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Communications Requirements for Protection & Control in the 1990's

COMMUNICATION REQUIREMENTS FOR PROTECTION AND CONTROL IN THE 1990'S

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ABSRACT

This paper addresses the rapidly changing utility communication requirements which result from the implementation of digital technology in the areas of protection, control, and monitoring. Data acquisition capabilities and the implications of adaptive relaying and automatic control functions are examined, along with methods of time synchronization and organization of information for faster fault analysis and corrective action. The impact of low energy current and voltage signal sources and fiberoptic communication media on reliability and cost are considered. Evolving industry practice and current standards activities are reviewed as they relate to communication architecture.

Introduction

The "Global Village", only dimly perceived by the visionaries of the 1950's, has become the reality of the 1990's. The explosive growth of information technology has altered every facet of our culture from finance and industry to entertainment and warfare. Politicians are elected by projection before the polls close; wars are won before the battle begins by neutralizing the enemy's communication; industries rise and fall on seas of innovation and productivity; and all are integrated by the dynamic web of communication. It is essential that the utility industry recognize and make optimum use of this new technology for the protection and control of electrical power systems, if the complex power quality, growth, productivity, and environmental requirements are to be met in today's competitive society.

Utility Practice

Until recently the communication requirements for system protection were typically limited to inter-substation communication of relay responses for transmission line fault clearing or remote tripping via power line carrier, analog microwave, or telephone circuits. With passive analog or electromechanical protective relays, analog,status, or fault analysis data was not available, and protection and control interfacing was accomplished via hard wired contacts. Thus, no significant intra-station communication requirements existed.

The communication requirements for control and monitoring have been focused mainly in the transmission area where SCADA systems have been applied to acquire analog and status data and execute remote operator control commands. The communication of these substation transducer and contact outputs have been at relatively low data rates via leased telephone or microwave circuits. The oscillographic and sequence of events data has until recently been accumulated on hard copy in the substation.

Drivers for Change

The rapid growth in computing power in the 1980's with the evolution of cost effective microprocessors is illustrated in *Figure 1.*

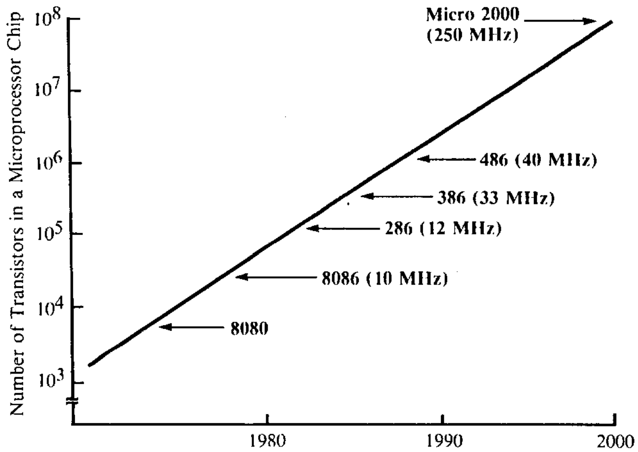

Figure 1: **Growth of Computing Power**

The original IBM PC of just a decade ago used a 29,000 transistor microprocessor chip. By the end of this decade Intel confidentally predicts microprocessor chips containing 100 million transistors capable of processing two billion instructions per second *(Ref. 1).* This growth is reflected in the development and application of digital fault recorders, intelligent SCADA remote terminal units (RTU's), and digital protection subsystems. The most significant of these innovations are the digital protection subsystems which include the inherent benefit of distributed data acquisition.

While these subsystems provide traditional protection functions with adaptive enhancements and extensive self test and diagnostics at a fraction of the cost of previous technology, the real impact is the inclusion of most of the substation control and monitoring functions in the protection subsystem associated with each circuit breaker. These functions include oscillography, sequence of events, fault location, alarm annunciation, fault reporting, metering, automatic reclosing, remote breaker control, monitoring of breaker health, potential integrity, and peak demand.

This first generation of these "Smart Relays" generally provide access for information, control and configuration via serial data ports (RS-232) with personal computer (PC) compatible communications to the local substation or remote operator via modem switches and conventional voice circuits. Substation communications networks are evolving to provide substation data management, time synchronization, and remote communication interfacing for these digital building-block subsystems. *Figure 2* illustrates a typical configuration for substation integration of digital protection and data acquisition subsystems with a substation host and local operator interface.

The recent development and introduction of commercially viable optical current and voltage transducers for high voltage power systems introduces a requirement for analog data com-

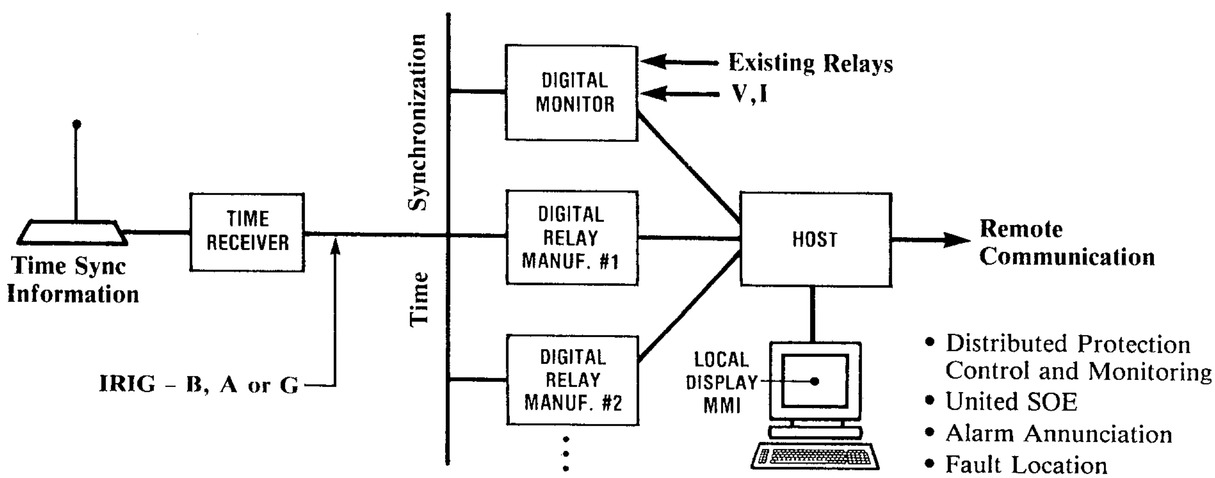

Figure 2: **Today's Evolving Substation**

munication via optical fibers in the substation. This fiber optic signaling not only replaces the copper cables for connection of the CT's and PT's to the protection, control and monitoring, but also requires the use of sensitive electronic devices for these functions.

Microprocessor based distribution automation prototype systems have been developed, installed and tested using conventional telephone circuits for feeder communications *(Ref. 2)*. Microprocessor based "Smart Meters" and load control devices have also been developed for end user application *(Ref. 3)*

The Flexible AC Transmission System (FACTS) developments already underway apply dynamic primary system controls such as thyristor controlled series capacitors, fast phase shifters and static VAR control to optimize transmission capacity and system stability. Many of these approaches involve new communication requirements for adaptive protection and accurate synchronism and control of remote system elements.

We are now at the threshold of integration of these distributed functions to realize significant gains in productivity, reliability and more effective management of the power system. The key to leveraging these technology advantages is communication. *Figure 3* illustrates the dramatic advances made in this area.

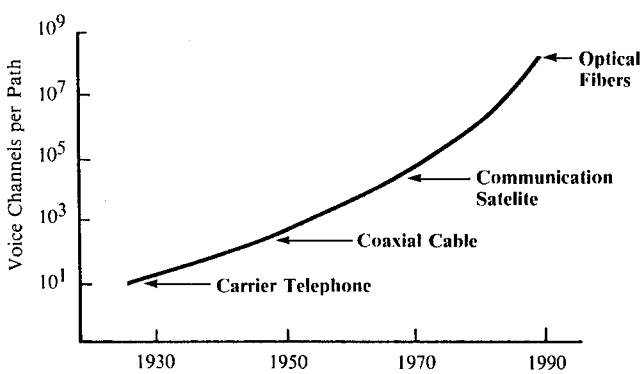

Figure 3: **Growth in Communications Capacity**

The technology innovations in fiber optics, digital signaling and other aspects of communications suggest several viable integration strategies for utility planners in the 1990's.The communication industry presents a number of answers to the above issues, many of which are in practice today, a number of which are conceptual or just gaining momentum, and a few that will present yet to be defined future opportunities. For those issues without answers, the electric utility industry will need to make its requirements known. This should not be too difficult since Utilities as a whole represent the second largest communication entity in the country.

Communications Industry Directions

Communication systems will advance along two fronts during the 90's; namely Communication Media and Communication Systems and Techniques. In the area of Communication Media, the following technologies will get the most attention:

- Fiberoptic cable
- Trunked/Packet Radio
- Power Line Carrier

Clearly, of the above, fiber will be the dominant technology. Besides the major drivers of the telecommunication and power industries, Cable TV is also pushing for new advances in fiber connectivity and functionality. The area of Communication Systems will be dealt with in the Standards section.

Fiberoptic Communications

Overall, two trends in fiber optic systems will emerge over the next several years. First, there will be rapid growth driven by increased cost effectiveness of the fiber solution. Secondly, there will be a shift from long haul to short haul applications. Cost effectiveness will have an impact on everyone's use of fiber. However, as fiber penetrates into the lower voltage areas, utilities will have cost incentives to establish extended Distribution Automation Systems as well as advanced functions such as Demand Side Management (DSM) through Variable Spot Pricing. From *figure 4* in can be seen that since 1980, the cost of fiber has dropped from $3.00/meter in 1980 to $.20/meter today.

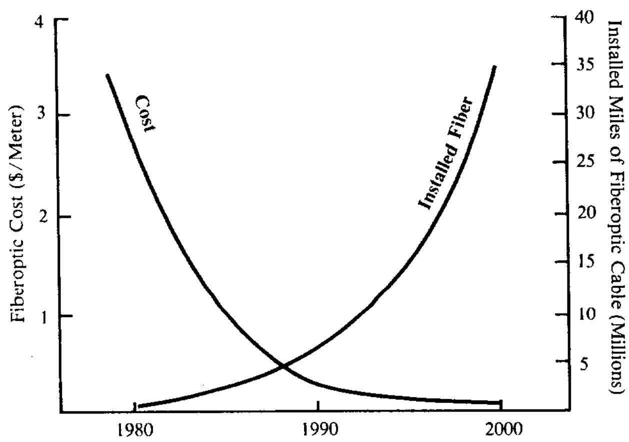

Figure 4: **Fiberoptic Trends**

It is interesting to note the proportion of single to multimode fiber being installed. In 1989, 89% of the 1.2 million miles of fiber installed was single mode. As a result, single mode fiber cable costs are lower per mile. This single/multi mode fiber mix is expected to increase marginally as we approach the year 2000 with almost 4 times as much fiber being installed yearly. Most people are not only saving money by installing the cheaper single mode fiber, but are looking to the future application possibilities that single mode fiber offers.

Some of the specific advances that will benefit the utility industry have come in the area of fiber distribution. It is often desirable to distribute the information transmitted in a fiber to multiple locations without having to perform optical to electrical to optical conversions. The splitter is a passive device which distributes light encoded information from one fiber into two or more paths. The typical 1x2 splitter sends half the optical power in each of the two exit paths. If there are a number of splitters on a line, the optical power reaching the end devices will be diminished by a factor of 2exp(No.-of-taps) which severely limits the number of taps possible. Recently, however, a variable ratio fiber splitter was introduced which allows power ratios from a 50-50% split to a 95-5% split over the wavelength range of 1300 to 1550 nm. This capability affects the utility both in distribution applications and in substation applications. At the distribution level, multiple fiber taps will now be possible on a feeder without requiring a repeater, subsequently reducing hardware costs and increasing system reliability.

In the substation arena, the ability to network multiple protection, control, and monitoring devices on a fiber bus brings the integrated substation concept much closer to commercialization. A Token Bus architecture as illustrated in *figure 5* has already been implemented *(Ref. 4)* using a star coupler and has demonstrated feasibility and improved functionality.

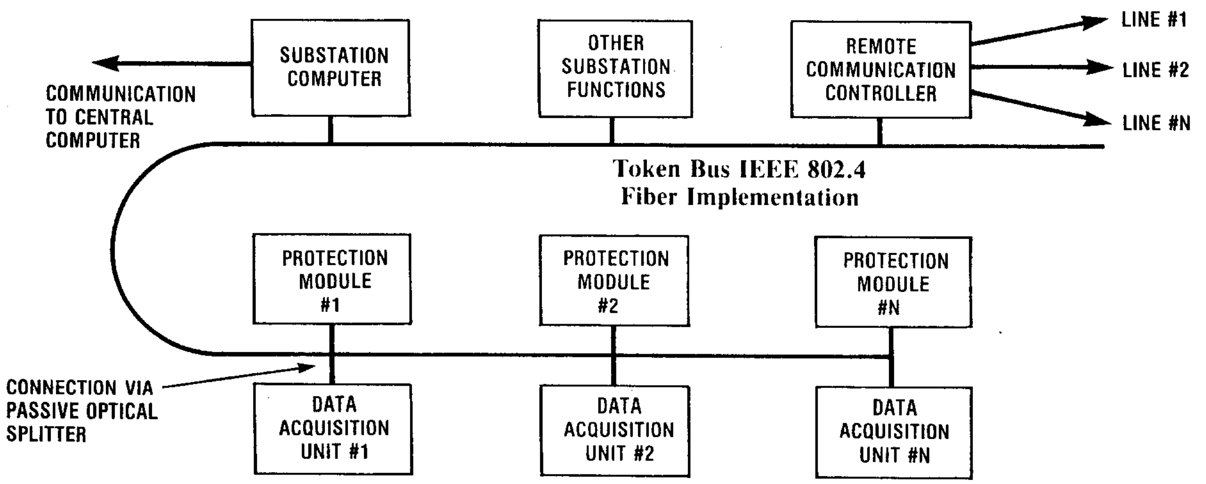

Figure 5: **Substation Communication via IEEE Token Bus**

As protection functions make increasing use of fiber communications, the protection engineer is forced to wrestle with the options of requiring a dedicated fiber per function, implementing a "Relay Fiber" with a number of protection functions multiplexed on the same fiber, or sharing a few channels on an already highly multiplexed communication fiber *(figure 6)*.

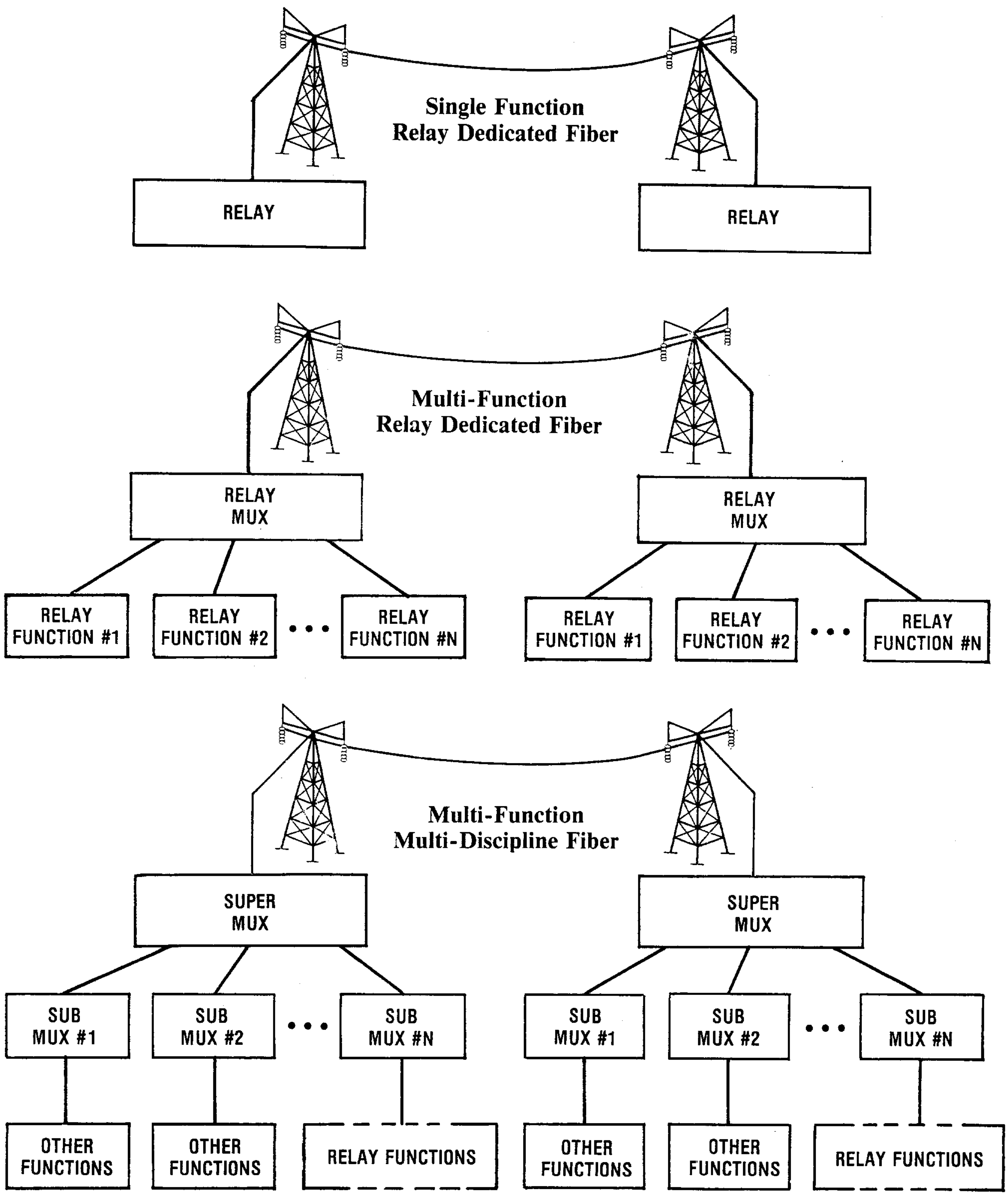

Figure 6: **Fiber Usage Options for the Relay Engineer**

There are pro's and con's to each of the above options. The single-function dedicated fiber provides the most secure data path. Typically, all equipment involved has been designed to the demanding requirements of the relay industry and will offer the most reliable hardware platform. Unfortunately, equipment connected in this manner may use only one millionth of the data capacity of the fiber. Cost justification for such use is on short lines where the cost of multiplexing equipment can be saved. Using a price of $3.00/ft installed cost for an 8 fiber OPGW bundle, and a cost of $20,000 for multiplexing equipment, the break-even distance of dedicated function VS. multiplexed system is between 6000 to 7000 feet. This distance expands to 100,000 feet (18.9 miles) if only the marginal cost of an extra fiber in the bundle is considered.

For distances greater than the above, the option of a multiplexed"Relay Fiber" becomes attractive. A number of manufacturers offer equipment that is "relay hardened" and expected to yield better overall reliability. These systems are based on the "T" carrier standard which operates at 1.544 Mbits/second and support up to 24 channels of data at rates of 64,000 bits/second/channel. The relay engineer is then in control of his own communication fiber and his own destiny.

The option of multiplexing a relay channel into a highly multiplexed fiber is clearly the most efficient use of the fiber's bandwidth. However, the relay engineer is now at the mercy of off the shelf communication equipment and is not in direct control of the maintenance and operation of his relay communication system. The ultimate decision will often cross corporate boundaries, making the result more political than logical. Each company must examine its operating requirements, assess the system risks, and as with all bottom lines, weigh the cost-benefit alternatives before committing to a strategy.

Radio Communications

Radio communication for use in monitoring and control will be the technology of convenience in the 90's. Radio communication systems can be established relatively quickly and are cost effective for reaching remote sites. There are two radio technologies to choose from, namely, Packet Radio and Trunked Radio. The choice of technology is largely dictated by the application.

Packet Radio is a networked system where data is packetized and shipped from node to node in a non-deterministic manner. The packet contains information such as source node and destination node addresses. As data is passed from one node to the next, the destination address is examined and the "least cost" path is chosen to continue the packet's journey. This type of system is used when path reliability is of concern and speed of response is not of paramount importance. Products are available on the market today that provide packet radios embedded in data acquisition and alarm packages for remote control and monitoring applications.

Trunked Radio as a communication medium is relatively new on the utility communication scene. The basic concept is that a "trunk" or single communication connection between two points can be effectively time multiplexed over a large number of people and/or applications. The system operates on licensed frequencies either in the 400, 800 or 900 MHz region. *Figure 7* gives an overview of the Trunked Radio topology. Each radio is assigned an address in the system. When the end node device wants to communicate, the trunking controller in the node requests a channel from the controller. The controller either assigns a channel immediately or queues up the request for the next available channel. The system is capable of broadcasting to all nodes or only a selected group of nodes. Today's systems can contain up to 25 "trunks" and are capable of simultaneous voice and data communication with baud rates up to 9600.

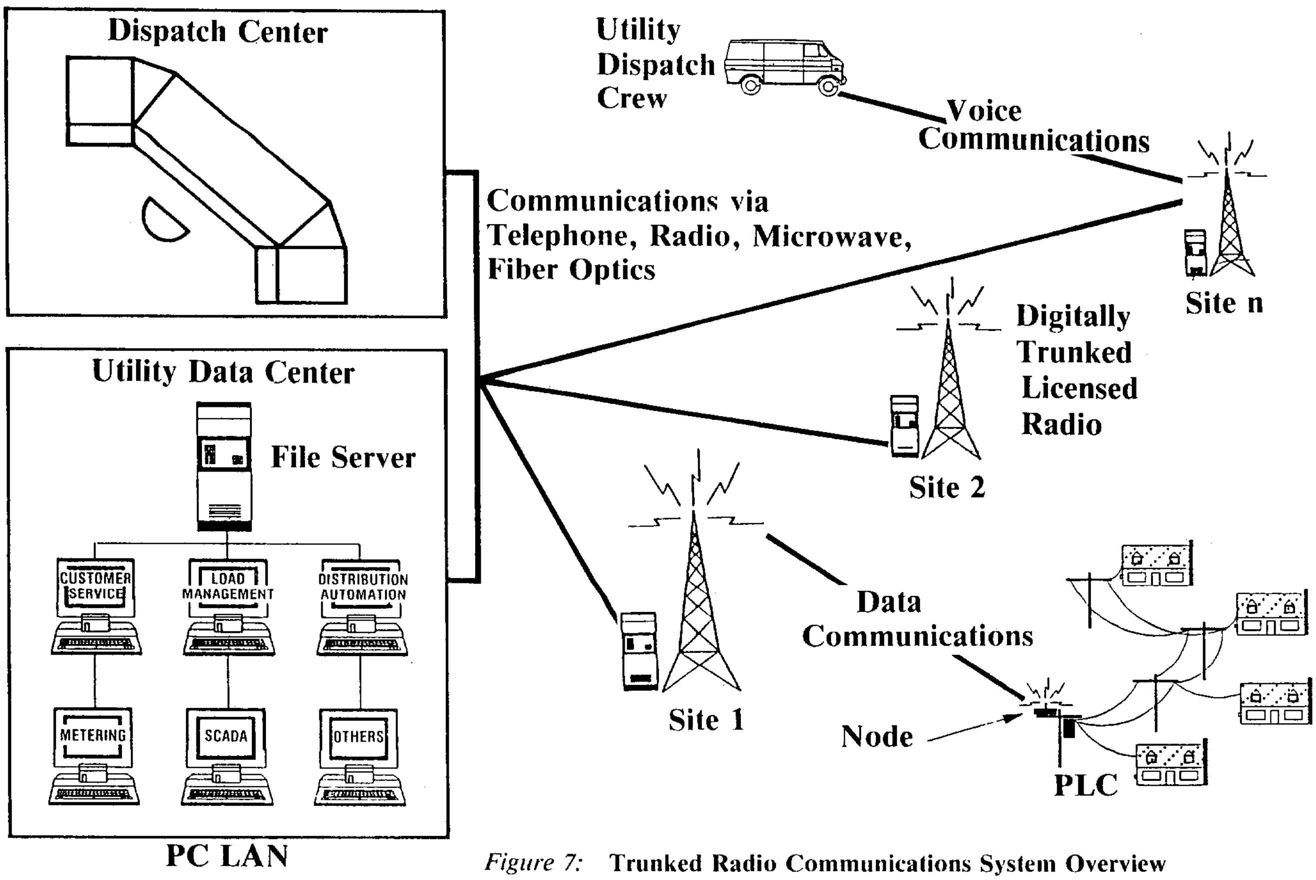

Figure 7: **Trunked Radio Communications System Overview**

As a result, a utility installing a trunked radio system not only enhances its internal communication and dispatch system, but also adds digital data access to its system. One transmitter can cover a 1200 square mile area and address up to 16,000,000 locations within the covered area or multiple areas.

The Trunked Radio system finds application in two key areas - Distribution Automation and Direct Load Control (DLC) / Home Energy Management. Wide area coverage and ease of implementation are of paramount importance here. Referring again to Figure 7, a ''Node'' can be established in a distribution substation or on a pole top. A distribution ''Node'' can be addressed and bi-directional communication established. Control information can be sent or operation data requested. In the DLC arena, the broadcast feature of the system gives instant control to potentially millions of households in seconds. Similarly, in a DSM system, new rates could be broadcast to millions of homes in seconds.

Power Line Carrier

Power Line Carrier (PLC) is an old technology that will be seeing some new applications in the 90's. With the recent completion of the Consumer Electronic Bus (CEBus) specification, a standard now exists for establishing two-way communication with electrical items in one's home via PLC. The complete communication protocol and modulation hardware will soon be available on a single chip. Depending on how quickly consumer product manufacturers adopt the standard, the ability to communicate with various appliances provides another method of implementing Variable Spot Pricing of Electricity. Most immediatelly, utilities will be able to make use of this new technology in communicating from the trunked radio ''Node'' directly with ''smart'' meters and other intelligent devices in the home as illustrated in figure 7.

The Need for Standards

There is a natural tendency for manufacturers to ignore the standards setting process and to provide the customer with innovative equipment and system solutions to meet their service requirements. It becomes apparent, however, that without compliance with some larger community of interest, such implementations ultimately result in higher costs for the customer and a smaller market segment for the manufacturer. Adherence to a corporate policy of compliance with applicable standards and support of the "Open System Interconnection" is clearly the most appropriate strategy for the utility equipment manufacturer. As protection and control becomes more complex and integrated with communication systems, the relay engineer will need to become better acquainted and more involved with the numerous utility applicable standards and standards bodies. Three areas of the more relevant standards are highlighted below.

The first area relates to communication protocols. Of the myriad that exist, the following will have appeal to the utility in the 90's:

FDDI - Fiber Distributed Data Interconnect is the much taunted 100 Mbit/sec redundant fiber token ring. Due to widespread manufacturer support, there will be a large number of products offered in this market making the interface cost attractive for many applications including intra-substaion communication.

MAP or 802.4 - The Manufacturers Automation Protocol is a 20 Mbit/sec token passing bus. Endorsed by General Motors for use in manufacturing automation, MAP is believed by many to be the ideal protocol for intra-substation communication due to its data bus approach which provides a reliable communication path, and also provides the ideal architecture for data sharing.

X.25 - A packet switching protocol that is finding application in utility Wide Area Networks. The packet concept allows for alternate path selection which results in a highly reliable communication system.

ISDN - The Integrated Services Digital Network is the phone company's offering of an integrated network that supports voice, data, and video transmission over existing copper telephone lines. Although current realization has not lived up to market projections, over 2 million installations are expected by 1994.

The second area of standards relate to the formatting of information for communication. Two standards are discussed as follows.

COMTRADE - The Common Format for Transient Data Exchange explicitly defines how both waveform and event transient data is to be formatted, primarily for exchange purposes. As the various manufacturers begin to support the COMTRADE format, it will become possible to automatically integrate different manufacturer's transient data files into one coherent report.

IRIG & Time Synchronization - The Inter Range Instrumentation Group timing standards have existed since the late 1950's. The IRIG standards specify how time and date information is to be modulated for communication in a local area. Many utility engineers are familiar with IRIG-B, a time communication format capable of resolution to the nearest millisecond. Other applicable IRIG formats are IRIG-A with a 0.1 ms resolution and IRIG-G with a 0.01 ms resolution. Time accuracies between 0.5 to 2 usec (depending on noise level) can be extracted from the above formats by use of a multiplying phase lock loop set to generate a 1 MHz signal locked to the incoming signal.

As system planners attempt to minimize capital expenditures, and at the same time push more power over the same lines, protection and control systems will become more complex. Subsequently, the protection engineer is faced with the task of gathering more data to determine the sequence of events for a given outage. Data gathering from multiple sites is often required. The relative value of this data is in its relationship to absolute time. The traditional sources of absolute time have been AM radio broadcasts, microwave, and GOES satellite. Todays utility engineer can now economically access the Global Positioning

Satellite system for about $5000. This system is well supported by the military and is capable of achieving 200 nanosec absolute time accuracy.

The last area concerns standards or groups of standards that form architectures. There is work progressing on two architectures of interest.

UCA - The first is the Utility Communication Architecture. UCA is the result of EPRI research into the area of utility communication. The approach taken was to first examine utility communication requirements. Based on their findings, a suite of existing standards were proposed as a framework for the architecture as well as adherence to the OSI model to meet the diverse utility communication requirements.

DSD - The second architecture of interest is the proposed standard on Digital Substation Design (presently in committee). This proposed standard defines a three tier hierarchy for the integration of protection, control, and monitoring in a substation.

> Ultimately,
> a Standard is Only a Piece of Paper
> Until It is Embraced by Enough People
> Who Call It Their Own.

The Information Impact

The following examples illustrate how timely access to all of the pertinent information can facilitate improved productivity, reliability and management of the power system:

- A typical value of 2 kilowatts per home is available for appropriate load management strategies. The utility capital investment alternative for added kilowatt capacity is up to ten times the cost of implementation of DSM strategies.

- A recent major outage involving the loss of 2600 MW required over a month of intensive investigation and analysis of the very limited data available to determine the cause of the problem. This extended exposure to an undefined risk represented a very serious reliability issue. The acquisition and immediate communication of all pertinent fault analysis data with available digital technology can have a major impact in such instances.

- Maintenance on a high voltage breaker typically involves a one to two week outage and costs $30,000. Transitioning from "calendar" or simple operation-count maintenance schedules, to optimized maintenance based on intelligent breaker monitoring represents large potential savings *(Ref. 5)*. Today's smart relays monitor and integrate breaker contact duty (I^2t) on a per-pole basis, trip operation times, trip circuit integrity, etc. to permit cost optimization of maintenance. The same considerations are reflected in the extensive self diagnostics imbedded in smart protection and control equipment which can alarm, shut down (or operate in a degraded mode), and identify the failure on a plug-in module by communications with a remote operation or maintenance center.

- The application of thyristor controlled series capacitor compensation of transmission lines facilitates improved load control and system stability, and accesses million-dollar-a-mile avoided costs in transmission line additions. These protection and control strategies require reliable high speed communications.

Conclusions

Rapid advances in digital technology have made increasingly powerful microprocessor based protection, control and monitoring equipment available for utility applications. The effective utilization of this enormous data processing capability is highly dependent on the development of appropriate communication systems. Innovations such as fiber optics and digital signaling offer various technically viable strategies for meeting these growing communication needs. It is, however, essential that standards and practices be developed by close cooperation between users and manufacturers to realize effective migration paths to highly integrated future systems.

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