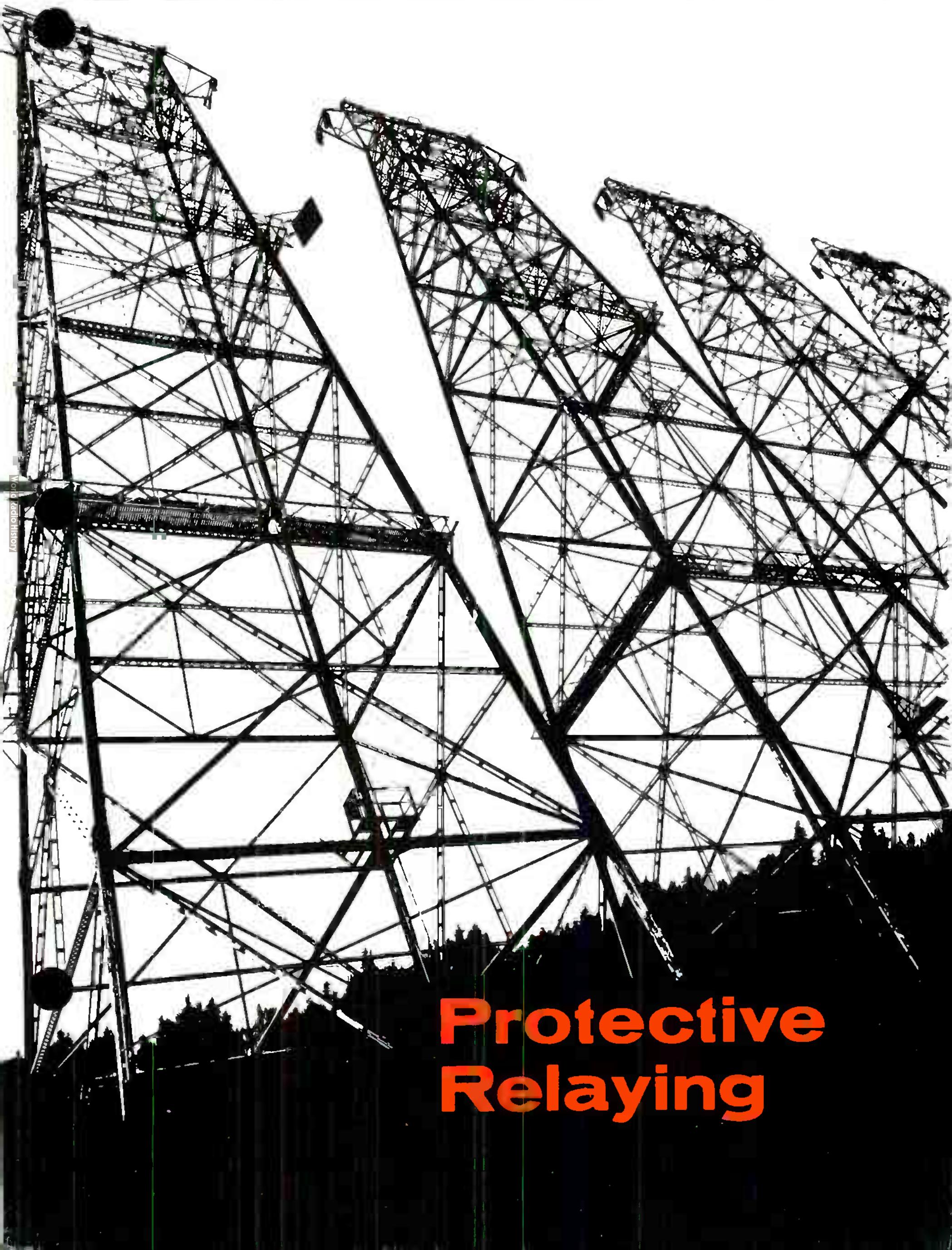
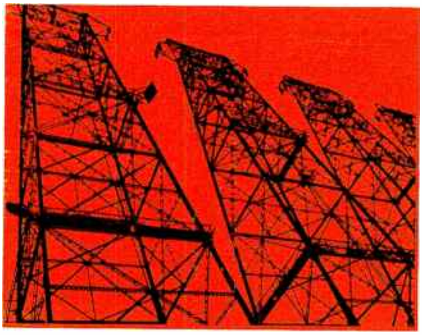
The Lenkurt

MARCH 1969

DEMODULATOR



Protective Relaying



Vital Communications for Power Transmission

The unique nature of power transmission introduces communication problems not found in telephony and similar industrial communications. "Faults" or outages in a telephone network interrupt valuable and important communications, but neither the uses nor the communications network are otherwise affected; the loss of communication and information is the greatest harm that results.

In power transmission, however, a different type of commodity must be moved — raw power, electrical energy which may achieve an incredible magnitude. When power fails, almost everything around is affected. A breakdown in the power distribution system can literally paralyze any part of the country that is deprived of electricity. This was darkly evidenced by the outage that struck the American Northeast in 1965.

No less important is the effect of a transmission breakdown on the generation and distribution network itself. Modern power transmission is a finely balanced operation in which great amounts of energy are transformed by generators into electricity and moved efficiently through distribution networks to the consumers. The power that is generated and transmitted is carefully matched to consumer demand and the load-carrying capacity of the transmission network. Faults upset this balance, possibly releasing the load from a generator without warning, or maybe doubling it, in the case of short-circuited lines. Such faults can suddenly release millions of watts of power which, if unchecked, can severly damage or destroy generating and transmitting equipment worth hundreds of millions of dollars.

Because of the extreme importance of protecting equipment and maintaining service despite the almost inevitable occurrence of faults, many techniques have been developed for minimizing the effects of such occurrences. The most important of these is the organization of power "grids" or multi-terminal transmission networks which link many power sources and load centers.

Successful operation of the power grid requires a rather elaborate combination of sensing relays on each transmission line for detecting the presence of a fault on the line and swiftly triggering circuit breakers to isolate the fault before serious damage can occur.

The Power Grid

In the earliest days of electric power, transmission was necessarily local. Generating stations were located

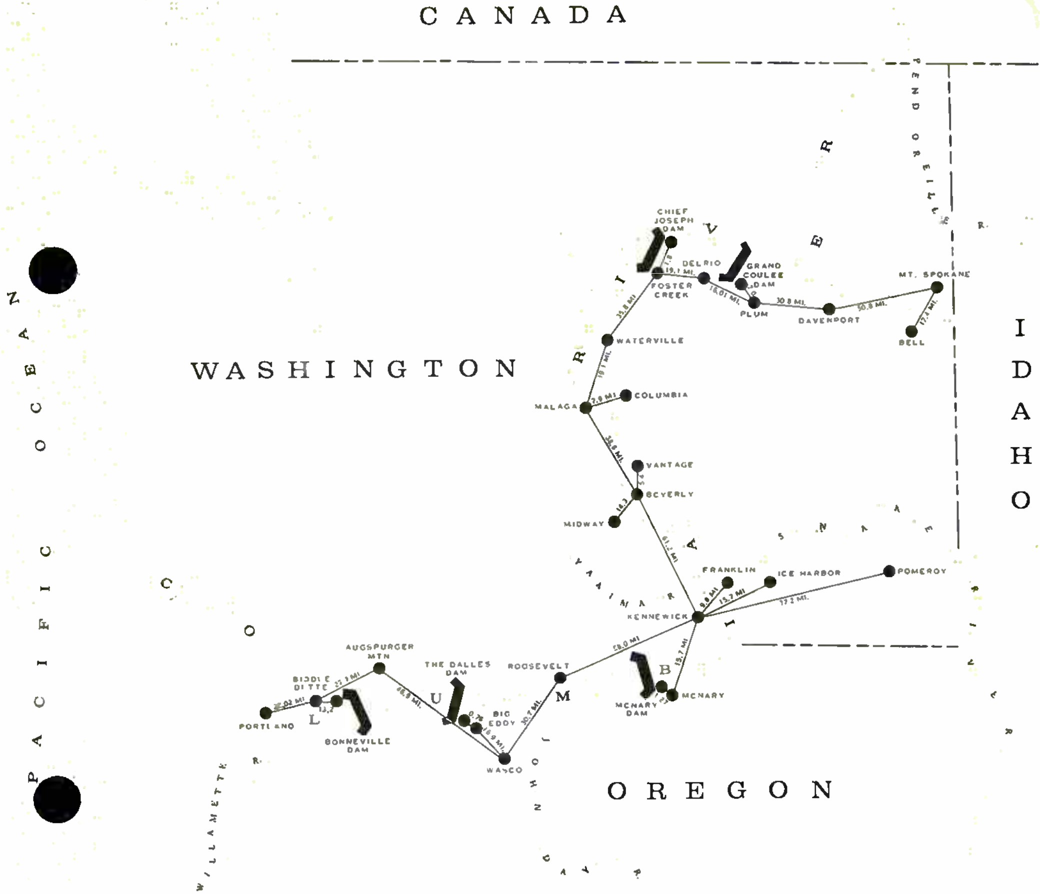


Figure 1. The Bonneville Power Administration's EHV network in the Pacific Northwest is typical of modern extensive power transmission systems. Recently, consideration is being given to creating an intertie between this network and a similar one in the Southwest.

close to the consumer, direct-current power was used, and voltage was low. Because of the low available voltage, current had to be high for a given amount of power. This limited the distance over which power could be transmitted, since transmission loss is proportional to I^2R, (where I is current and R is line resistance).

With power distribution restricted to short distances, standby generators capable of meeting peak loads were required to permit routine maintenance and to protect against failures. Naturally, this was very expensive.

Since then, the practice has changed. Alternating current permits transformers to be used to step the voltage up to very high values for transmission. By raising the voltage and lowering current, transmission loss is reduced, permitting power to be transmitted efficiently over great distances.

It soon became evident that widely spaced generators, each serving its own

Figure 2. Typical substation with adjacent switching yard.

area, could be connected together to provide "mutual aid". If one generator or transmission line should fail, another could take on its load, thus maintaining service. As long-distance transmission became more efficient, it became possible to connect a greater number of widely separated power plants together in the network.

This capability has been further enhanced through a technique known as load shedding. Through the use of supervisory control systems, generator frequencies can be monitored. When overloads are indicated, portions of the power load can be transferred to other generators' networks. If a given generator's frequency falls below a predetermined rate – usually 58.5 Hz – it is shut down automatically and its entire load transferred to other parts of the facility.

Obviously power grids are more efficient and beneficial to all parties as they are increased in size and area. It is possible to adjust generating capacity to accept load changes more smoothly, since periods of peak demand in various parts of the grid may not necessarily coincide. For instance, daily peak load often comes at nightfall. This will obviously occur at different times in cities which are widely separated in longitude. Similarly, there may be a considerable seasonal load difference between cities of the far north where winter daylight hours are few, and in the far south where electricity is used in large quantities for summer air conditioning. The ability of each area to help the other permits more modest investment in generating plant.

A catastrophic fault in large power grids, however, can affect far more consumers and more actual power than in simpler systems. Without some means of rapidly isolating a serious fault, literally hundreds of millions of watts from the grid could be released, causing serious damage to the transmitting and generating equipment. Even individual generating sites may have a tremendous power capability. For instance, some large generating plants produce currents as high as 50,000 amperes at 250,000 volts if the main bus (uninsulated circuit junction) is short-circuited to ground. In this case, more than ten *billion* watts would be dissipated in the fault and equipment. At this rate, enough power would be liberated *in one second* to supply all the power requirements of a small town for a full year. A surge of this much power, if unchecked, can seriously damage transformers, generators, or transmission lines.

To guard against such damage, fast acting circuit breakers must be used to disconnect a "faulted" circuit as rapidly as possible. Speed of operation is essential in minimizing or preventing damage. Typically, modern high-power circuit breakers are built to break the flow of current within three cycles (1/20th second) of the occurrence of the fault. Even at this speed a major fault of the size mentioned above would still dissipate 150,000 kwh before the circuit could be broken.

Even where less power is involved, speed is very important in isolating a fault. This presents a problem since accurate discrimination between true faults and such natural occurrences as switching transients requires time. For instance, switching transients or momentary heavy loads (surges) which are within the capacity of the system should not cause circuit breakers to trip as if a fault were present. However, actual faults must be promptly recognized and isolated swiftly.

Protective Relaying

To reduce uncertainty as much as possible, many special fault-sensing arrangements have been developed. Most employ sensitive relays which are able to distinguish between normal conditions and faults. One of the most basic types of protective devices is called an "overcurrent" relay. It protects against loads which are beyond the ability of the equipment to safely accommodate. Such loads may occur because of unusual peak demand, faults, or a combination of these. The overcurrent relay does not discriminate between faults and heavy demand.

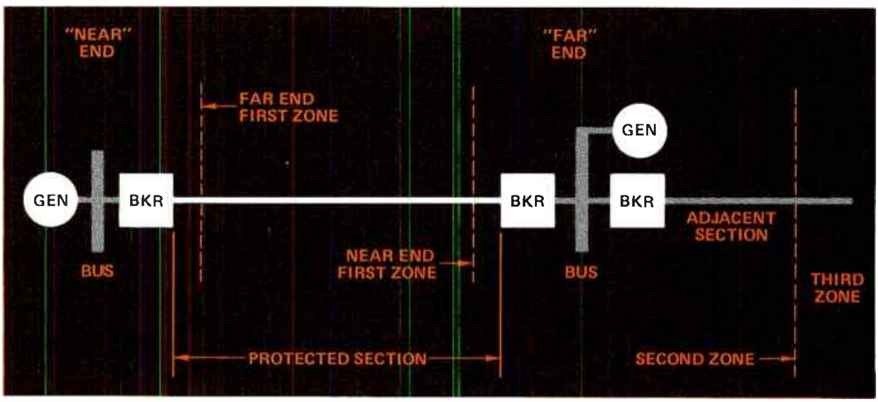


Figure 3. Schematic representation of a typical transmission line. Distance relays must be adjusted to respond only to faults in "first zone," thus avoiding false trips due to ordinary switching transients in far-end switch yard. Different type of sensing arrangement is used to detect faults in second zone. Second zone includes portion of adjacent section, third zone includes everything beyond.

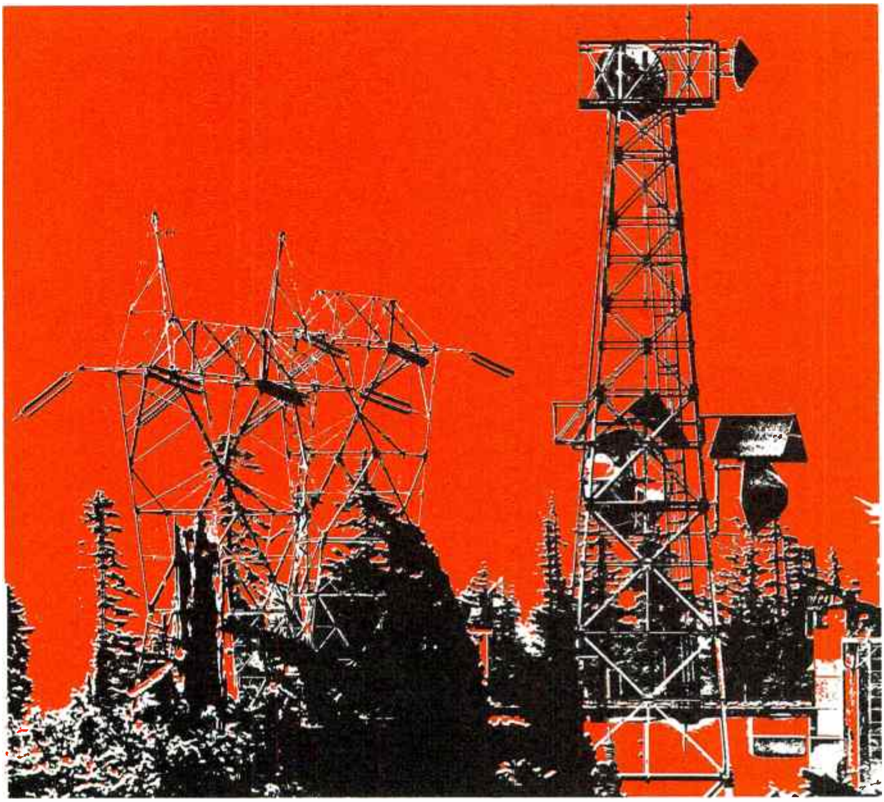


Figure 4. Microwave radio is fast becoming an indispensable adjunct to effective, reliable transmission of electric power.

One of the basic types of protective relay which can distinguish between faults and normal overload is the "distance" relay. These devices monitor voltage and current on the line independently. Under normal conditions, increased voltage will result in increased current. In some fault conditions, however, (such as a ground fault or transmission line short-circuited to ground), line voltage will drop and current increase. The relay is sensitive to the relative values of current and voltage, and the resulting impedance. When a fault occurs, line impedance will change and the relay will trip if not prevented from doing so by other relays which guard against false trips. Because the transmission line is reactive, the impedance change varies with the distance from the fault. It thus becomes possible to adjust the relay to respond to faults which occur within a certain distance, but ignore those beyond.

Another way of sensing line faults is to compare the phase of the current at one end of the line with the phase at the other. Under normal conditions, the two ends will be in phase. If the line is short-circuited or grounded, however, the phase at one end will reverse with respect to the other. The phase reversal will be detected and cause circuit breakers at both ends of the line to trip.

In order to achieve reliable tripping, yet avoid false trips, conventional relay arrangements may be quite elaborate. Often two or three back-up relay arrangements are employed to provide high speed and supplementary protection as well as preventing false tripping because of faults in adjacent transmission sections.

Many different relaying methods may be used, according to circumstances and line characteristics. A typical basic arrangement for a two-terminal transmission section is diagrammed in Figure 3. High speed distance relays are used at each end of the line to provide fast "first zone" protection. The relays are adjusted to respond to faults occurring within 90% of the distance to the far end of the transmission line. It is necessary to adjust the relay for less than the full length of the line to avoid responding to momentary transients and surges caused by normal switching at a distant switchyard. At the distant end, a similar arrangement is used. Thus, faults occurring within the center 80% of the line will be detected at each end and quickly isolated by tripping the breakers at both ends.

If a fault occurs within the far 10% of the line, the distant breaker will immediately trip, thus disconnecting its end of the line. However, since the fault is beyond the reach of the near-end relay, it cannot respond. Consequently, the generator at the near end will still be feeding power to the fault.

To prevent this from continuing, an "overreach" relay (Figure 5) is used. It is a sensitive distance relay that is adjusted to respond to faults occurring not only on the protected transmission section, but also in the first 20% of the adjacent section.

In order to prevent this relay from tripping the near-end circuit breakers for faults in the next section, a blocking signal is transmitted, which, in effect, identifies the fault as lying in the next section and prevents breakers in the local section from operating. In order to allow the blocking signals "first priority," the overreach relay is normally made slightly slower acting than the first zone relays and the blocking signals. This time delay also may tend to prevent tripping in response to routine switching transients occurring at the far end.

Obviously, some sort of independent communications channel or so-called "pilot" circuit is required to link each end of a transmission line in order to trip the breakers at both ends of the line in case of a fault. Traditionally, these pilot channels have taken the form of wire or cable circuits, "power line carrier" channels, or channels transmitted by microwave.

Each of these methods has its own advantages and disadvantages. Physical circuits are generally limited to short distances, usually 10 or 15 miles, mostly because the shunt capacitance and series resistance of the line alter the currents which are put on the line to detect faults. This effect becomes excessive as distance increases.

Power line carrier is widely used for protective relaying, but is gradually giving way to microwave because of its limited information capacity, relatively high cost, and dubious reliability at the moment it is needed most — during a fault. Power line carrier systems transmit tones in the frequency range 30 to 200 Hz directly over the power lines themselves. Normally, the carrier transmitter and receiver are coupled to one phase wire of a three-phase transmission line. If the fault

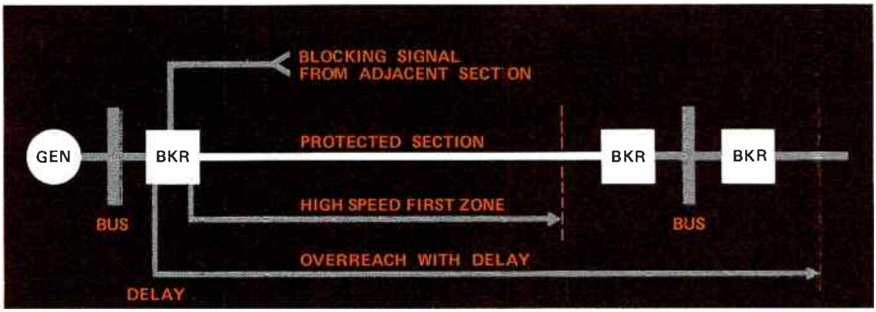


Figure 5. Typical "overreach" arrangement with third zone blocking. High speed distance relays at both ends detect first zone faults. Sensitivie overreach relay detects second zone faults, but is blocked by signal from far end which indicates when the fault comes from the adjacent section. A slight delay is built into the overreach circuit to allow the blocking signal to have "first priority" in acting.

occurs on the particular line carrying the signal, there is some chance that the signal still may be able to get through the fault by inductive and capacitive coupling to the adjacent phase wires.

During a fault (which may consist of a short circuit between phases or between one or more phases and ground), noise is extremely high, and this may obscure communication even if the phase wire carrying the signal is not involved. Because of these possible hazards to communication, many protective relaying arrangements which use power line carrier are arranged to prevent or *block* the tripping of a circuit breaker. Thus, it is not necessary to transmit through a fault. If a blocking signal continues to be received, it tends to confirm that the fault lies in another transmission section. Of course, many other blocking arrangements may be used to prevent a circuit breaker from tripping in error. These blocking arrangements are effective and dependable but are generally most suitable for simple two-terminal transmission lines.

As power grids grow more complex, there is greater use of multi-terminal transmission sections, that is, sections which have one or more branches. A fault in such a section is much harder to detect accurately than in a two terminal network since it may occur in a branch carrying some fraction of the energy appearing at the other terminals. Fault detecting techniques such as phase reversal are particularly difficult due to a substantial loss of sensitivity to the fault condition.

Multi-terminal sections also greatly increase the communication problem because it is necessary that each terminal be able to signal directly to each of the others. In the case of power line carrier, this uses up the limited signal bandwidth very rapidly. For example, a two-terminal line would require only two frequencies, one for each direction. A three terminal line requires six frequencies, while a four-terminal line must employ 12 frequencies. Once used, these frequencies should not be used again in nearby sections of the grid because of the difficulty of removing them from the power lines.

Although frequency traps are customarily used, they are necessarily simple devices (since they must operate at hundreds of thousands of volts), and are thus not completely effective in blocking carrier frequencies. Since most carrier tones are used as blocking signals, undesired tones from a distant transmission section, even though attenuated, might prevent a breaker from tripping during a fault. As a result, limited available bandwidth on power lines restricts the use of power line carrier in large or complex power grids.

Transferred Trip

One solution to these problems is the use of remote tripping or *transferred trip* as it is often called. The principle of transferred trip is directly opposite that of conventional blocking schemes which prevent a circuit breaker from tripping. With transfer trip, distant breakers are tripped on command of a signal from a terminal where a fault has been identified. Thus, all breakers in a section – even where there are several branches – may be tripped rapidly to isolate the fault. It is necessary to arrange the fault detecting relays to overlap their areas of sensitivity so that a fault anywhere in the line will cause at least one terminal to trip and transmit a signal to the other terminals. Naturally each terminal is still free to trip at high speed if the fault is detected by that terminal's high speed relays.

A principal objection to transferred trip operation is that it lacks security. It may produce false trips as a result of noise or other interference – hence, it is not "fail safe". In the event that the communications channel over which the trip signal is sent should fail, protection of the grid would decline.

Offsetting this argument are the inherent simplicity and adaptability of the transferred trip method, and the fact that it provides 100% backup for the relaying methods on the transmission line itself.

Security, Speed, and Reliability

Most faults consist of a short circuit between phases of the transmission line or between one or more phases and ground. Often these result in an arc. When this happens electrical noise is tremendous. Since a power line carrier channel must be assumed to be unreliable at the time of a fault, this is the basic reason that many conventional protection methods use the transmitted signals to *block* the tripping of breakers.

Installation of modern microwave systems relieves this problem by establishing reliable communication channels that are not associated with the line, and are therefore free from the interference caused by line faults. In the past, microwave seemed too costly and was considered unreliable. Two factors are changing this, however. Modern solid-state microwave systems are now able to operate directly from batteries, thus eliminating outages due to power failures. In addition, substantial improvements are achieved by increased use of transistors and by effective techniques for switching to standby equipment very rapidly in case of equipment failure. Furthermore, the cost of the coupling and frequency trapping equipment required for power line carrier has tended to increase greatly as higher and higher transmission voltages are used. This increased cost has not relieved the shortage of carrier frequencies or increased information capacity.

Although microwave provides communication channels that can be used for any of the conventional relaying methods which normally use a pilot wire or power line carrier, it is also

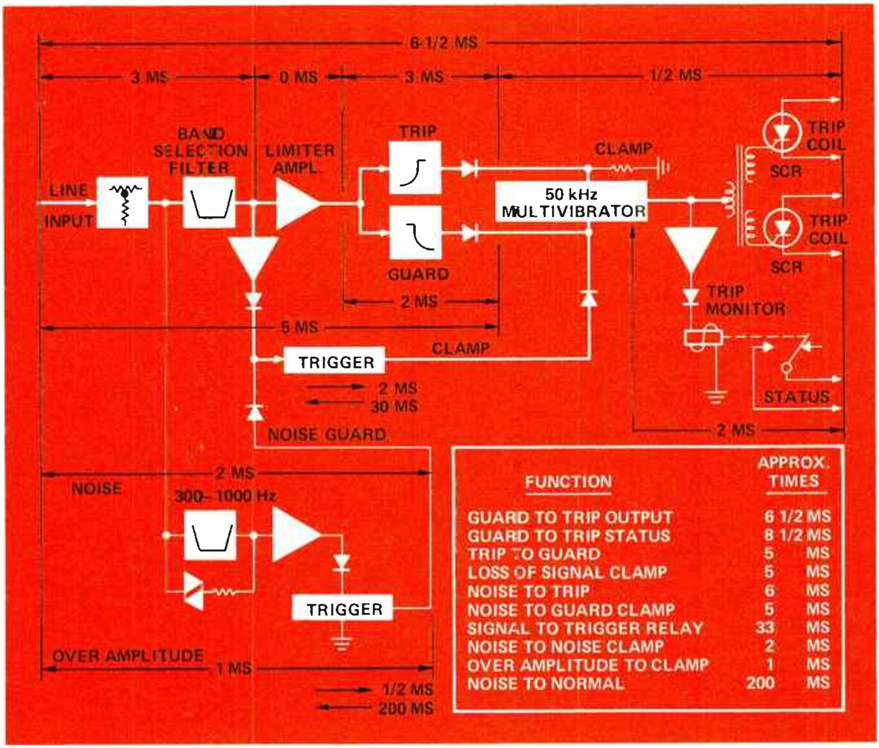


Figure 6. Lenkurt Type 937A achieves very high security against false trips due to noise by using overlapping and interlocking circuits which distinguish between noise and desired signals. Special care is devoted to time constant of filters used to separate noise and signals. Interposing relays are eliminated by SCR's.

suitable for remote tripping. Accordingly, its use in power transmission is growing very rapidly.

With higher transmission voltages, a transmission line carries much more power than formerly. This makes it especially important to react to a fault with utmost speed. Modern relaying equipment and circuit breakers are able to isolate a line within about three cycles after a fault occurs. But additional time delay in responding to a fault may be introduced by the communications equipment and additional relays which may be used to trip the circuit breaker. Relays are often used in tone equipment of older design to control the fairly large amount of current required to trip the circuit breaker. However, with few exceptions, they contribute more delay and more unreliability than any other component in the system. In protective relaying the equipment may not be actuated even once a year, with the result that contacts may oxidize or become dusty, and fail to function when energized. In addition, relays add as much as 18 milliseconds further delay to the tripping of the breaker.

Both of these objections can be overcome by using modern solid-state components such as silicon controlled rectifiers (SCR's). These heavy-duty devices have no contacts or moving parts, and switch within a microsecond after being keyed, thus eliminating a major source of needless delay. Furthermore, the SCR is not subject to chatter or dropout. Once triggered, it goes on conducting, thus assuring that tripping will be completed.

One of the biggest problems encountered in transferred trip protection is to provide positive tripping on command, but avoid false trips caused by noise, hum, or other sources of interference. This is essentially a communications problem which yields readily to techniques developed for multichannel carrier equipment.

The highly successful approach taken in the Lenkurt 937A protective relaying equipment is diagrammed in simplified form in Figure 7. One of the unique features of this equipment is the careful attention give to the most critical factor in protective relaying, time — that is, the absolute time delay required for electrical energy to get through the various electrical filters used. The time delay imposed on a signal by a filter is inversely proportional to its bandwidth; the narrower the bandwidth of the filter, the slower the operation. In the 937A equipment, noise and signal tones follow separate paths having different time delays. The noise is given a "fast" path to a clamping circuit which overrides or blocks a multivibrator trigger circuit and prevents a false trip. Similarly, the guard tone filter is designed for a faster response time than the trip filter. This gives the guard signal "priority" and helps prevent spurious tripping. The circuit is arranged so that a trip signal can actuate the SCR output devices only if the trip signal is applied simultaneously with the removal of the guard tone. Several additional protective circuits are also incorporated to eliminate improper operation under various other conditions which might occur in service.

Total elapsed time between keying and the rise of current in the circuit breaker trip coil is 8 milliseconds in the 937A, almost all of it contributed by the filters. Although it is possible to reduce this delay by increasing the bandwidth of filters, this would impair the ability of the equipment to discriminate between noise and authentic tripping signals. In actual service, this design approach has proved more than adequate. Tripping signals never cause false trips, even if, during a major fault in an adjacent section, intense noise and heavy current surges occur in the switch yard.

As ever increasing power loads are handled by ever larger and more complex grids, tripping time becomes the most critical factor in protective relaying. Because of this, more emphasis will be placed on the faster solid-state devices such as SCR's. For the same reasons, microwave radio and protective relaying systems working in conjunction will also be subject to more attention in the future.

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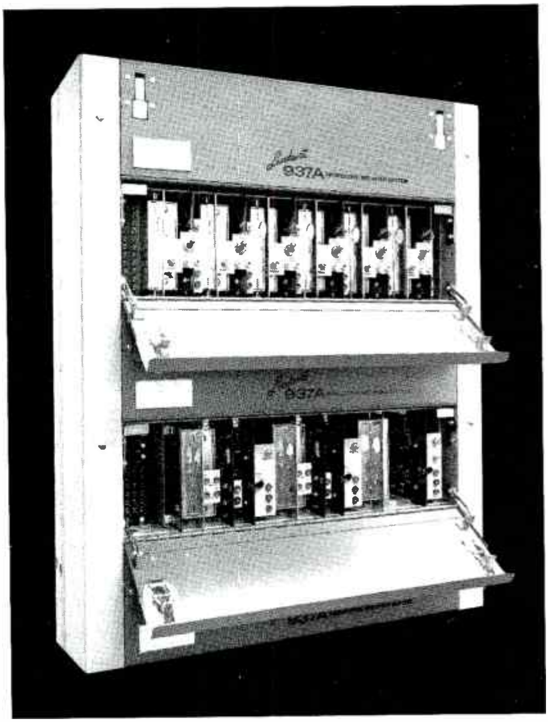

EIGHT MILLISECOND PROTECTION

Three outstanding features distinguish the Lenkurt 937A Protective Relaying System — instantaneous reponse, high current output and maximum reliability. It is all solid-state with SCR's, transistor-controlled outputs and signal/noise monitoring circuits for preventing false trips. For more detailed information write Lenkurt, Dept. C720.

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