New Techniques
in
Transmission Line Protection

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INTRODUCTION

Distance functions for high voltage transmission line protection have been traditionally applied on a per-phase or phase-pair basis.(1) Therefore, an overall total of six single-phase functions is required to provide one zone of protection for faults of all types, i.e., three functions for phase fault protection and three functions for single-line-to-ground fault protection. There are a number of distinct advantages in relaying on this basis:

1. Independent zones of protection are provided. Thus, if one did not operate as planned, the remaining zone or zones would remain operative.
2. Redundancy and a certain degree of backup is provided within each zone. For example, three functions would operate for a three-phase fault, whereas a combination of phase and/or ground distance functions might operate for some unbalanced faults. Thus, if difficulty was experienced with one or more of the functions involved, protection would still be provided.
3. Probably the most important advantage of all is operating time. Since the zone one functions operate independently of all other functions, fast operating times can be achieved, especially for heavy faults where operating time may be critical. Overall faster operation is also achieved for three-phase faults because operating time is related to the point on the voltage wave at which the fault occurs. Hence, at least one of the three single-phase functions will be in a position to operate quickly during three-phase faults.

Since the cost and complexity of this approach cannot always be justified on lower voltage or less critical lines, a new modular system has been developed. This system, designated the SLS1000, uses the latest in distance measuring principles to provide complete stepped distance and pilot protection without the need for total phase and zone redundancy. Other objectives were to:

1. Provide improvements in performance via new circuit and measuring techniques.
2. Simplify ease of application, setting and installation.
3. Design a low cost and compact modular package to house this system, as well as future systems now being designed.

BASIC SYSTEM

The SLS1000 is a complete system that uses distance functions to provide protection for faults of all types. The basic system provides a standard step distance relaying scheme (see*Figure 1*), or it can be used with a communication channel to provide the most commonly used pilot relaying schemes. In both of these respects, the system is no different than schemes using single-phase functions. They differ in that one main measuring function is used in this system to make the distance measurement.

This main measuring function is controlled by phase selectors (often called starters) which select the faulted phase or phase-pair to which the measuring function must be connected during a fault. Three phase selectors are provided, each connected on a per-phase basis.

Typically, the measuring function would be set with a zone 1 reach and tripping would be initiated without time delay after the phase selector(s) operated provided the fault fell within the reach of the main measuring function.

The phase selectors also start zone timing functions which extend the reach of the main measuring function as time progresses to provide stepped distance protection. Up to three zones of protection are thus provided via this single measuring function. A fourth zone timer can be connected to initiate tripping through the phase selectors.

DISTANCE FUNCTIONS

There can be up to eight distance measuring functions in the SLS1000; three phase selectors, the main measuring function, a permissive zone measuring function for use in pilot schemes and out-of-step detection, and three blocking functions for use in blocking type schemes. All employ the same basic principle of measuring distance; they compare the phase angle between their operating and polarizing quantities to determine if the fault is within their reach.

Phase Selectors

The phase selectors form the heart of the SLS1000 system. The phase selectors must:

1. Detect the presence of a fault on the portion of the system to which it is applied.
2. Identify the faulted phase during single-line-to-ground faults.
3. Identify the faulted phases during multi-phase faults.
4. Initiate zone timing to extend the reach of the main measuring function.
5. Operate correctly during the open-pole period following a single-pole trip when such tripping is employed.
6. Not operate on load current.

If there were no load current in the system, or if fault currents were always above load current, the simplest type phase selector would be an overcurrent function. Unfortunately, systems without load are meaningless, and in many cases fault currents are less than load current, thus precluding overcurrent functions from use. For this reason, distance type functions are preferred and usually employed.

Various types of distance functions were evaluated for use as phase selectors before settling on the concept used in this new system. The resulting function is a variation of a positive sequence polarized mho ground distance function. Simplified circuitry for the function is shown in *Figure 2.* The response for the function is shown in *Figure 3* for a three-phase fault. The characteristic for unbalanced faults will be similar, but not identical, to the dynamic characteristic shown in *Figure 3.* The K factor and the positive sequence voltage (with memory) in the operate circuit are used to:

1. Expand the reach so that the function will see faults with impedance less than or equal to the set nameplate reach Z_R.
2. Provide faster operation and hence improved performance for all fault types.

Positive sequence voltage polarization provides a stable and reliable polarizing quantity to produce:

1. A variable mho characteristic for unbalanced faults. Increased arc/fault resistance coverage is thus provided.
2. A continuous output for zero-voltage unbalanced faults.
3. Good performance of the phase selectors during the open-pole period following a single-pole trip; i.e., there will be little or no phase shift in the polarizing quantity even though there is a reduction in magnitude. This is true for the phase selector associated with the open phase, as well as the unopened phases.

A memory filter is used in the polarizing circuit to provide dynamic operation for three-phase zero-voltage faults. A line pickup feature is provided for the case of closing into a zero-voltage three-phase fault when line-side relay potential is used. The line pickup circuit uses overcurrent tripping with undervoltage supervision.

The phase selector is directional for most system conditions. The area shown below the R axis applies for capacitive faults in the forward direction. The function will operate for faults directly behind it for the case where the sum of the line impedance of the protected line and the source impedance at the remote end of the line is greater than four times the setting of the phase selector. The loss of directionality comes about because of the positive sequence voltage signal added to the operating signal and has no significance because the measuring function is directional or is supervised by a directional function so that no operation will occur for reverse faults.

In summary, the phase selectors form a crucial part of systems such as the SLS1000. Because it is required that they perform correctly for all fault types, conflicts in performance may arise, and compromises may have to be made and accepted in both their design and application. The phase selectors have been designed with these requirements in mind to give the best possible performance with the least amount of compromise in both design and application.

Main Measuring Function
A. Multi-phase fault protection

For multi-phase faults, the main measuring function is always applied as a variable mho phase distance fuction. The characteristic for such a function is shown in *Figure 4.* The figure shows the quantities identified as I and V only. In actuality, these quantities would be those associated with the faulted phase pair, i.e., I_A-I_B and V_{AB} for the A-B phase pair.

Note, that the polarizing quantity is supplemented with positive sequence voltage V_1. This is what gives the function its variable characteristic. The variable mho characteristic provides:

a) Increased arc resistance coverage

b) Steady-state output for zero voltage phase-to-phase faults

c) Increased security for reverse faults.

B. Single-line-to-ground fault protection

For phase-to-ground fault protection, the main measauring function can be applied as a variable mho characteristic, or as a regular or modified reactance characteristic. The choice is up to the user. The characteristic for the variable mho function is shown in *Figure 5.* Note here that the use of positive sequence voltage for the polarizing quantity produces the variable mho characteristic. The following advantages can be attributed to the variable mho:

a) Increased fault resistance coverage

b) Steady-state operation for zero voltage phase-to-ground faults.

Before discussing the reactance characteristic used in the SLS1000, a brief discussion of reactance functions in general seems appropriate.

A typical reactance function is shown in *Figure 6.* This function uses the familiar IZ-V as the operating quantity, but the polarizing quantity is derived from the current I. For the balance point fault shown, V_{OP} and V_{POL} are exactly 90° apart. If the fault is moved closer to the relay location, Z_L will decrease relative to Z_R, thus the V_{OP} phasor will rotate clockwise and the angle Θ will become less than 90°. This is an operate condition so the function will produce an output. As the fault is moved further away, Z_L will increase relative to Z_R and the opposite will occur; i.e., the V_{OP} phasor will rotate counterclockwise to increase the angle Θ and so stop operation.

If breaker B is closed, and if E_L and E_R are held at the same angle so there is no load flow, results similar to that shown in *Figure 6* will be obtained and the reactance function will measure the correct impedence. Infeed from both ends of the line amplifies the drop in the resistance and so causes a distance function to appear to see a larger resistance than is actually there. The end of the line with the lowest contribution to the fault will be affected the most. In both the above cases, the operating quantity is proportional to, and in phase with, the drop in the fault resistance. The polarizing quantity leads the current by 90° hence V_{OP} and V_{POL} are 90° apart which is the balance point condition. This is true because the total current in the fault which produces the drop in R_F and the current in the relay which produces the polarizing signal are at the same angle.

Now consider the case of load flow. In this case the effect of load current will cause the relay current and the total fault current to be at different angles. This will cause the drop in the resistance to rotate relative to the polarizing quantity. Rotation of IR_F in the clockwise direction will decrease the angle Θ and cause operation; i.e., the function will overreach. Counterclockwise rotation will be in the direction away from operation, hence the function will underreach. Thus, the effect of load flow and the direction of load flow on a fault with resistance in it is to cause underreaching or overreaching of the reactance function shown. Another effect to consider is non-homogeneity of the system, i.e., the system impedances are at different angles. Here, too, the total fault current and the relay current will be out of phase and, depending on the system, overreaching or underreaching can result. The R-X diagram of *Figure 7* illustrates this phenomena.

The polarizing quantity for the reactance function used in the SLS1000 system is derived from the negative sequence current at the relay, rather than the total relay current. Negative sequence current polarization eliminates the effects of load flow. This is illustated in *Figure 8,* wherein the angle Θ between the polarizing and operating quantities remains at 90° regardless of load current. This is so because the operating quantity is proportioned to the total fault current while the polarizing quantity is proportional to the negative sequence current I_2 in the relay. Since the total fault current and the negative sequence relay current are in phase, V_{OP} and V_{POL} will be 90° apart. Note this in-phase relationship will disappear if the system is non-homogenous and this function too would have a tendency to overreach or underreach.

The SLS1000 reactance function has been designed so that it can be applied as a modified reactance (tent) function in those cases where overreaching can result. The characteristic for this function is shown in *Figure 9.* The angle of tilt Ø is adjustable over the range of 0-65° in 5° steps. An independently adjustable timer is provided to control the duration of the tilt; i.e., the function will operate in the tent mode for the duration of the timer setting, at which time it reverts to a regular reactance function. Typical applications of the function in the tent mode will be discussed later.

A negative sequence directional function is used to supervise the non-directional reactance function.

Permissive Zone and Out-of-step Blocking

Many of the commonly used pilot relaying schemes require a permissive (overreaching) function that works in concert with the communications channel to initiate tripping. The function is termed permissive because it must receive permission from the channel – either presence or trip or absence of block – before it can initiate tripping. It is termed overreaching in that it must be set to overreach the remote terminal so that a fault anywhere on the transmission line will be detected.

The SLS1000 system has a separate permissive function that operates independently of the measuring function. This function takes on the characteristic of the main measuring function, and is fixed in reach to the third zone setting of the measuring function. Thus, for single-line-to-ground faults, the permissive function will act as a variable mho function if that feature is selected; otherwise, it will operate in the reactance mode (regular or modified as selected).

For multi-phase faults, the permissive function will act as a variable mho function. The function will be circular in shape except for three-phase faults or during power swings when it will be lenticular in shape. The lens-shaped characteristic is required because it is used as part of the out-of-step blocking logic – See *Figure 10.* The logic for this scheme is such that the impedance for a three-phase fault will plot inside the permissive zone and the phase selector characteristics simultaneously. During a swing, the impedance locus will first enter the phase selector characteristic and then enter the permissive zone some time later. The out-of-step blocking output can be used to block outputs from the permissive zone, first zone and the time zones.

Blocking Functions

The blocking functions are always required in blocking type schemes. These blocking functions look away from the protected line and are used to initiate sending of a blocking signal to block tripping at the remote terminal where the permissive/overreaching function may have operated. The blocking functions have the same characteristics as the phase selectors. A timer is also included with the blocking functions to initiate time-delayed tripping if such tripping is desired. Hence, the blocking functions may also be used to provide time delayed backup protection.

PERIPHERAL FUNCTIONS

The following peripheral functions are included as a standard part of the equipment:

1. **Out-of-step blocking** – The out-of-step blocking scheme was described earlier and is shown in *Figure 10.*
2. **Fuse failure detection scheme** – The fuse failure detection scheme uses the presence of negative sequence voltage and the absence of negative sequence current to detect that one or two fuses have blown. The logic for the scheme is shown in *Figure 12.*
3. **Single-pole-tripping** – The system includes all the necessary logic and outputs to implement single-pole tripping. Selection between single-pole and three-pole tripping is made via a jumper in one of the modules.

OPTIONAL FUNCTIONS

The following optional functions are available:

1. **Recloser** – Single-pole and/or three-pole reclosing control for either one or two breakers.
2. **Synchronism check relay** – Separate angle and slip cutoff adjustment. Line and bus voltage check is also included.
3. **Ground overcurrent backup** – Directional or non-directional with inverse time characteristic. Directional function is dual polarized.
4. **Line overload monitor** – One or two levels with separate time delay for each level.

Further description of these functions can be found in the literature (2) (3). Only the synchronism check function will be discussed here because of its unique features.

Synchronism Check Function

A typical synchronism check function looks at the angle between the voltages on both sides of a breaker and will produce an output if the angle is within set limits, and if it stays within the limits for a set period of time. The time delay and angle settings establish the cutoff frequency (slip frequency above which synchronism check function will not operate). Because the angle must be within the set angle for the set time delay, lower slip cutoffs will lead to longer time delays and vice versa. If slip cutoff is one of the criteria in establishing a synchronism check scheme, then once the time delay is established to meet the cutoff, that time delay will be introduced at all times. Thus, a requirement for fast reclosing and low slip cutoff are in conflict with each other.

The synchronism check function used in the SLS1000 system has been designed to allow for fast reclosing while setting a reasonably low slip cutoff setting. To accomplish this, the relay is provided with a high set and low set slip cutoff feature. To understand the operation of this synch-check function, assume the following:

1. The line shown in *Figure 11* has a fault cleared by opening Breakers A and B. Breaker B is then allowed to close after a dead time T_D without synchronism check, thus re-establishing the voltage V_L at Breaker A.

2. The voltage V_B is assumed to be fixed in phase; i.e., V_B establishes a reference.
3. The line voltage V_L can appear anywhere relative to V_B and can even be rotating relative to V_B if the systems on each side of the breaker are out of synchronism.

CASE 1 – Systems are in synchronism but separated by an angle $\emptyset$.

If the angle between V_L and V_B is greater than the set angle Θ, then the synchronism check function will not operate.

If the angle between V_L and V_B is less than set angle Θ, the synchronism check function will produce an output but with a time delay that is related to the high set slip cutoff setting F and the set angle Θ. This is expressed as follows:

$$T = (1000)(\Theta)/(F)(180) \qquad (1)$$

Where: T is in milliseconds
F is slip cutoff setting in hertz
Θ is set angle in degrees.

CASE 2 – Systems are out of synchronism and V_L is rotating relative to V_B.

For this condition it is desirable to block a synchronism check output unless the slip is less than the low slip cutoff setting. This is accomplished by making a setting that allows time for the function to make a low slip measurement before the characteristic angle is entered. The following setting is proposed:

$$F_H = (180 - \Theta)/(360)(T_D)$$

Where:
F_H = high set slip cutoff setting
Θ = set angle in degrees
T_D = Transmission line dead time in seconds

It is obvious that no output will be produced for slips higher than the above cutoff setting F_H.

For slips less than this setting, the voltage phasor will return at nearly 180 degrees from the phasor V_B, thus allowing time for the low slip measurement to be made. If the slip is above the low slip cutoff setting, all outputs will be blocked. If the slip is below the low slip cutoff setting, an output will be permitted, but only after the phasor enters the characteristic angle and stays there for a time corresponding to the high slip cutoff setting. In other words, the low slip cutoff circuitry is used to block or permit outputs by the angle check and high slip cutoff circuitry.

APPLICATION

The SLS1000 System may be applied on most sub-transmission and transmission lines with the exception of lines with series capacitor compensation.

Because of the requirement for fault identification and classification prior to the distance measurement, systems such as the SLS1000 cannot be expected to produce operating times similar to those obtained with single-phase or polyphase relaying systems. Typically, operating times in the order of 1.5 to 2.0 cycles can be expected. If operating times in this order can be tolerated, and if the redundancy provided by single-phase systems is not required, then the SLS1000 System should be considered. The system will also provide an economical and compact backup package for a single-phase or polyphase relaying system.

The system has all the logic and outputs necessary to operate in either a three-pole tripping or single-pole tripping mode. Single-pole tripping has its advantages primarily where transmission capacity is limited and where single-line-to ground faults are predominant.

Depending on the particular application, the logic module allows selection of any of the following schemes:

1. Four zone stepped distance
2. Zone 1 extension
3. Zone 2 acceleration
4. Permissive overreaching transfer trip
5. Permissive underreaching transfer trip
6. Directional comparison blocking (requires blocking function module)

Schemes 3 through 6 require an appropriate communications channel. All schemes are suitable for single-pole or three-pole tripping. Additionally, these schemes provide inherent distance backup independent of the communications channel.

The blocking scheme always requires the blocking functions. A timer is included with these functions to allow time delayed backup tripping. The blocking functions can, therefore, be applied to provide backup protection for faults in the reverse direction. One example, sometimes referred to as reversed third zone(4), may be beneficial where system conditions as shown in *Figure 13* can exist. In this system, the effect of infeed makes it impossible to set the backup functions at A to see remote faults (F1, for example) in the adjacent line sections. It may be possible to set the reversed zone at B to see such faults because the impedance from A to B is eliminated from the required setting.

For single-line to ground faults, the distance function can be applied as a variable mho function, or it can be applied as a reactance function (regular or modified). The choice is up to, and field selectable by the user. If high resistance ground faults are of no concern, the variable mho function will provide the most secure performance because it is much less affected by the problems introduced by system load and non-homogeneity. The reactance function may be used to provide fault resistance coverage greater than that provided by the variable mho. However, if the system is non-homogenous, and if the possibility of overreaching is of concern, the modified reactance (tent) characteristic should be considered. When applied in this mode, the function may underreach for some faults expected to be within its reach, but only for the time delay set to control the tent.

Typically, this time would be set longer than the first zone tripping time for Zone 1 faults in adjacent line sections, but shorter than the normal second zone tripping time in the protected line section. For example, a fault at F2 in *Figure 13* may cause a regular Zone 1 reactance function at Terminal A to overreach. If the tent characteristic is used, overreaching could be avoided, and Breaker C would clear the fault as expected. If system conditions were such that the fault was within Zone 1 reach of the regular reactance function, but outside of the tent, tripping would not occur until the tent evolved to a regular reactance function at the end of the set time delay. Since this time delay is less than normal second zone timing, the time added to the Zone 1 function will be minimal. This time delay will only be added to the stepped distance scheme because the schemes using a communication channel will provide fast tripping for a fault anywhere on the line.

The scheme has facilities for separately adjusting the positive and zero sequence angles of the replica impedances used in the distance functions. The range of adjustment is sufficient to allow application of the system on cable circuits.

DESIGN FEATURES

Packaging

The SLS1000 system is packaged in a modular design consisting of pluggable printed circuit board modules which are housed in two separate cases (A and B). The principal magnetic elements (transformers, transactors, and telephone relays) are also contained in pluggable modules, there being one magnetics module in each case. Case A contains the distance relay functions and case B contains the recloser plus optional features. Multi-conductor cables provide the interconnection between the two cases.

The modular design offers the advantages of reduced size, reduced cost, and mounting ease.

Circuitry

The SLS1000 employs innovative circuitry which incorporates state-of-the-art electronics into traditional relaying functions. The following are among the new techniques included in the SLS design:

Timing Circuits

The characteristic timers and the majority of the delay timers are of the digital type, i.e., the time ranges are established by counting a prescribed number of reference pulses (clock pulses). These pulses are provided by a continuously running crystal oscillator. CMOS electronic devices are employed as counters.

The digital timers are a marked improvement over conventional resistor-capacitor (R-C) timers used in earlier designs. Performance variation with temperature and age are significantly reduced. Furthermore, since a common oscillator is used to clock all of the counters, there is essentially no variation from one timer to the next.

A description of the operating principles in a later section entitled "Impedance Measuring Circuitry" includes a detailed discussion of the timing circuit employed in the main measuring function.

Analog Electronic Switching

The switching of the selected AC voltage and current (IZ) signals into the main measuring unit is accomplished using CMOS analog switches. Referring to *Figure 1,* these are located in the fault type switching network and zone switching network. The state of each switch (open or closed) is determined by a DC logic level signal (12 volts) connected to its control gate.

This switching method has several advantages over conventional contact switching, namely:

- Speed
- Power consumption
- Low ON resistance for low level signals (no contact resistance)
- No thermal emf problems
- No bouncing and no mechanical wear
- Definite break before make

Digital Settings

The timer settings are made using digital rotary switches (thumbwheel type). The reach settings (in ohms) are made using a series of specifically valued toggle switches.

These methods for setting the relay provide exact inputs and therefore eliminate the need for further adjustments. The increments have been selected to allow for adequate resolution of setting. The digital settings are readily visible to an operator or tester.

Targets

Light emitting diodes (LED's) are used for trip targets in the SLS1000. These have the advantages of lower power consumption and longer lifetime over incandescent lamp targets used previously.

The targeting technique uses latching reed relays to energize the LED's. These relays constitute mechanical flip flops. They are set at the time of tripping and remain latched until reset. If station battery control power is removed for any reason while a target(s) is lit, the reed relay(s) will remain latched so that when power is re-applied, the same target(s) will light again. Resetting is accomplished by means of a single pushbutton on the front of the targeting module. Depressing this pushbutton momentarily lights all of the LED targets, thereby providing a means for checking the LED's.

The SLS1000 offers a choice between using its targets to indicate the phases faulted or the poles tripped. For example, in the event of an A-B fault resulting in a three pole trip, fault type targeting will cause the A and B LED's to light corresponding to the phases faulted whereas trip type targeting will cause the A, B, and C LED's to light corresponding to the poles tripped. The selection between fault type targeting and trip type targeting is made via a link within the targeting module.

The following latching LED targets are included.

A – Phase A Fault/Trip
B – Phase B Fault/Trip
C – Phase C Fault/Trip
I – Zone 1 Trip
II – Zone 2 Trip
III – Zone 3 Trip
IV – Zone 4 Trip
CH – Channel (Pilot) Trip
FF – Fuse Failed in Potential Transformer

Impedance Measuring Circuits

The operation of the main measuring unit can best be understood by way of an example. An explanation of the reactance measuring technique offers the most insight into the circuitry.

Consider the case of a B-G fault. Refer to *Figure 14.* Of all the operating and polarizing quantities available on standby, only those associated with a B-G fault will be transmitted through the switching networks. This is due to the presence of BG control signals on the appropriate analog switches. The control signals originate in the fault type logic circuitry (see *Figure 1)* which determines the fault type based on the phase selectors that have operated. *Figure 14* shows operating and polarizing quantities for SLG/reactance faults only.

The desired quantities, separated by an angle Θ, are switched into the coincidence logic. Recall that $\Theta < 90°$ is an operate condition (see *Figure 8*). The coincidence logic output consists of a pulse train where the positive pulses (or blocks) have a width of $\alpha = 180° - \Theta$. These are fed into the count command input of the counter.

Starting from zero, the counter increments during the positive portion of the pulse train and decrements during the negative portion. The Cx outputs reflect the internal count at any given point in time and are continually changing as the counter counts up and down. The subscripts (X) indicate the significance of the various output ports. For example, for a count of 30, the output combination will be $C_{10} + C_{20}$ (all other outputs absent). On the next clock pulse, if the count command is positive (up), the count will be incremented to 31 and the output combination will become $C_1 + C_{10} + C_{20}$. If, on the other hand, the count command is negative (down), the count will be decremented to 29 and the output combination will become $C_1 + C_8 + C_{20}$.

The counting rate is determined by the clock input which is connected to a 21.6 KHz oscillator. Note that this frequency corresponds to a period of 46.3 microseconds per clock pulse which is equivalent to one electrical degree on a 60 Hz base: $1/(60 \times 360) = 46.3 \times 10^{-6}$. Consequently, each clock pulse into the counter represents one electrical degree.

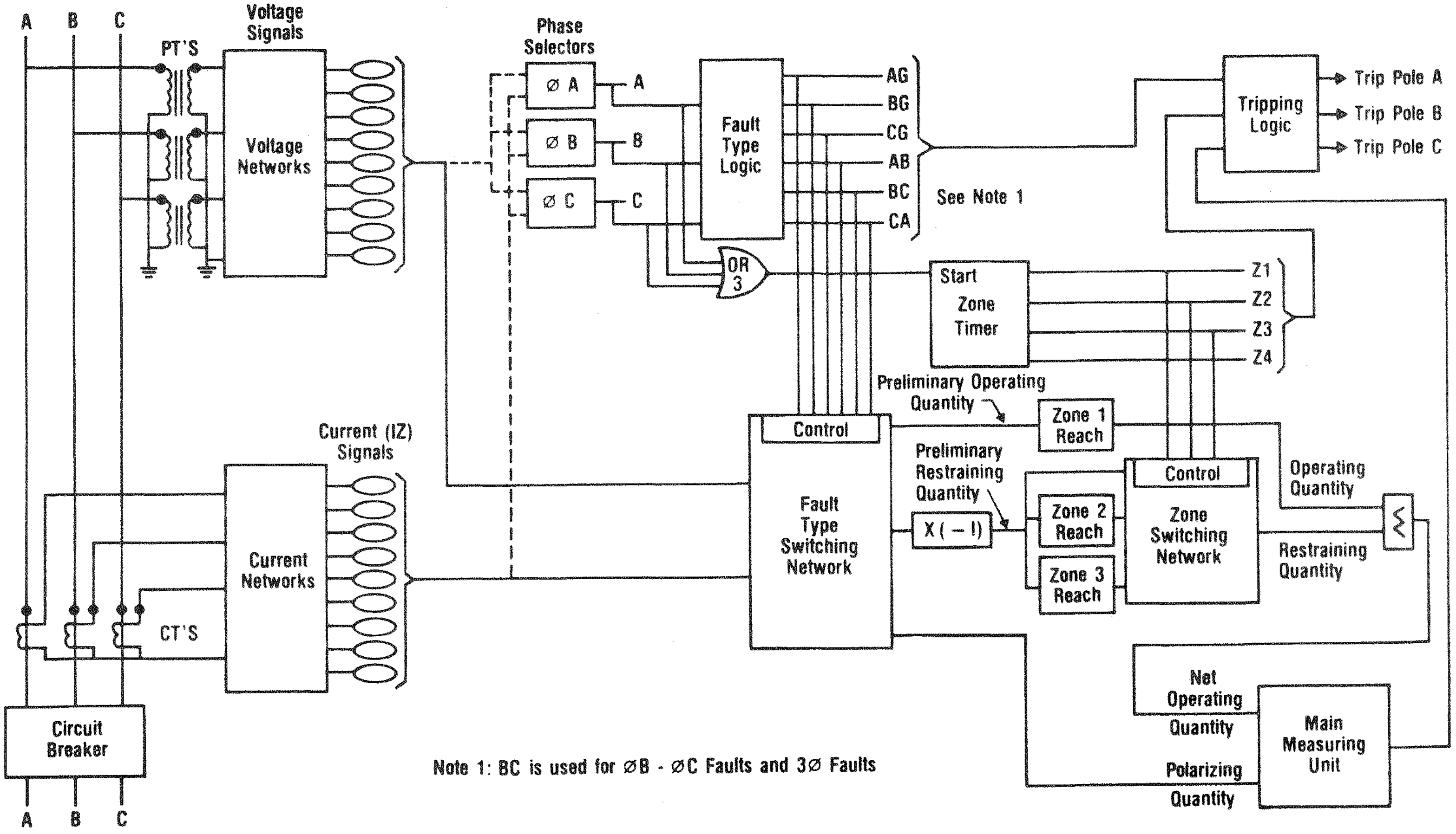
The digital comparator shown in *Figure 14* issues a trip command when the running count at its A inputs equals the setting at its B inputs. For SLG faults, the setting is determined by the ground characteristic angle switches. A conventional reactance characteristic would be obtained by closing the "10" switch, thereby yielding a setting of $B_{80} + B_{10} = 90°$ (B_{80} always present). The reactance "tent" characteristic (see *Figure 9*) is obtained by setting the comparator for any angle greater than 90°. The tent angle will be $\varnothing = (\text{B setting}) - 90$. Closing the "20" switch for example yields a tent angle of $\varnothing = (80 + 20) - 90 = 10°$.

CONCLUSION

The SLS1000 System was designed to complement single-phase relaying systems. The system is flexible enough to meet a variety of applications, and uses new techniques and packaging to provide improved performance, simple application, and ease of installation and setting.

References

1. *SLY/SLYG 60/80 Phase and Ground Distance Relays;* G.E. Publication GET-6651.
2. *Modular Transmission Line Protection SLS System 1000;* G.E. Publication GEA 10986.
3. *SLS1000 Instruction Book;* G.E. Publication GEK-86044.
4. *The Art and Science of Protective Relaying;* C. Russell Mason.



Note 1: BC is used for ØB - ØC Faults and 3Ø Faults

Figure 1. Basic System

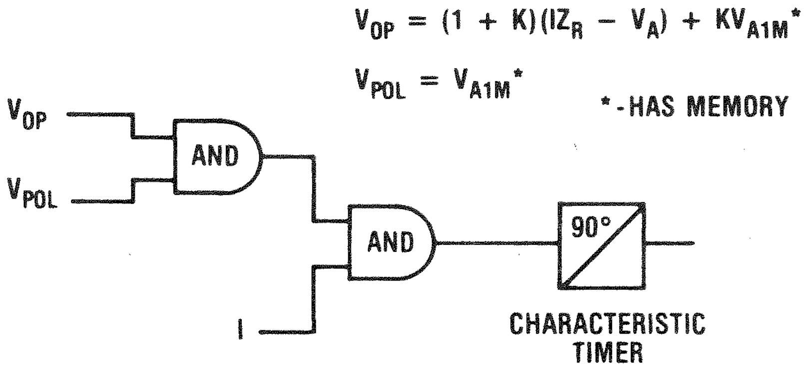


Figure 2. Phase A Selector – Simplified Circuit

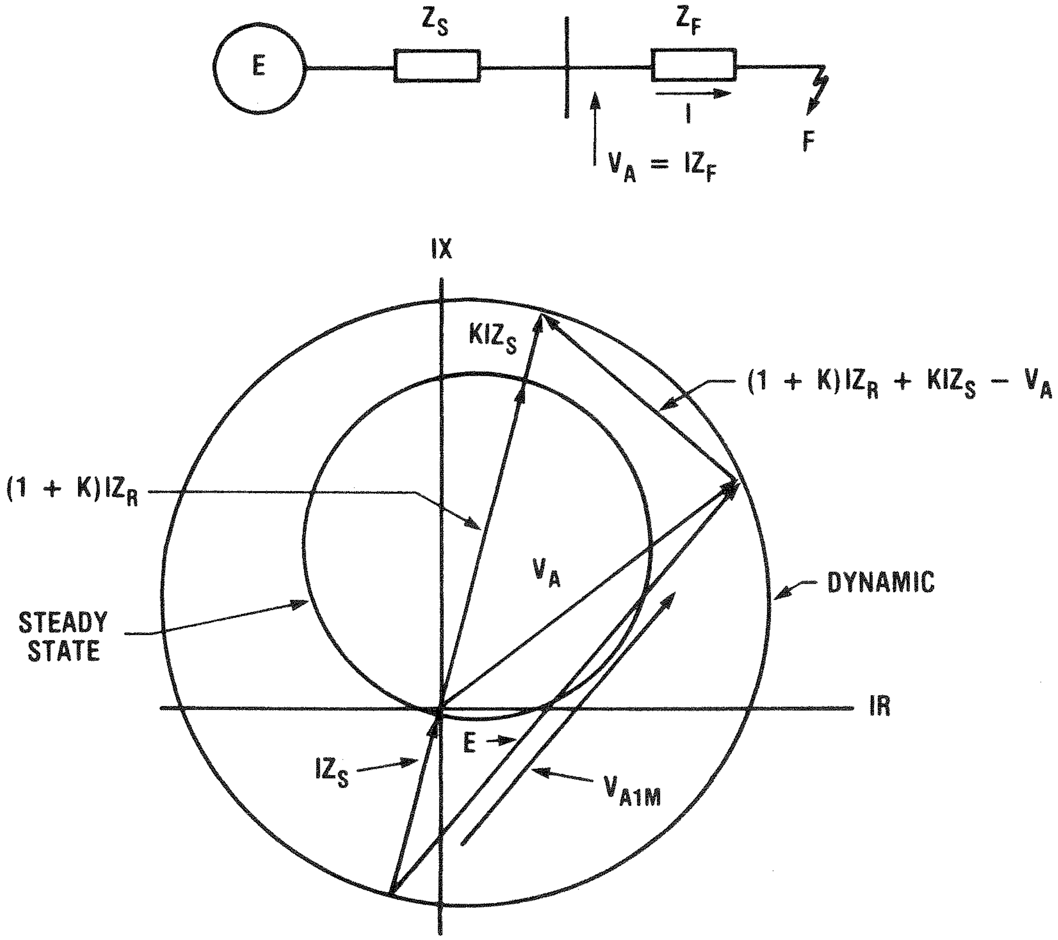


Figure 3. Phase A Selector Characteristic for three-phase Fault

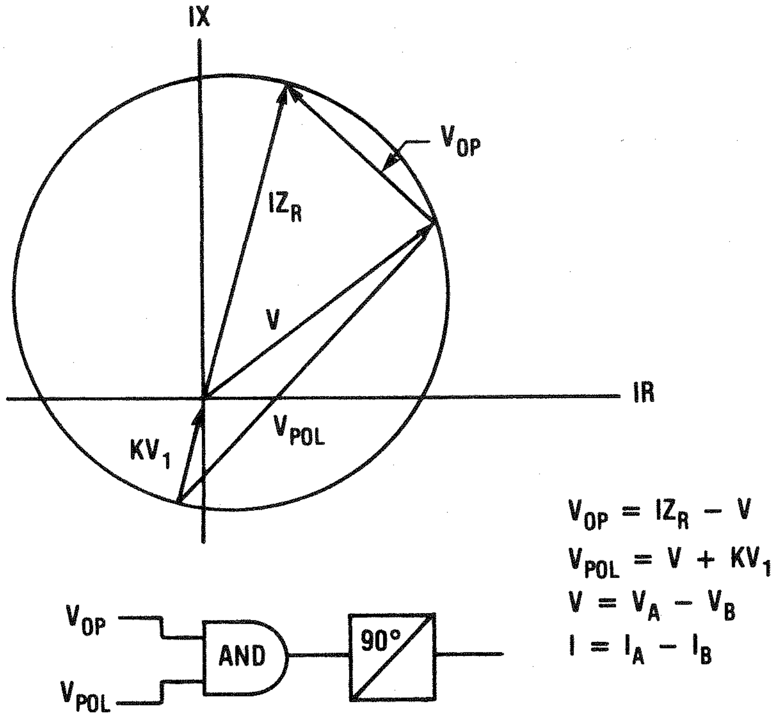


Figure 4. Variable Mho Function, Multi-phase Faults

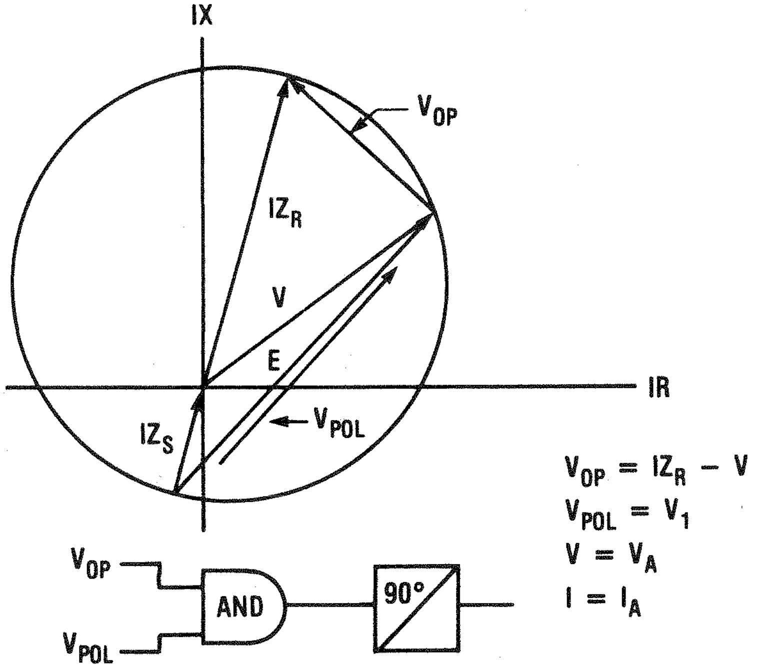


Figure 5. Variable Mho Function, Single-line-to-ground Faults

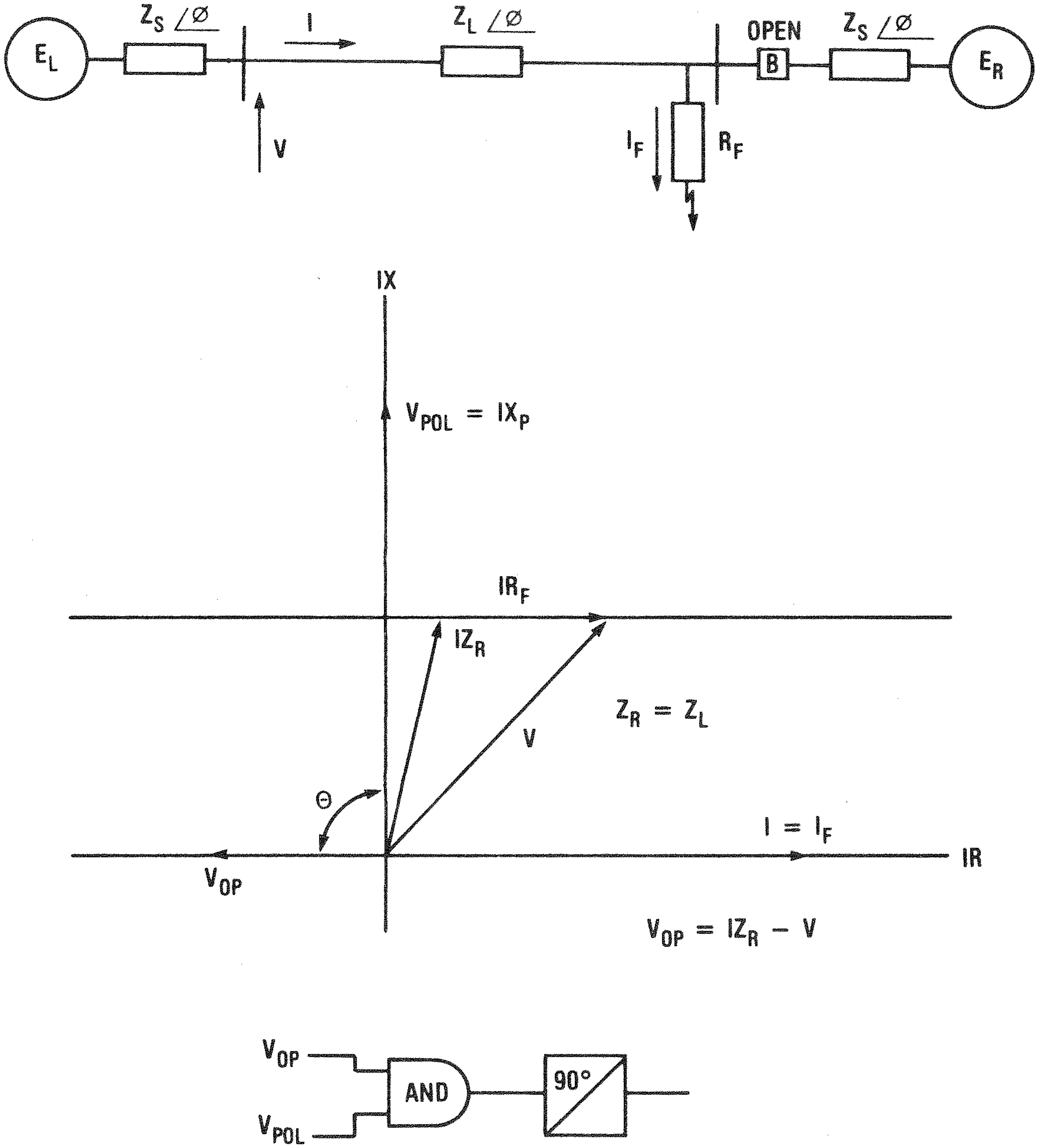


Figure 6. Typical Reactance Function

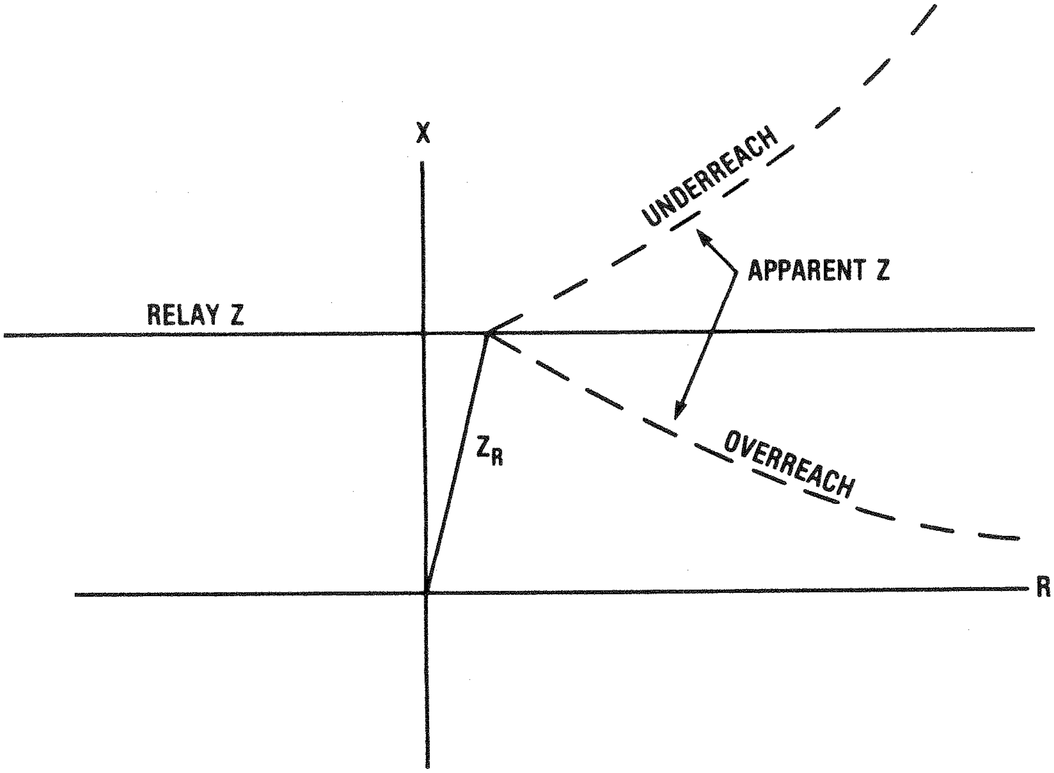


Figure 7. Effects of Load and/or Non-homogeneity on Typical Reactance Function

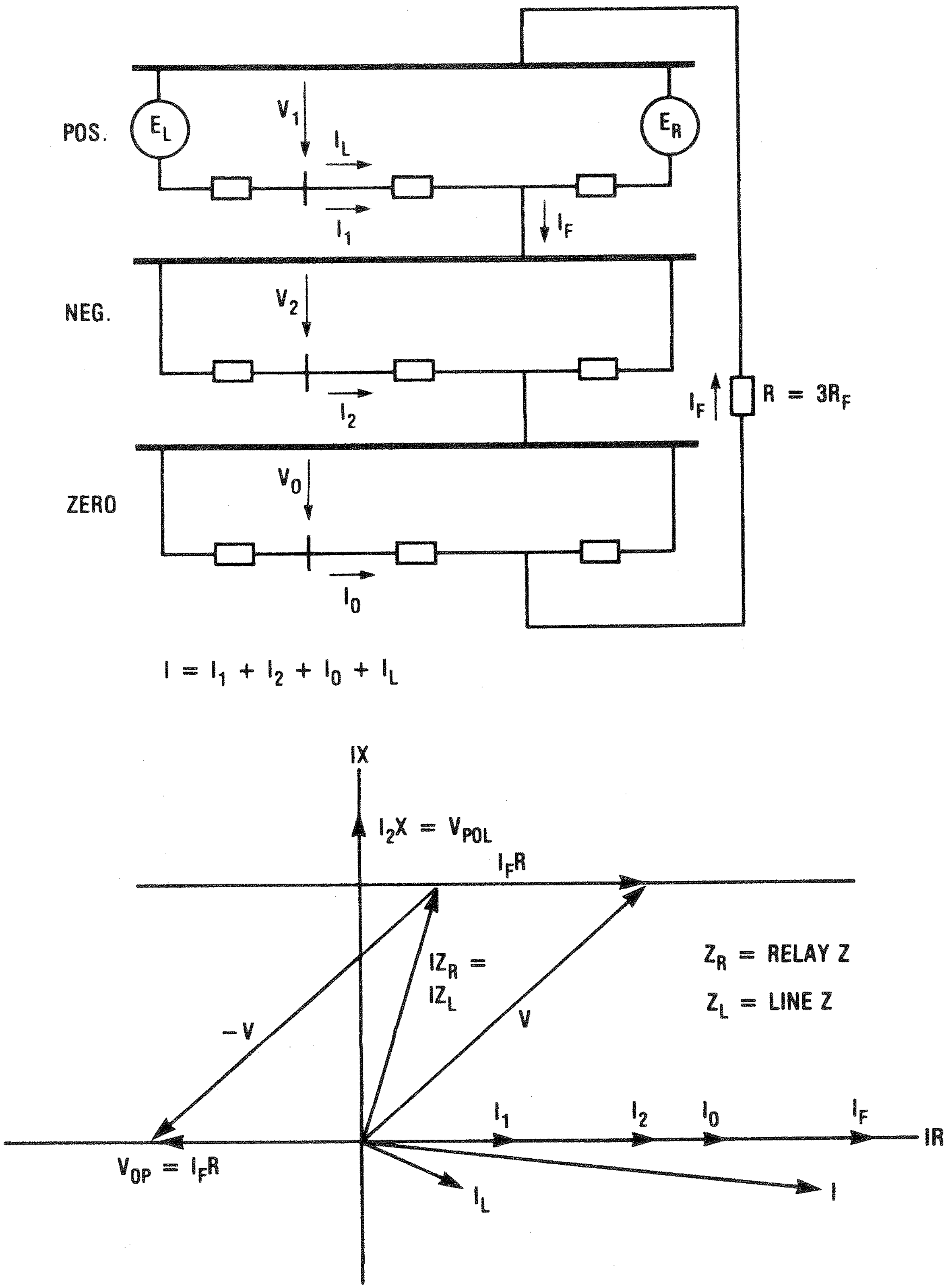


Figure 8. Negative Sequence Current Polarized Reactance Function

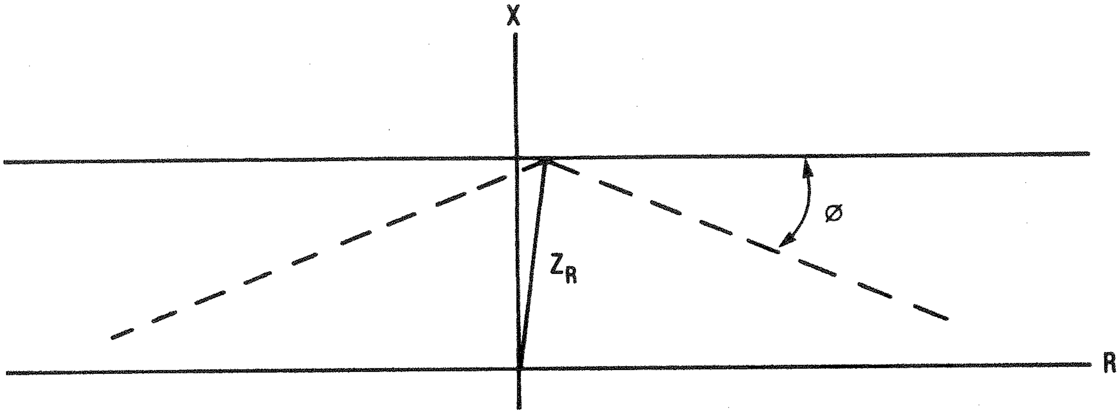


Figure 9. Modified Reactance (Tent) Function

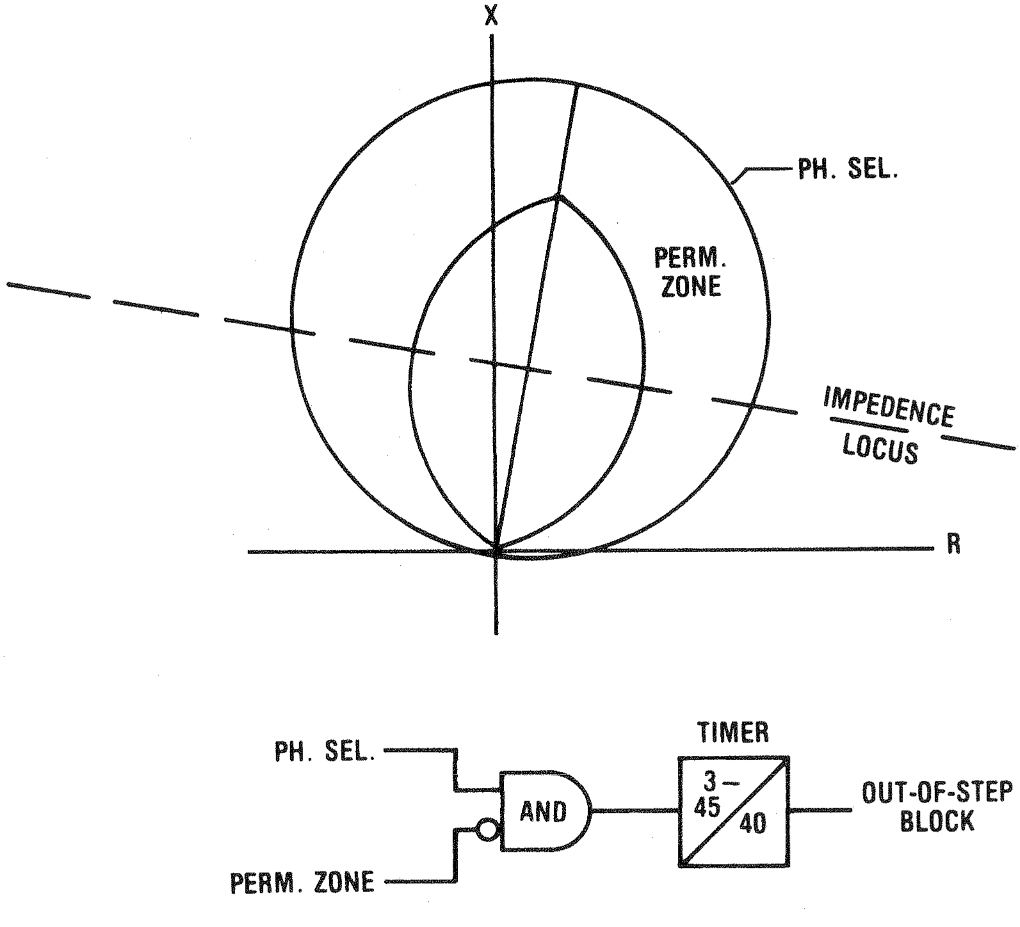


Figure 10. Out-of-step blocking

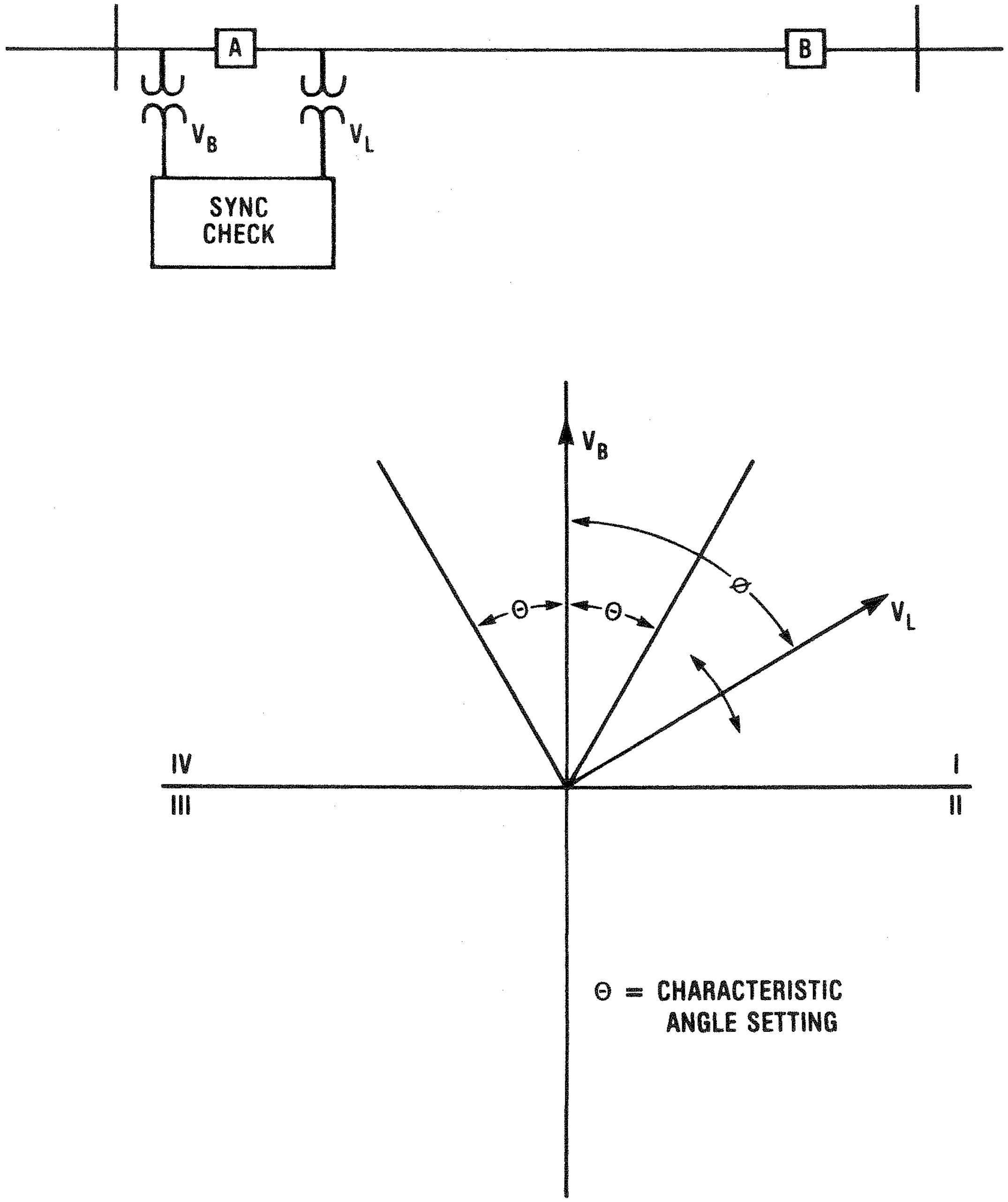


Figure 11. Synchronism Check Function

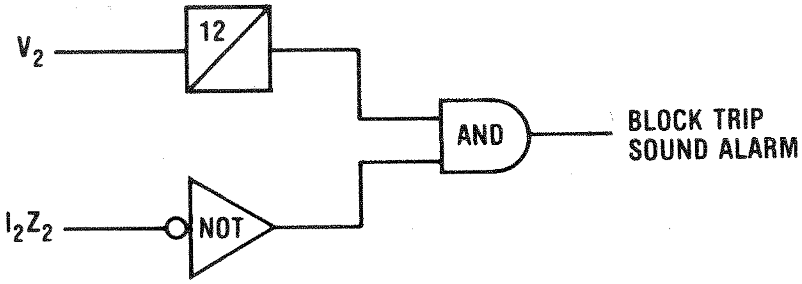


Figure 12. Fuse Failure Detection

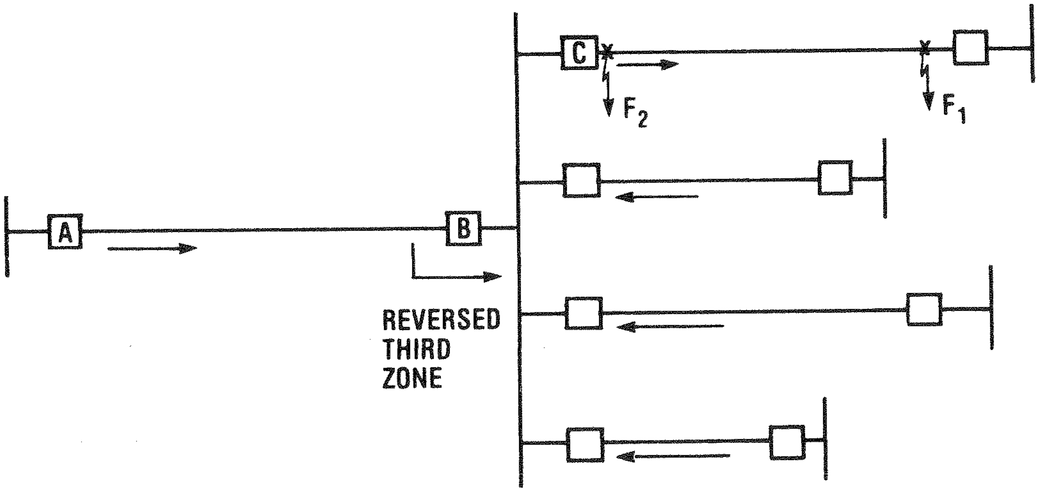


Figure 13. Typical Power System

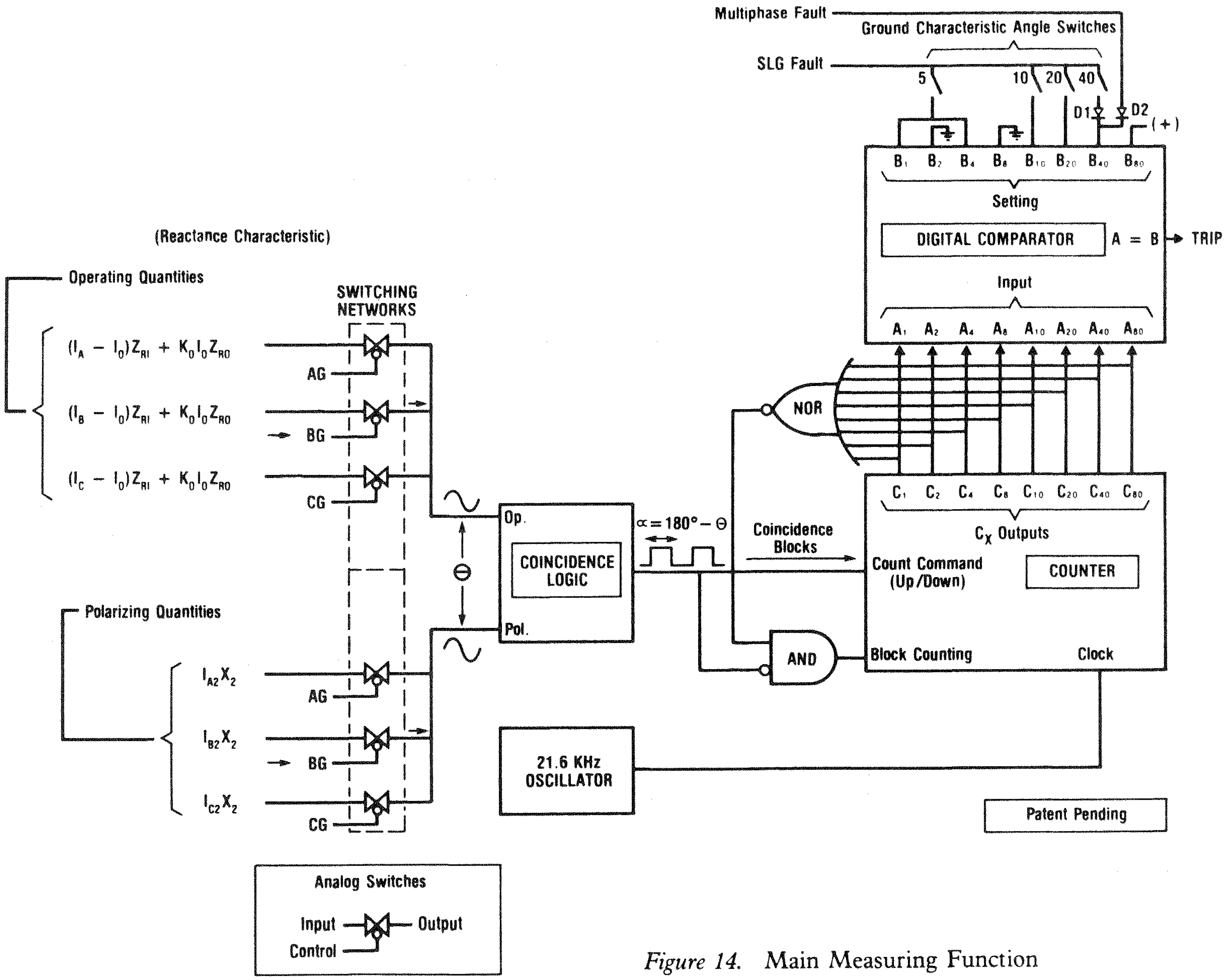


Figure 14. Main Measuring Function