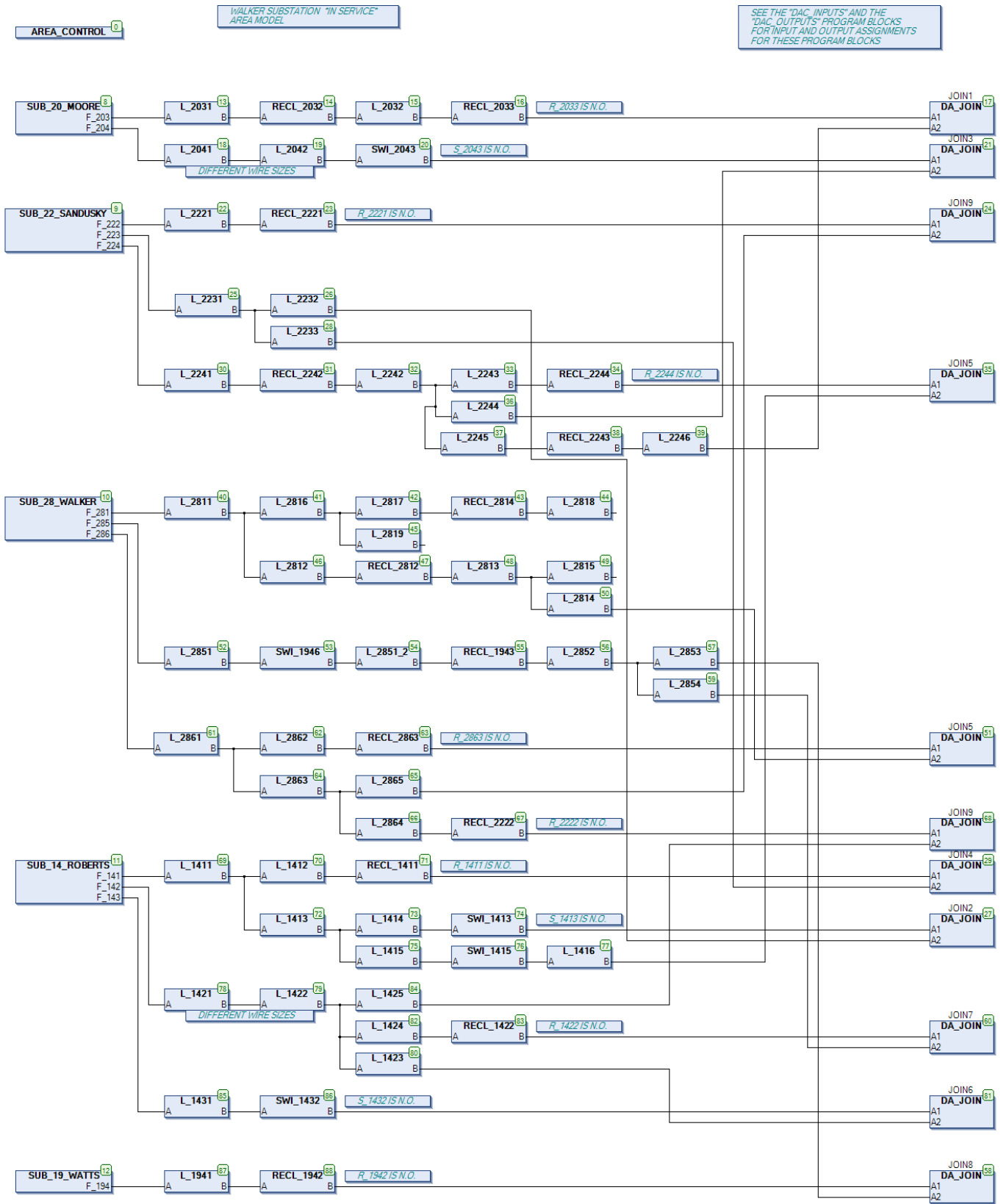
JOIN8 [58]
DA_JOIN
A1
A2

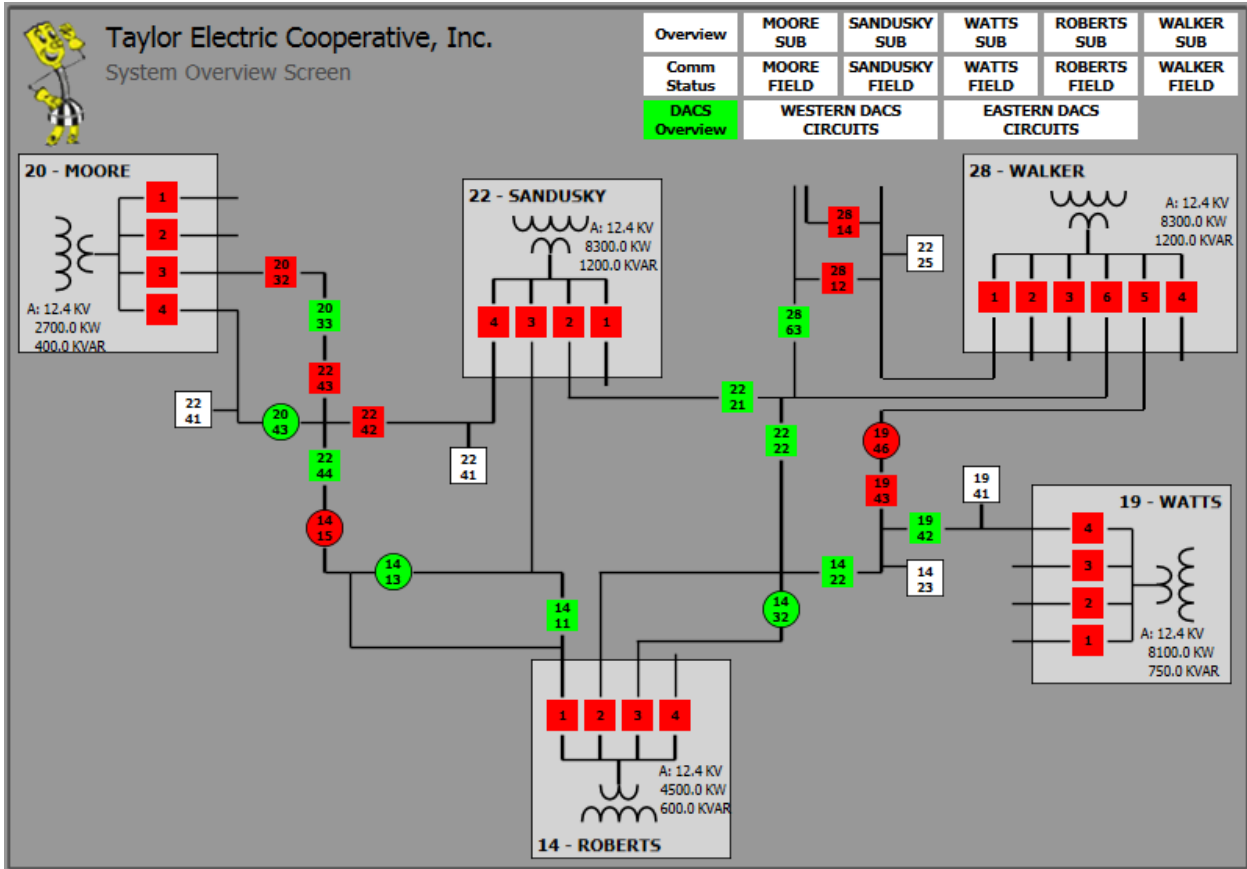Fig. 7.   SCPAC application program DA system configuration.

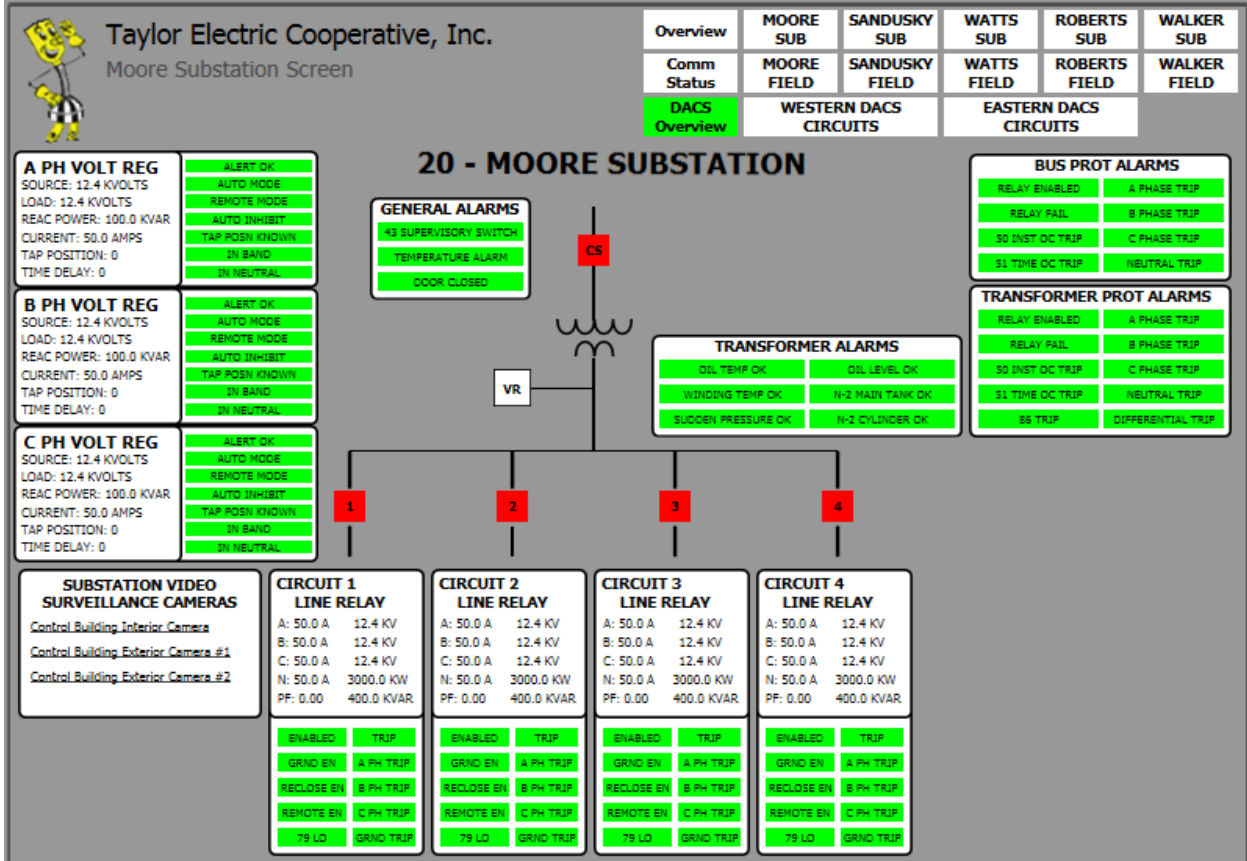Fig. 8. SCPAC HMI system overview screen.

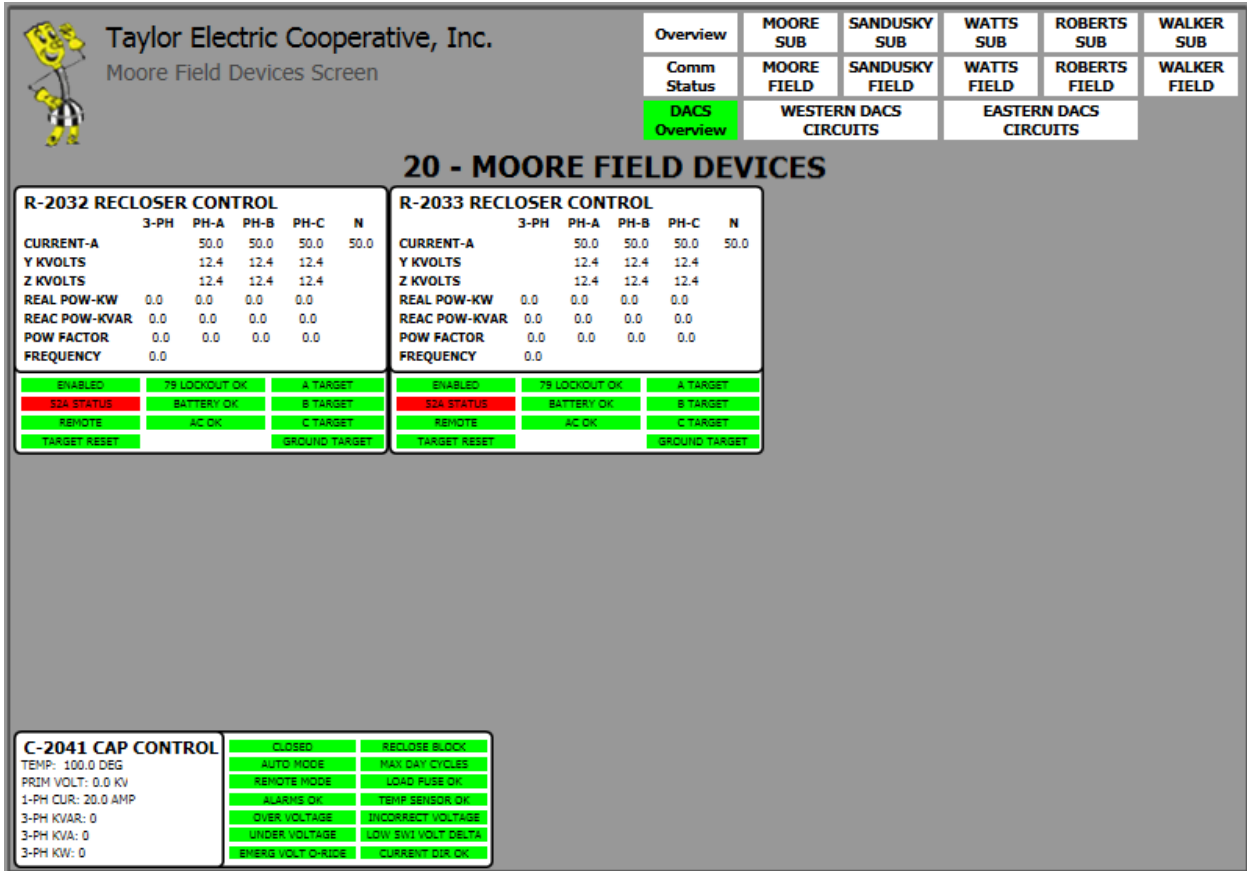Fig. 9. SCPAC HMI substation detail screen.

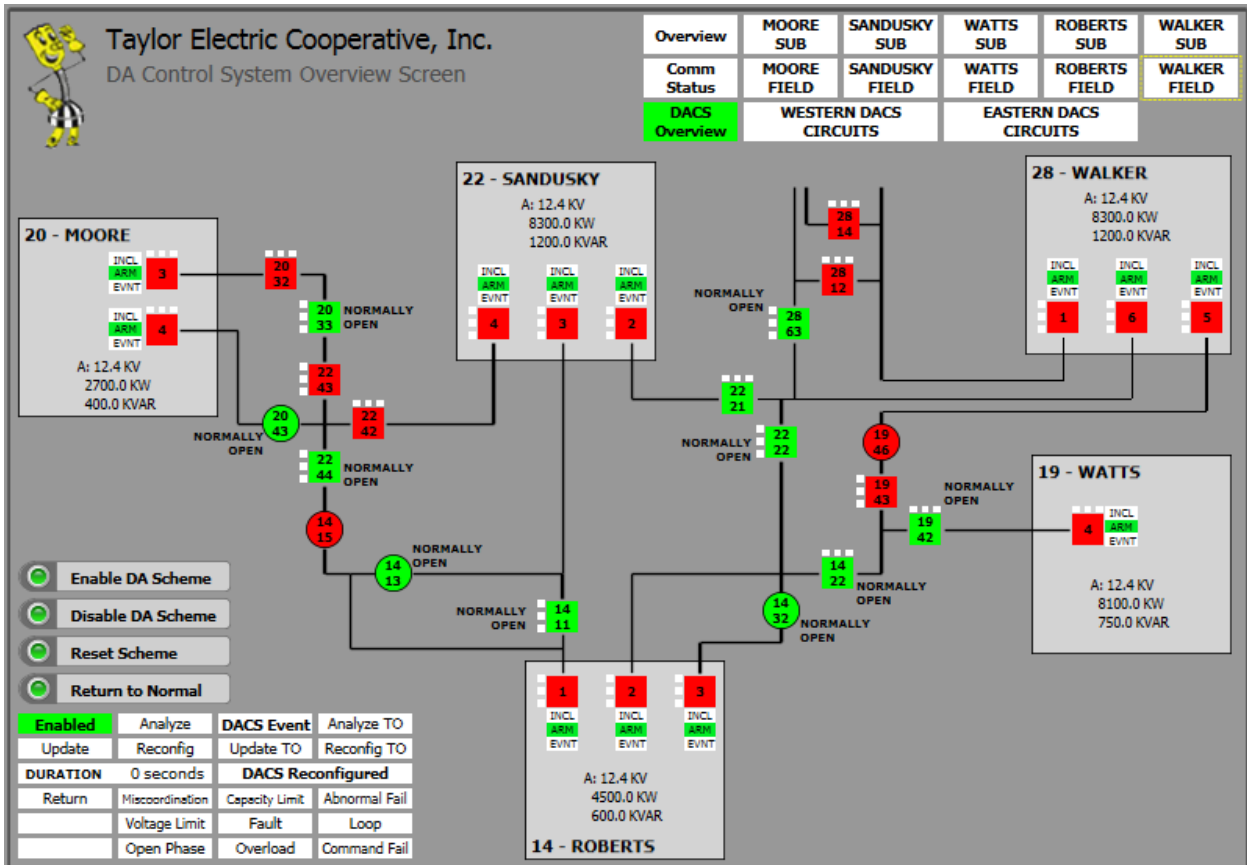Fig. 10.   SCPAC HMI field device detail screen.
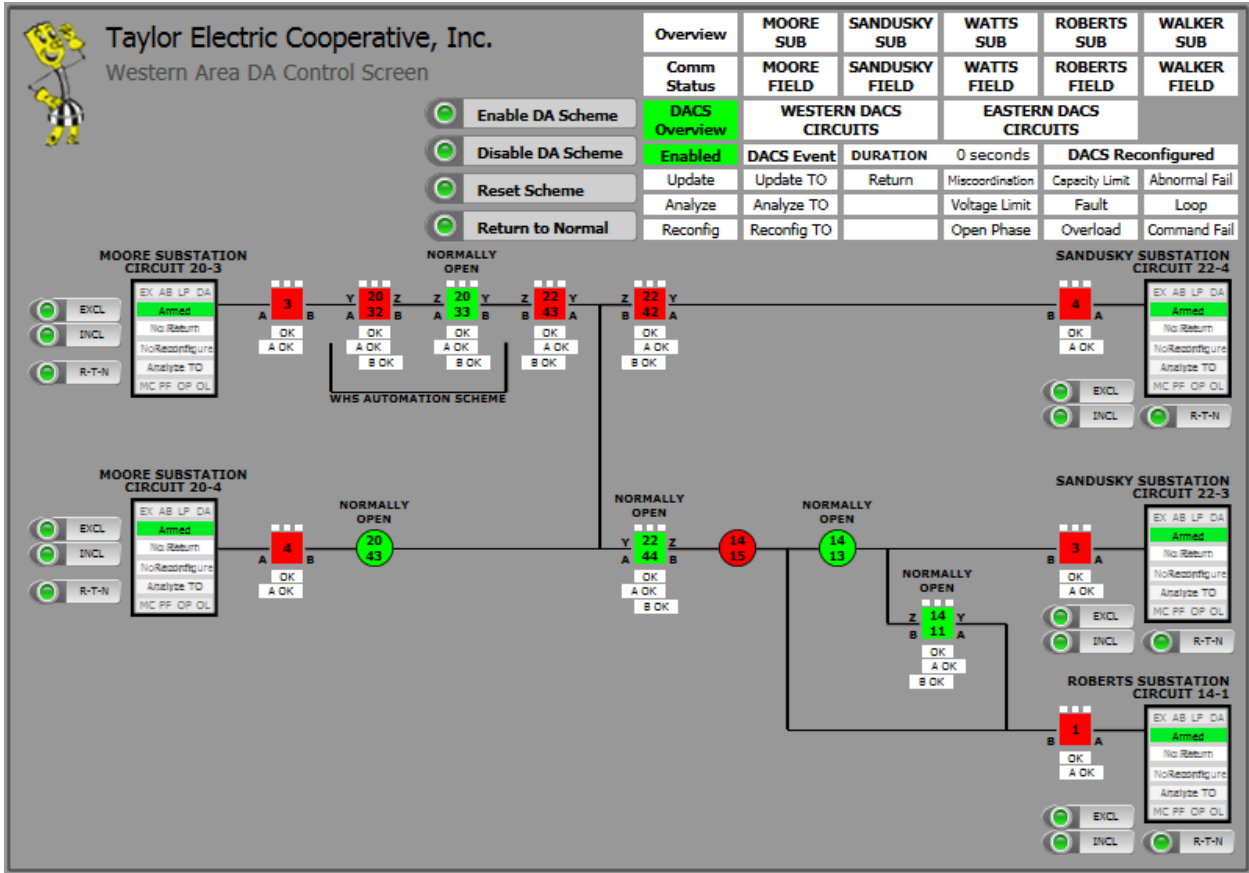

Fig. 11.   SCPAC HMI DA control system overview screen.

Fig. 12.   SCPAC HMI DA control screen for a specific area.

Fig. 13.   Substation interior video image.

VI. FUTURE WORK

When the Walker substation is completed and ready to be commissioned, additional on-site work will be required to include the Walker substation in the SONET fiber-optic communications, DA, and surveillance systems. As a part of this work, the SONET fiber-optic cable network will be modified. The interface between the TEC SCADA system and Walker substation SCPAC as well as the interfaces between the Walker substation SCPAC and the field devices will be tested. The DA system will be modified and tested. The Walker substation video cameras will be tested, and the network video recorder will be modified and tested.

Because the SONET fiber-optic communications system, DA system, and video surveillance system equipment and technology are modular and expandable, the DA and substation video surveillance systems can easily be expanded in the future to include new substations, feeders, and devices as TEC expands and grows.

VII. CONCLUSION

The implementation of multiple technologies provided an opportunity to improve electric power delivery reliability to TEC customers and security for cooperative resources. New and old communications system technologies were combined to provide a reliable, robust communications system between the control center SCADA system, substation SCPACs, and field devices. The DA control system provides a method to improve the reliability of electric power delivery to TEC customers, now and in the future with the expansion of the system to other areas. The substation video surveillance system provides a method to improve the safety of TEC personnel and the security of substation assets.

The implementation of these technologies presented challenges (some technical, some administrative) that were addressed and solved using a team approach. During this project, the participation of all key stakeholders in the problem-solving process was essential to the success and operation of the systems.

VIII. ACKNOWLEDGMENT

IX. REFERENCES

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[3] M. Feller, B. Fazzari, R. Van Singel, and W. C. Edwards Jr., "Case Study: Using Distribution Automation to Build the Next Generation Utility in the City of Wadsworth," proceedings of the 14th Annual Western Power Delivery Automation Conference, Spokane, WA, March 2012.

X. BIOGRAPHIES

Robert H. Gandy received his B.S.E.E. degree from the University of Alabama in Huntsville in 2010. He is presently an electrical engineer at Taylor Electric Cooperative, Inc. He has been with Taylor Electric Cooperative for the last three years. He has a total of six years of experience with municipal utilities and electric cooperatives, with roles ranging from engineering aid to electrical engineer and also director of NERC compliance.

Phillip G. Costantinou received his B.S. in mechanical engineering, B.S. in electrical engineering, and B.S. in computer engineering from the University of Missouri-Columbia in 1983 and 1984 and his M.S. in computer science from the University of Missouri-Kansas City in 1992. He has broad experience in the field of industrial control, manufacturing, and automation systems. He has worked for nearly 30 years in a variety of roles with several companies in the areas of manufacturing and consulting engineering. He is presently an automation engineer in engineering services at Schweitzer Engineering Laboratories, Inc., a member of IEEE, and a registered professional engineer in five U.S. states.

Robert J. Ince served for four years in the U.S. Air Force. He graduated from RETS Electronics School in 1972 and from Broward Community College in 1981. Robert joined the Westinghouse Electric Corporation relay instrument division in Hillside, New Jersey. In 1981, he transferred to the Westinghouse relay instrument division in Coral Springs, Florida, as a relay system test supervisor. Robert joined RFL Electronics in 1985 and held various customer service and sales positions until joining Schweitzer Engineering Laboratories, Inc. in 2012 as a communications application engineer. He is a member of IEEE.