DIGITAL COMMUNICATIONS FOR RELAY PROTECTION

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Abstract

Electric utilities are expanding communications infrastructure due to increased need for information. Due to performance, price, and technological advances, digital communication systems are frequently chosen as this multiple user data network.

This two-part paper describes the application of digital communication in power system protection.

Part 1 describes the digital communications architecture and topology that can be applied to existing and new protection systems, digital channel characteristics and transport systems applicable and not applicable for protection, future digital communications technologies of interest to the protection engineer, and the need for future standards.

Part 2 reviews existing analog communications relay schemes and describe digital interfaces to them.

An Annex is provided to define terms used.

Part 1 : Digital Communications Systems

1 Introduction

With increasing demand for communications, digital communication technologies are being applied at an increasing rate. Electric utility applications are also increasing as the advantages and characteristics of the various digital communications technologies are better understood.

The telecommunications industry is one of the leaders in digital communications technology. They can drive the technology and the market. Electric utilities have a much smaller impact on the digital technology market. Accordingly, electric utilities typically buy versions of telecommunications industry products with modifications made for this industry, such as, surge withstand capability. This is also the case for the protective relaying digital communications systems as well.

Understanding digital telecommunication system architecture is also important, since the telecommunications equipment is applied as used in that industry. Typically communications requirements needed for protection are more stringent than those needed for telecommunications. This is of particular concern when communications facilities are used for multiple applications of which relaying is only a part. In these cases, extra assurance of adequate relay channel management, control, and performance is needed.

2. Digital Communications Architecture

2.1 Digital Telephone Hierarchy (T-1)

Thirty years ago the North American telephone industry introduced high speed switching digital transmission technology to better utilize existing facilities and minimize investment in future plant. It is called Digital Service One (DS-1) or Transmission One (T-1) and operates at 1.544 megabit per second (Mbps). This primary group bit rate can accommodate twenty four 64 kilobit per second (kbps) or DS-0 voice channels, similar to the voice channels used in relay schemes. Two other popular transmission rates, the 6.312 Mbps DS-2 rate consisting of 4 DS-1 channels and the 44.736Mbps DS-3 or T-3 rate consisting of 28 DS-1 channels, are in widespread use. This family is often called "async" or asynchronous as it assumes that the signals being time division multiplexed are not at exactly the same frequency and uses "bit-stuffing" to allow for this.

The multiple bit stuffings to go from DS-1 to DS-2 and DS-3, etc. added complexity and processing delays to the communications systems particularly as higher multiplexing was required. This lead to the creation of a new Bellcore synchronous multiplexing scheme, primarily using fiber optics as the transmission medium, called SONET (Synchronous Optical Network).

2.2 SONET Hierarchy

The International Telecommunication Union (ITU) SONET standard provides a synchronous digital hierarchy with sufficient flexibility to carry many different capacity signals. A basic signal rate of 51.84Mbps, called Optical Carrier level 1 or OC-1, can accommodate 672 DS-0 concurrent voice channels. Multiples of OC-1, i.e., OC-3 (155.52Mbps), OC-12 (622.08Mbps), OC-48 (2488.32Mbps), OC-192 (9953.28Mbps) are commonly used. SONET provides for synchronous end to end or path sub OC-1 channel capability. The lower speed data rates are byte interleaved via time division multiplexing to form the OC-1 signal. The basic OC-1 data frame, which has 9 rows of 90 columns of bytes, contains a transport overhead area of first three bytes of each row and a Synchronous Payload Envelope (SPE) area. Part of the overhead is used for channel performance monitoring, path checks, and network management. A virtual tributary or VT1.5 (1.728 Mbps with overhead and SPE) is the SONET equivalent of a digital DS-1 or T-1 signal.

SONET is applied around the world. In Europe, it is called Synchronous Digital Hierarchy (SDH) with the OC-3 (155.52 Mbps) rate called the Synchronous Transport Module (STM-1).

3 Communications Configuration

3.1 Point-to-Point

A point-to-point system is the simplest configuration for a digital communications system. Channel(s) are available between only two equipment or nodes. Point-to-point systems are common in networks where the channel switching is provided by separate switching equipment than the communications transmission equipment or where there is a lot of traffic or information is required between two points.

3.2 Star

A star configuration is comprised of multiple point-to-point systems all with one common point. At the common point, or hub, the channels from one spoke of the star can be rerouted to another spoke of the star via digital cross connect equipment. To reduce the vulnerability of the spokes of this star configuration, redundant systems are commonly used.

3.3 Linear Drop and Insert

A drop and insert system allows multiple sites to communicate with each other along a fiber optic or other digital communications media route. In a drop and insert system, a DS0 channel can be configured between any two points or nodes. Information communicated between two non-adjacent nodes is passed directly through intervening nodes. Once a channel has been dropped, the bandwidth can be reused for other channels within the system. A single intermediate drop and insert node replaces two "back-to-back" nodes in a system configured as point-to-point systems. Drop and insert is illustrated in Figure 1, communications between Point "A" and "B" and points "B" and "C" are using the same channel. The communications between points "A" and "C" pass directly through the node at point "B".
This linear system design does not provide channel backup against fiber or equipment failures as ring topology designs do.

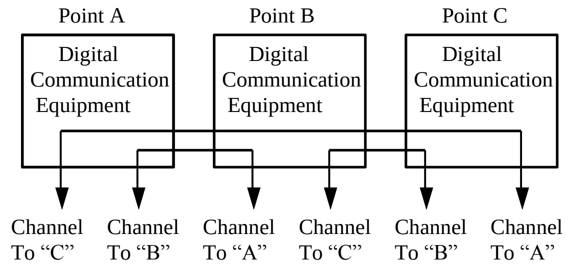

Figure 1 Drop and Insert System

3.4 SONET Rings

In addition to the above topologies, Bellcore Standards TR-496 and TA-1230 define Path Switched and Line Switched SONET Rings. Each of these ring topologies offers pros and cons regarding different types of teleprotection applications.

Path-switched rings are simpler, more dependable, and switch typically in a couple of milliseconds making them useful for teleprotection applications. Line-switched rings require complex handshaking signals between the limited number of addressed nodes. This can delay startup by as much as 60 ms, however this results in a more efficient use of fiber communications in many applications.

3.4.1 SONET Path Switched Ring

In a path switched ring only the affected Virtual Tributary (VT) signals are switched. An example of this is shown in Figure 2. VT signals enter the ring at a node and are simultaneously transmitted around the ring in both directions. This scheme uses one direction around the ring as the primary signal path, and the other direction around the ring as the secondary or protection path. If a signal path failure is detected, node switching with the local multiplexer occurs and service is restored within a few milliseconds.

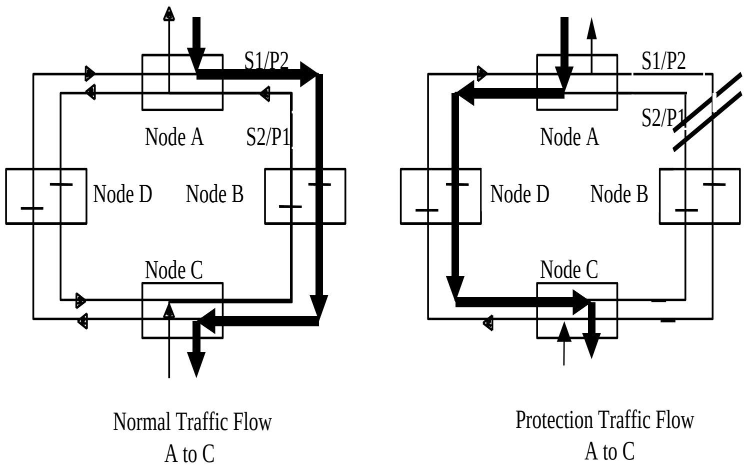

Figure 2 Path Switched Ring Operation

When applying teleprotection over this type of ring topology, some precautions need to be taken. For example most current differential and phase comparison systems can not compensate for unequal channel delays between the transmitter and receiver paths, since a setting is fixed to compensate for one propagation delay value. So substantial changes in receive path propagation, as could occur in protection path switching, could result in false operations in the protection system.
For this reason, some systems allow inter-node communications to force both ends to switch, in order to keep the two path delays equal.

3.4.2 Line Switched Rings

In the two-fiber bi-directional line-switched ring (Figure 3), switching occurs at the line rate (OC-N). This requires that half of the available bandwidth be reserved to provide the protected path.

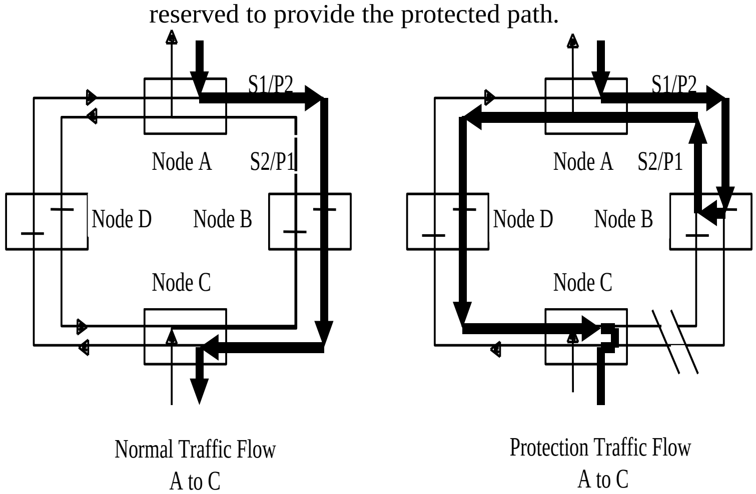

Figure 3 Line Switched Operation

From a teleprotection viewpoint, this is worse than path switched rings because (a) the restoration time is long, possibly 60ms (b) delays are longer due to the switched path length. Systems that are designed with fixed propagation delay compensation can be vulnerable to false operations, depending on the size and number of nodes in the SONET network.

4 <u>Digital Channel Characteristics</u>

4.1 Bit Errors

Bit errors occur when the data bits that are sent are not the same as the ones that are received. Bit errors can be caused by the transportation media and/or transmitting or receiving equipment problems. The received signal strength, its level, its noise content, and signal jitter are directly related to resultant bit error rate. Elevated equipment temperature, power supply input voltage, high humidity and altitude, etc. may add bit errors. All equipment should have a specified maximum bit error rate (BER) and the conditions that the equipment must operate under to achieve that rate.

Bit errors will result in the protective communication equipment detecting incorrect information. The way that this affects the protective communication equipment's output depends greatly on the equipment design and the end to end communication protocol used. In most cases the equipment will ignore erroneous bits. If errors occur during the transmission of a command, the result will be either a delayed signal or a missed signal. If the bit errors become excessive the likelihood of false operation increases.

Fiber optic systems are typically engineered to give a typical BER of 10^{-12} with a worse case BER of 10^{-6}. With a BER worse than 10^{-6} , the channel may be considered seriously impaired. A voice application at 10^{-6} BER would not exhibit significant noise but a data application could have serious problems. Fiber optic systems will exhibit bit errors due to electrical and optical malfunctions. Signal rerouting to secondary or protected paths also can cause bit errors.

Most telecommunications systems will operate with a BER at least 10^{-3}. Most teleprotection can operate at BER levels approaching 10^{-3} but dependability and security start to suffer. Teleprotection systems are most susceptible to security problems from bursts of errors and dependability problems from random errors. A burst of errors on a digital channel is more likely to mislead error checking circuitry than a continuous stream of data errors. Random long term errors pose dependability problems because teleprotection tends to have long term squelching to help provide security.

4.2 Alarms

Generally teleprotection equipment will alarm when BER levels of 10^{-3} are exceeded. At this level the digital receiver produces an AIS (Alarm Indication Signal) of all 'ones'. The teleprotection receiver is designed to recognize this pattern and respond according to user selection.

4.3 Channel Delay

Channel delay is the sum of the communication electronics and the communication path delays. The equipment delay varies from a few to several hundred microseconds and is of concern for current differential relaying. The speed of light in optical fiber is approximately 70% of the speed of light in air, since its reciprocal, the index of refraction of glass, is 1.4677. Metallic cables generally have a similar velocity. Digital microwave paths propagate at the speed of light in air, resulting in times slightly faster than that of fiber. The following table shows the propagation time for various path lengths.

Medium Propagation Times (microseconds)

Kilometers	Miles	Fiber	Microwave
1	0.6	4.9	3.3
10	6.2	48.9	33.3
20	12.4	97.8	66.7
50	31.1	244.6	166.7
100	62.1	489.2	333.3
250	155.4	1223.1	833.3
500	310.7	2446.2	1666.7
1000	621.4	4892.3	3333.3

Both the actual time delay and delay changes may be of concern. With certain types of Phase Comparison and Directional Comparison equipment, changes in the path delay will have an effect on the relay's ability to determine the proper direction of system faults. Changes in delay are caused automatically by variation in path from path/line switching, or due to operation or design changes. It is very important that the protective relay communication scheme be designed to assure proper operation if any of these changes should occur. If the communication path could be operated in several configurations, the scheme should be checked in each configuration to assure proper operation.

Some protective relay devices now have the ability to self adjust for variations in channel time delay. This type of equipment is desirable for path switched systems. If this feature is not available, separate communication equipment may be needed for each path operated by suitable type of output logic. Note that equipment could misoperate if path switching should occur during a fault.

4.4 Resynchronism

Upon circuit switching, the Bellcore SONET specifications state that resynchronism time may be 60 ms. This is quite acceptable for voice communications and most digital communications. For relaying applications this may be unacceptable, especially during relay fault operation. Several relay channel bank and SONET manufacturers have reduced this time to approximately 10 ms. Fortunately resynch is a rare event. Experience will show how often it occurs at the same time relays are needed to operate.

5 <u>Transport Systems</u>

5.1 Fiber optics

The use of optical fiber media has dramatically increased in the last fifteen years. This is due to multi vendor availability, much lower purchase and installation costs, dielectric characteristics, increased bandwith potentials, and communications speed. Optical fibers are available as part of the overhead ground wire (OPGW), in a self supported dielectric conductor, as a messenger conductor, or designed for underground environment. Utilities are using a variety of installation options to build a very reliable communications backbone with minimum common mode failures. Fiber optics is especially attractive when utilizing available bandwidth to combine communications needs of the electric utility, e.g., telecommunications, SCADA, video, data, voice, switching. With currently available fusion and mechanical splices, approximately 60 miles of single mode 1500nm optical fiber with 0.20 - 0.40 decibels per kilometer (dB/km) attenuation can be used without a repeater, and slightly less distance with lower cost 1300nm fiber.

5.2 Microwave

Terrestrial digital microwave signals are electromagnetic waves in the radio frequency spectrum above 890 MHz and below 20 GHz. Microwave is frequently applied to span or skip natural land and water barriers and man-made barriers. Microwave systems are point to point with a maximum distance of 30 to 60 miles before the need to regenerate or repeat signals.

Good microwave system design should properly coordinate frequencies, provide for signal degradation due to multipath fading and atmospheric and weather conditions, use proper power and antenna for the application, and where possible make use of original analog microwave path licenses with "grandfathered" regulatory and environmental rules.

Digital microwave, due to its complex digital coding schemes, offers better performance, i.e., improved signal to noise ratios and lower dollar equipment costs, is now the preferred terrestrial transmission method, and will continue to dominate the microwave market segment in the future. Digital microwave operates in the 2, 4, 6, or 11 GHz bands.

5.3 Digital Radio

Digital radio is increasingly used by the electric utility industry for a large variety of general and emerging specialized applications. A number of different radio systems exist, e.g., VHF and UHF, trunked, cellular, and multiple-address system (MAS) which are primarily for portable mobile applications.

VHF (30-172 MHz) and UHF (450-512 MHz) radio has not been used for general protection applications due to possible unavailability along with propagation limitations. Consequently applications have generally been limited to direct transfer trip for low speed less critical applications.

Trunked radio in the 800 MHz band was primarily designed for shared voice communications, is not used as protection channel because of variable user congestion and lack of security.

Cellular mobile radio operates in the 800-900 MHz range (824-849 MHz Rx / 869-894 MHz Tx) and is a shared channel technology. When a user desires to use a communication path, a signal is sent to a central controller that responds telling the user what channel to use. This channel assignment may stay the same throughout the data transfer or may switch at any time. Noise, adjacent channel interference, changes in channel speed, overall speed, channel switching during data transfer, power limitations, and lack of security make this type of channel undesirable for protective relaying.

With the availability of personal digital service (PCS) digital cellular technology comes devices designed for data transport. As the time division multiple access (TDMA) and the code division multiple access (CDMA) products mature, protection concerns, such as real time communications requirements may be met allowing limited relay applications. Future CDMA is of particular interest due to its secure spread spectrum technology and its power line applications in digital power line carrier.

5.4 Metallic media (coax and twisted pair)

Metallic media are the oldest and most commonly used form of electronic communication media. The large installed base of metallic systems and relative ease of interface make it attractive to adapt digital communications to metallic transport. Metallic media has been enhanced to serve the needs of digital communications. Consequently, metallic transport is not likely to become obsolete any time soon.

Metallic media in the communication world are roughly divided between twisted pair (or "copper") systems and co-axial cable systems. Twisted pair has been the primary standard and has the largest installed base. Signals are routed point to point on twisted pairs of 18 to 32 gauge copper wire in multiple pair cables.

Modem manufacturers have recently announced 33.6 kbps V.34 modems and 56 kbps pulse code modulated (PCM) modems. Although speed has improved for some circuits, buffering, retransmit, error correction, and unpredictable speed during noisy circuit conditions limit relay applications. Integrated Services Digital Network (ISDN) and Digital Subscriber Line (DSL) technologies, designed for the telecommunications industry, show promise for relay applications due to increased speed and lower delay. However, unwanted induction and conduction on the metallic media will continue to be issues to deal with in the substation environment.

Coax has been more commonly used with high frequency and bandwidth broadcast systems like cable TV (CATV). Transporting data over cable is currently a popular topic due to the demand for Internet bandwidth. Developing adequate bandwidth from the user to the hub is a challenge; currently hybrid fiber coax (HFC) designs offer the largest bandwith. Since coax can transport several gigabits of data over thousands of feet relatively shielded from interference, it may be useful in this role for protection systems.

5.5 Satellites

With smaller dishes, lower cost, and lower orbiting satellites offered by very small aperture terminal (VSAT), this technology may be useful for many utility applications, such as supervisory or adaptive control. Unfortunately, end to end delays in the order of 250 milliseconds rule out most protective relay applications.

6 Future Relaying Using Digital Communications

Protective relaying communications is and will continue to be implemented on digital communications networks. Networks will allow relays very fast access to remote relay information for tripping decisions, as well as, initiating tripping commands. With the peer to peer communications systems being developed in substation LANs, local relay information will also be available very fast. Many new relaying concepts, such as adaptive relaying and synchronized phasor relaying depend upon the capability of the digital network to rapidly transmit and make this information available. The ability to communicate with the relays also allows access to additional data from the relays, e.g., oscillography, targets, alarms, fault and metering information.

7 Packet Switching Networks

Packet Switching is a wide area networking (WAN) communications technique where digital data is organized into groups or packets for transmission over shared data networks rather than transmitted over the dedicated lines of a telecommunications network. Packet switching is typically used for computer networks, such as the Internet. Each user communicates in bursts of data over short periods of time. These bursts of data, known as packets or cells, are of various bit lengths or of fixed bit lengths. Transmitting in bursts, over a common communications network allow for multiple users to communicate over a single network, keeping the cost of the communications network low. Unfortunately, for protective relaying communications, a packet's transmission time can be variable and delivery order of packets may be non-deterministic. Adequate bandwidth, new packet technologies and new relay designs, however, may overcome these limitations. For instance, considerable advancements in real time Internet multimedia have occurred as illustrated in the International Telecommunication Union (ITU) H.324 family of standards. Several other packet or cell switching technologies are also popular, such as Frame Relay and Asynchronous Transfer Mode (ATM). Both offer higher channel speed or bandwidth capability ATM, particularly when applied over SONET, may over come the inadequacies of traditional packet switching systems for protective relaying communications.

8 Network Management

One of the features of a digital communications system of interest to the protection community is the network management systems (NMS). NMS can be used to continuously monitor, control, manage and test communications channels. This system should prove invaluable in assuring relay channel availability, dependability, and security. It can be used to automatically and rapidly change communications system configuration when system problems or changes occur. The event data collected by NMS will also be useful in system analysis. Proper consideration should given to the security of the NMS to prevent the inappropriate rerouting, or inservice testing of relaying communications circuits.

9 Need For Standards

Currently relay digital communications utilize many different communication schemes, bit rates and media. One of the more common digital channels utilized is the telecommunications 64kbps standard for voice channels, implemented with a International Telecommunications Union (ITU) V.35, or Electronic Industries Association (EIA) RS- 422 electrical interface. These electrical interfaces are susceptible to electrical interference and should be shielded and restricted to short runs. A fiber optic isolated driver to implement these 64kbps interfaces would provide immunity to the substation electrical environment. Recognizing the need for a standard, a joint working group effort of the IEEE Power System Communications and Power System Relaying Committees is developing of a fiber optic relay to multiplexer interface standard. Ultimately, relay standards should be developed for relay communications equipment and relays to be interoperable.

Part 2: Migration From Analog Communications

10 Applying Pilot Relay Schemes To Digital Media

Table 1 summarizes popular relay systems applicability with various media. Various generations of relays are illustrated.

Figure 4 shows many of the currently used means of interconnecting relays. It is not intended to show all possible combinations. The center of the digital system is the digital multiplexer or channel bank. It conditions the various input channels and, if the input is analog, does the Analog to Digital (A/D) conversion. The multiplexer then assembles the digital signals into a SONET VT or T1 data stream and sends the data out on optical fiber or electrical media to a higher-level multiplexer. For received signals, the multiplexer reverses this process, converting the received data stream into appropriate signals for the connected relays.

10.1 AC Pilot Wire Current Differential

AC Pilot Wire relaying is used for short line or cable protection. Relays at line or zone ends continuously communicate line current information. Relay tripping occurs when differences between local and remote current information exceeds the relay setting. Relay settings allow for a certain deviation due to system unbalances, communication noise, and current transformer inaccuracies.

AC Pilot Wire relaying was popularly used when dedicated twisted pair copper was available for relay end to end continuous communications. This service is no longer available from telephone companies. Consequently, protection systems had to be modified or replaced. Fiber optic current differential replacement is a popular choice.

AC pilot wire relays do not have facilities for compensating channel delay so it is important to establish that the characteristics of the interface and the channel delay are suitable. Depending upon the relaying accuracy required and the application (2 or 3 terminal), the total relay to relay delay must be less than 0.5 to 5 ms. It is also important that the A/D has sufficient dynamic range for the application.

One method of connecting an AC Pilot Wire Relay to a digital channel bank is shown in Figure 4. Arrangement A is an AC Pilot Wire (PW) relay connected to a PW adapter which does the required Analog to Digital (A/D) conversions and provides the power to drive the sensing element of the relay. Connection to the digital system is through a 56/64 kbps digital interface (DIF) module in the channel bank. The other end of the line uses Digital to Analog (D/A) and a PW adapter as well.

Figure 4 Arrangement B is another connection method to a Pilot Wire Interface Module (PWIM) which is part of the channel bank. The PWIM performs the functions of both the PW adapter and DIF in arrangement A. PWIMs are generally available only in channel banks especially designed for substation use, not in general-purpose telephone channel banks.

10.2 Phase Comparison and Current Differential

Phase comparison and current differential relaying systems send current phase information and current phase and magnitude information respectively making these schemes highly dependent upon the communications channels for proper definite zone operation.

Early forms of phase comparison systems utilized single frequency half duplex ON-OFF power line carrier (PLC) for communicating information between relays. The ON carrier state was used to block tripping and the OFF carrier state was used to allow tripping. Each relay used the same one half cycle of power line current information to determine a trip or block condition. Later forms of phase comparison systems utilized two or three state frequency shift modulated (FSK) channel equipment on power line carrier or audio tone equipment.

One of the critical specifications of the channel in a phase comparison and current differential application is the absolute delay of the channel. Since the phase of the power frequency current is being compared to the phase of the current at the other end of the line, any time delay added to the remote signal is a phase error in the comparison process. For example, a channel delay of 1 ms creates a phase error of 21.6 degrees and that will have a significant impact on relay reliability. In a current differential system, a 1 ms delay creates a false differential current equal to about 37.5% of the through current. For this reason channel delay compensation is usually added to each relay before phase information is compared.

Analog phase comparison and current differential relays generally have only manually adjustable time delay compensation. Accordingly, variable time delay media, such as those from path switching, are not recommended if the changes would exceed the tolerance of the relay.

Microprocessor-based phase comparison or current differential relays can have automatic time delay compensation, based on continuous delay measurement. This makes them much more tolerant of path switching than earlier types. However, automatic compensation schemes which assume equal channel delays in each direction may be fooled by some digital network arrangements, e.g. SONET rings in which all traffic flows around the ring in one direction..

Phase comparison or current differential relays using audio tones can communicate over digital systems using 4-wire voice frequency interfaces modules (4WIF), as shown in Figure 4 Arrangements C and E respectively. This method does not change the system operation in any way and the same relay system equipment can be used without replacement of any parts. Utilizing a digital communications system in this manner does not benefit the security and dependability except to the extent that the digital channel may be using a better medium, i.e., fiber optics. The relay system reliability may increase because of the increased reliability of the fiber optics.

Microprocessor-based phase comparison and current differential relays can utilize a 56 or 64 kbps direct digital interface (DIF) with the digital communications equipment, as shown in Figure 4 Arrangements D and F respectively. Arrangement F shows an optical fiber and optical fiber interface (OFIF) option that may be useful for lengthy relay to communications equipment runs. This option will reduce interference and ground potential rise problems. The digital channel also has additional capacity over the analog channel which may be used to communicate additional information, such as relay channel performance data.

10.3 Directional Comparison

Directional Comparison schemes were developed to provide fast tripping for faults anywhere on the transmission line. These schemes combine the directional and distance characteristics of an impedance relay with various pilot communication channels. Impedance relays typically determine direction by comparing the phase angles of various operating voltages and currents either measured or computed by the relay. Typical directional or polarization quantities include the faulted phase voltages and currents, quadrature voltage and fault current, and positive, negative, and zero sequence voltages and currents. Most relays today will use pre-fault voltage to ensure the integrity of the fault direction.

Pilot or communications channels for directional comparison can operate over a wide range of choices such as audio tone, power line carrier (PLC), microwave, and optical fiber. Channel type will either be on/off or frequency shift keying (FSK) carrier depending on the type of scheme implemented. Channel delay is not as critical as for current comparison schemes, however, general coordination rules must be observed. When the different channel types are integrated with the various distance elements, a number of different directional comparison schemes from the dependable direction comparison blocking (DCB) to the secure directional comparison unblocking (DCUB) schemes.

Digital communications can be added to audio tone directional comparison schemes by adding A/D and D/A converters, as shown in Figure 4 Arrangement J. Digital relaying may offer an improved media advantage at the expense of system reliability due to the extra equipment. This has not been a popular approach since directional comparison has been purposefully designed to have less communications dependence than phase comparison or current differential.

10.4 Transfer Trip

Transfer Trip Schemes use communications to provide trip information to a remote relay. The remote relay then may trip as in the Direct Transfer (DT) trip schemes or use the additional information local before tripping as in the permissive schemes, i.e., Permissive Overreaching Transfer Trip (POTT) and Permissive Underreach Transfer Trip (PUTT). These schemes typically use frequency shift audio tones over leased telephone, microwave, and fiber optics.

Figure 4 Arrangement G shows a conventional audio-tone direct transfer trip (DT) connected to the digital communication system through a 4-wire voice channel interface module.

Figure 4 Arrangements H, J, and K show permissive transfer trip relaying systems. In Arrangement H the relay signaling contacts and received signal indication are connected to the digital system by a Transfer-trip Interface (TTIF) module. These modules are generally available for channel banks intended for substation use, but not in channel banks for general-purpose application.

Figure 4 Arrangement J connects the relay by means of an audio tone transfer-trip equipment connected to a 4-wire interface module (4WIF) in the channel bank.

In Figure 4 Arrangement K, the relay is connected through a digital transfer-trip equipment which has a short-haul optical fiber output. As in Arrangement F, an Optical Fiber Interface (OFIF) is then used near or in the channel bank to convert the fiber to a 56 or 64kbps digital signal.

10.4.1 Permissive Overreaching Transfer Trip (POTT) Scheme.

This scheme requires a remote trip signal to permit local relay tripping. This is a secure relay scheme since both line end relays input are required before a trip decision is made. The dependability is impacted by the selection of the communications media. Since communications are required during the fault, a separate communications medium and path are desirable.

10.4.2 Permissive Underreaching Transfer Trip Scheme.

This scheme is similar to the overreaching scheme, although the relays are set for direction and to underreach the line ends.

10.4.3 Direct Transfer Trip Scheme.

This scheme does not need local information for a trip decision, therefore the reliability of the communications circuit is directly related to the systems reliability.

<u>11 Concluding Engineering Considerations</u>

In summary, the engineering of a successful system requires that the performance of the communications systems meet the requirements of the relaying equipment with particular attention to the following:

11.1 Delay

Whereas analog systems were typically constant paths, digital systems can have unpredictable path changes, especially with leased facilities, and data interfaces (modems, 56/64 kbps).

11.2 Dependability

The likelihood of failures in both the equipment and media should be assessed considering backup facility operation. This should be compared with the operational requirements.

It is important to understand that the real probability of inadvertent data crosses and loopbacks in digital systems requires that dependable channels must include unique addressing mechanisms.

11.3 Security

This term is used to describe the freedom from unwanted operations (e.g. false trips). An assessment of the likelihood of data corruption, such as error bursts and data crosses, with the susceptibility of the teleprotection receivers must be made.

11.4 Electromagnetic Susceptibility

Equipment should meet the IEEE surge withstand capability (SWC) standard. Since each application is location dependent, equipment proximity to high voltage and neutral conductors, switching power sources, and other stationary and mobile communications equipment should be examined carefully. This is becoming increasing difficult with new GHz frequency bandwidth allocations.

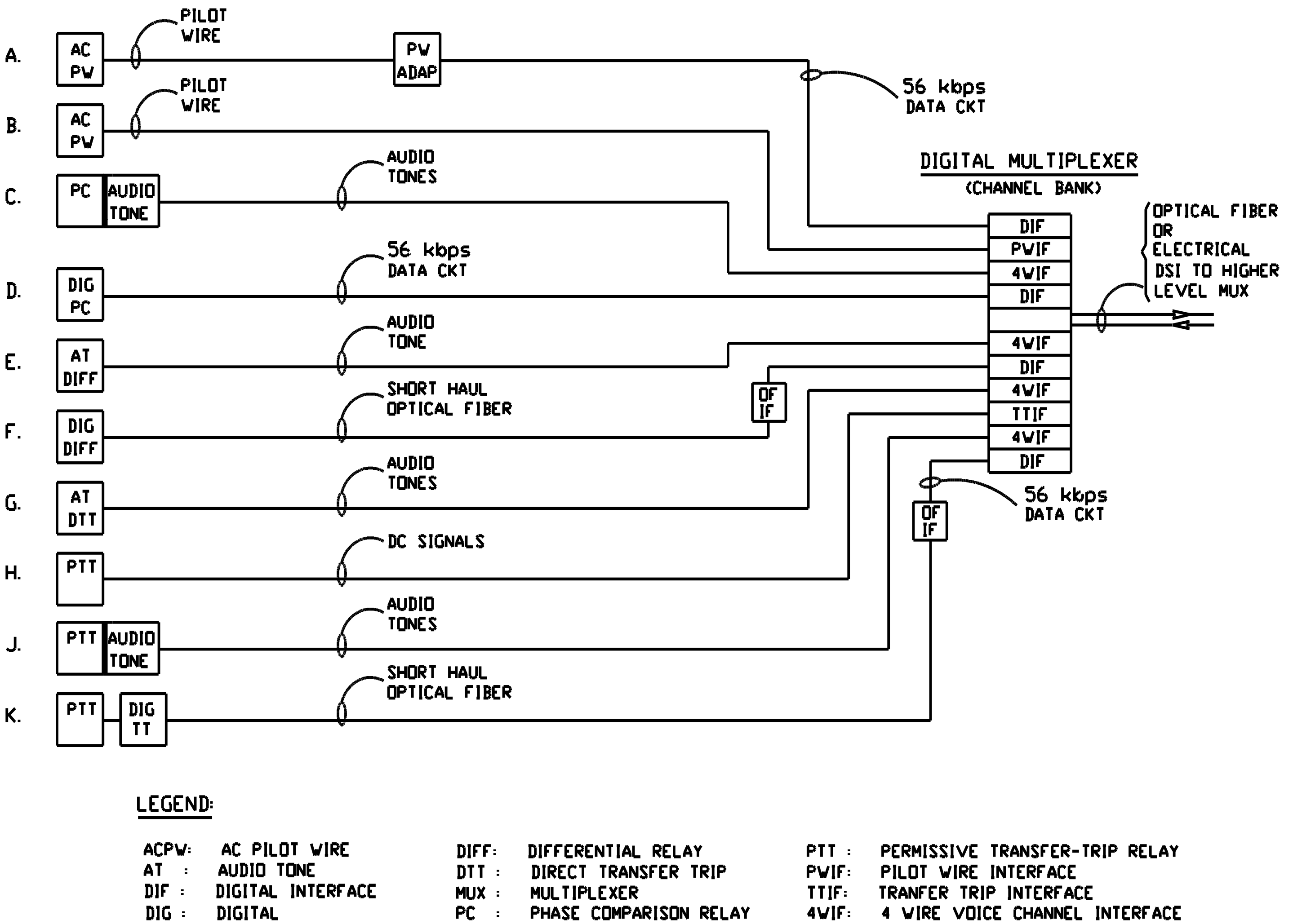

Figure 4 Interconnecting Relays with Digital Channels

Annex

Definitions

The following definitions are representative of how these terms are used in the telecommunications industry.

adaptive relaying - a protection philosophy which permits and seeks to make automatic or semi-automatic adjustments to various protection functions in order to make them more attuned to prevailing power system conditions.

asynchronous - A communication practice where the transmitting and receiving units are not timing the received data via some common clock. EIA 232 is a common asynchronous communications scheme.

bandwidth - In an analog communications system bandwidth refers to the amount of spectrum occupied by the communications signal. In a digital system it is used to refer to the data rate. i.e. " OC3 is a higher bandwidth channel than OC1."
bit stuffing - A technique used to synchronize signals to a common rate before multiplexing. In asynchronous systems the number of bits stuffed varies according to the difference between the outgoing synchronous data rate and the incoming asynchronous rate.
bps- bits per second is a unit of measure of the speed of data transmission when there are only two signal levels (e.g. 0 and 1). The term Baud is commonly misused to mean bps.
byte interleaved - a process used in time division multiplexing where individual bytes from different lower speed channel sources are combined into one continuous higher speed bit stream.
communication protocol - A formal set of conventions governing the format and relative timing devices and other of message exchange parameters between two communications terminals.
data crosses (crosstalk) - Unwanted transfer of energy from one adequate circuit to another.
DACS - Digital Access Crossconnect System - A device which can rearrange the lower speed logical paths in a multiplexed signal for retransmission at the higher rate.
digital cross connect - Any device used to connect electrical or logical signals between devices. Electrically this refers to a patch panel. See DACS.
dynamic range - The difference, in decibels, between the overload level and the minimum acceptable signal level in a communications system.
error bursts - A burst of incorrect data bits in a communications system. Error bursts usually occur during resynchronizaion or bit slippage. Error bursts are more typical than steady state errors in digital communications.
FSK - frequency-shift keying. The form of frequency modulation in which the modulating signal shifts the output frequency between predetermined frequency values.
index of refraction - The ratio of the phase velocity in free space to that in the medium.
multipath fading - The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results causing distortion.
multiplexer - a device allowing two or more signals to pass over and share a common transmission path simultaneously.
overhead bits - Bits in a serial data stream assigned for the use of the communication equipment and not available for payload. Overhead bits are used for functions associated with transporting the payload such as switching and network management.
packet - an ordered group of data and control signals transmitted through a network, as a subset of a larger message.
packet switching - A data transmission technique, which divides user information into discrete envelopes called packets, and sends information packet by packet.
phasor - a complex number representation of a fundamental frequency component of a waveform. A phasor includes amplitude and phase angle information
synchronous - A mode of transmission in which the sending and receiving terminal equipment are operating continuously at the same rate and are maintained in a desired phase relationship by an appropriate means. This means can be an external clock or a clock accompanying the data.
teleprotection - A type of communication terminal equipment used by the relaying industry for sending discrete contact logic signals from point to point with a high degree of security and dependability.
time division multiplexing. Sharing a communication channel among several users by allowing each to use the channel for a given period of time in a defined repeated sequence.
trunked radio - a system that allows multichannel radios to communicate via a central radio backbone. The radios are assigned to a unique channel at the time a connection is made.

TABLE 1

RELAY SYSTEMS AND CHANNEL APPLICATIONS

ELECTRO-MECHANICAL SYSTEMS (< 1965)

RELAY SYSTEM TYPE (a few , if any, transistors/tubes)	METALLIC CIRCUIT (PILOT WIRE)	AUDIO LEASED CIRCUIT	ANALOG M.W. AUDIO	DIGITAL M.W. AUDIO	DIGITAL MUX FIBER	FIBER SONET	DIRECT FIBER	PLC SSB (4 kHz)	SINGLE FUNC. PLC
PERMISSIVE OVER-REACH (POTT)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
PERMISSIVE UNDER-REACH (PUTT)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
DIRECTIONAL COMPARISON BLOCKING (DCB)	NOTE 1	OK	OK	OK	OK	NR	OK	OK	OK
DIRECTIONAL COMPARISON UNBLOCKING (DCUB)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
PHASE COMPARISON	NO	NO	NO	NO	NO	NO	NO	NO	OK
CURRENT DIFFERENTIAL	OK	NR	NR	NR	NOTE 2	NOTE 2	OK	NR	NO
DIRECT TRANSFER TRIP	OK	OK	OK	OK	OK	OK	OK	OK	OK

STATIC / DISCRETE SYSTEMS (> 1965)

RELAY SYSTEM TYPE (some digital logic)	METALLIC CIRCUIT (PILOT WIRE)	AUDIO LEASED CIRCUIT	ANALOG M.W. AUDIO	DIGITAL M.W. AUDIO	DIGITAL MUX FIBER	FIBER SONET	DIRECT FIBER	PLC SSB (4 kHz)	SINGLE FUNC. PLC
PERMISSIVE OVER-REACH (POTT)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
PERMISSIVE UNDER-REACH (PUTT)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
DIRECTIONAL COMPARISON BLOCKING (DCB)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
DIRECTIONAL COMPARISON UNBLOCKING (DCUB)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
PHASE COMPARISON	NOTE 1	OK	OK	NOTE 3	NOTE 3	NOTE 3	OK	OK	OK
CURRENT DIFFERENTIAL	OK	OK	OK	NOTE 3	NOTE 3	NOTE 3	OK	NR	NO
DIRECT TRANSFER TRIP	OK	OK	OK	OK	OK	OK	OK	OK	OK

MICROPROCESSOR SYSTEMS

RELAY SYSTEM TYPE	METALLIC CIRCUIT (PILOT WIRE)	AUDIO LEASED CIRCUIT	ANALOG M.W. AUDIO	DIGITAL M.W. AUDIO	DIGITAL MUX FIBER	FIBER SONET	DIRECT FIBER	PLC SSB (4 kHz)	SINGLE FUNC. PLC
PERMISSIVE OVER-REACH (POTT)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
PERMISSIVE UNDER-REACH (PUTT)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
DIRECTIONAL COMPARISON BLOCKING (DCB)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
DIRECTIONAL COMPARISON UNBLOCKING (DCUB)	NOTE 1	OK	OK	OK	OK	OK	OK	OK	OK
PHASE COMPARISON	NOTE 1	OK	OK	NOTE 4	NOTE 4	NOTE 4	OK	NOTE 3	OK
CURRENT DIFFERENTIAL	NR	OK	OK	NOTE 4	NOTE 4	NOTE 4	OK	NR	NO
DIRECT TRANSFER TRIP	NR	OK	OK	OK	OK	OK	OK	OK	OK

NR Not Recommended
NOTE 1 Possible Using Audio Tone
NOTE 2 This Application Must Keep Channel Delay To A Minimum Possibly Less Than 0.5 To 5 ms
NOTE 3 OK Using A 4 Wire Tone Interface
NOTE 4 OK Using A 4 Wire Tone Interface But Better To Use 64 kBps Digital Interface