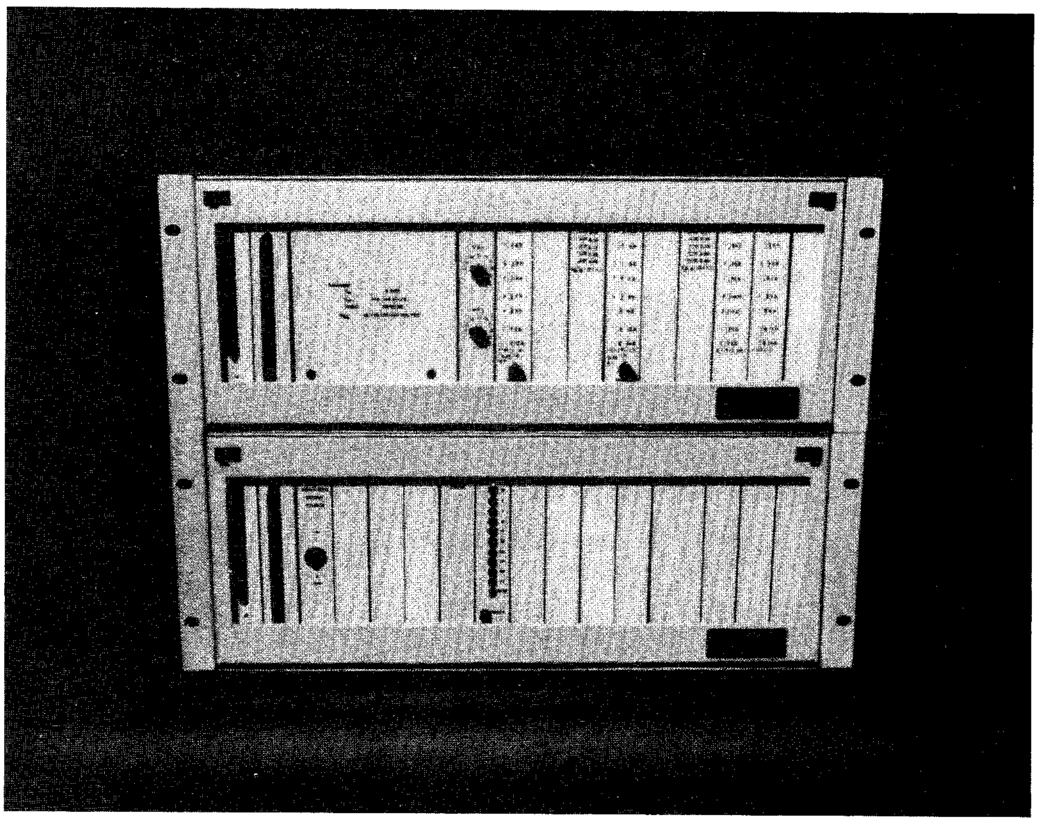
GEK-86668A

INSTRUCTIONS

TLS1000
MODULAR RELAY SYSTEM
APPLICATION AND SETTINGS GUIDE



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CONTENTS

	PAGE
INTRODUCTION	3
DESCRIPTION	3
MEASURING FUNCTION CHARACTERISTICS	4
FORWARD REACHING FUNCTIONS	4
Phase Distance Functions	6
Ground Distance Functions	6
REVERSE REACHING (BLOCKING) FUNCTIONS	7
ADDITIONAL FEATURES	7
Characteristic Timer Adjustment	8
Adjustable Phase Shift	9
Zero Suppression	9
Level Detector	9
Zero Sequence Current Restraint	9
APPLICATION CONSIDERATIONS	9
OPERATING TIME	10
Filtering	10
Forward Offset	12
Zero Suppression	14
ARC/FAULT RESISTANCE	16
SERIES COMPENSATED LINES	20
SINGLE POLE TRIPPING	22
SCHEME AND CHANNEL CONSIDERATIONS	23
STEPPED DISTANCE PROTECTION	24
PILOT PROTECTION	24
OTHER FEATURES	26
FAULT DETECTOR	26
LINE PICKUP (CLOSE INTO FAULT)	27
RECLOSING CONTROL	27
SEQUENTIAL RECLOSING	27
PT FUSE FAILURE	28
OUT-OF-STEP BLOCKING	28

CONTENTS (Cont'd)

PAGE

DESIGN FEATURES 29
PACKAGING 29
SETTINGS 29
CIRCUITRY 29
Timing Circuits 29
Operate Circuits 30
TARGETS 30

SETTINGS GUIDE 31

STANDARD SETTINGS 31
Voltage Functions 31
Overcurrent Functions 31

Distance Functions 32
First Zone Functions 32
Overreaching Functions 33
Zero Suppression Setting 34
S Signal 34
IO Restraint Signal 34
Blocking Functions 34

Logic Timers 35

Stepped Distance Protection 36

Out-of-Step Blocking 37

Effects of Non-Homogenity 38

Sample Calculation and Setting Checklist 39

WEAK INFEED CONDITIONS 50

APPENDIX I
LOGIC AND ELEMENTARY DIAGRAM LIST 58

APPENDIX II
GENERAL SPECIFICATIONS 59

APPENDIX III
MEASURING UNIT SETTING RANGES 61

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INTRODUCTION

The TLS1000 protective relaying system is designed for use in virtually any application. As such, it has a number of features that will only be required in certain applications. The intent of this bulletin is to provide the following:

1. A description of measuring functions used in the system, and the features included in each.

2. A discussion of the applications where these functions and features might be used.

3. A **SETTINGS GUIDE.**

4. Technical Specifications

It is not necessary to read the entire bulletin to apply the TLS1000 system. The **SETTINGS GUIDE** can be used alone to determine which features to use and to make all of the necessary settings. The **DESCRIPTION** and **APPLICATION** sections may be referred to if further details are required.

This bulletin discusses the schemes and equipment in general, but does not contain detailed information about either. These details are discussed in separate General Electric publications, GEK-86659 - TLS MODULAR RELAY SYSTEM SCHEME DESCRIPTION, AND GEK-86638 - TLS MODULAR RELAY SYSTEM EQUIPMENT INSTRUCTION BOOK.

DESCRIPTION

The TLS1000 protective relaying system can be applied on most transmission lines, including those with unique application requirements. Thus, one relaying system can be used to provide fast, reliable protection on long or short lines, compensated or uncompensated lines, double-circuit lines, etc. In all of these applications, single-pole tripping can also be provided when required.

Single phase distance functions are used in the TLS1000. Each forward zone of protection uses three functions for phase faults (one for each phase pair) and three functions for ground faults (one for each phase). Two or three zones of protection can be provided and timers are included in the logic to implement time-delayed tripping. If independent zones are not required, the first zone function can be switched to second zone reach following a time delay controlled by the overreaching/third zone function.

Two types of blocking functions are used in the TLS1000 system. The blocking functions are required in all hybrid and blocking type schemes and must also be used in series compensated line applications. The first type of blocking function is a variation of positive sequence polarized mho ground distance function. Three such functions are used - one for each phase. The second type of blocking function uses negative sequence quantities operating into an amplitude comparator to form a directional function.

A common logic module is used to provide stepped distance protection plus the following pilot relaying schemes:

1. Permissive overreaching transferred trip/unblocking
2. Permissive underreaching transferred trip
3. Hybrid (weak infeed and channel repeat)
4. Directional comparison blocking
5. Zone acceleration.

The channel interface for each of the pilot relaying schemes is provided through contact inputs and outputs.

Line pickup circuitry (close into fault) is provided to insure tripping when closing into a bolted three phase fault. An additional line pickup circuit is supplied in single pole tripping schemes to insure tripping (three pole) when reclosing into a fault following a single pole trip.

Out-of-step blocking and an AC potential failure detection scheme are also included as standard features.

The TLS system is contained in a modular package consisting of two separate cases. The printed circuit boards, transformers, transactors and output relays are contained in pluggable modules. Multi-conductor cables provide the interconnections between the two cases. Each case includes two test/disconnect plugs, each of which has fourteen points. A single regulated DC-DC power supply module provides the DC supply voltages to both cases. The modular design offers the advantages of both reduced size and reduced cost. A complete TLS1000 system is shown on the front cover.

MEASURING FUNCTION CHARACTERISTICS

FORWARD REACHING FUNCTIONS

The forward reaching phase and ground distance functions use the variable mho function as the basic operating characteristic. This type of characteristic can be derived using a simple, two-input comparator as shown in Figure 1.

Although many such functions have been used over the years, there are some applications wherein a variable mho function using a two-input comparator might not provide the best overall performance. To overcome the limitations imposed by these applications, other inputs are applied to the comparators used in the distance functions in the TLS1000. These inputs combine with those used to derive the variable mho function, and with each other, to form additional characteristics.

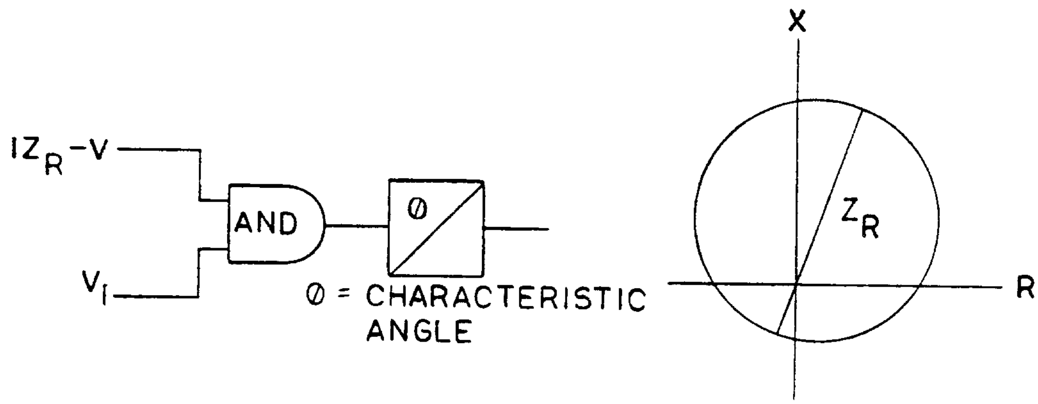


Figure 1 (0285A8942-0, Sh. 1) Two Input Variable Mho

Simplified circuitry for a multi-input phase angle comparator is shown in Figure 2. The phase angle measurement is made by comparing the coincidence time of all of the phasors applied to the comparator.

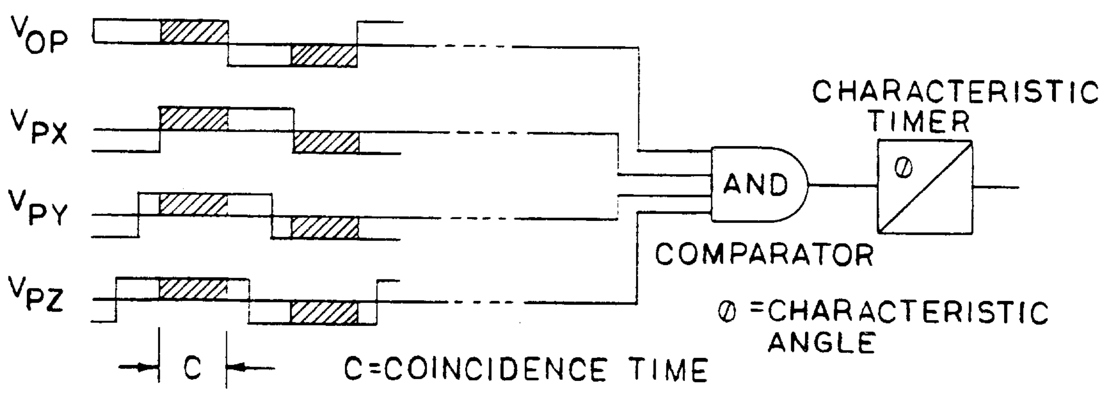


Figure 2 (0285A8942-0, Sh. 2) Phase Angle Comparator

If all the phasors are coincident for a time corresponding to the characteristic timer angle setting, or conversely, if all of the phasors are separated by less than the characteristic timer angle setting, the function will provide an output.

The comparator input signals used in the TLS1000 system and the characteristics that they provide are described below.

PHASE DISTANCE FUNCTIONS

The following signals are used in the phase distance functions:

Operating Signal: $V_{OP} = I_{\phi\phi}Z_{R1} - V_{\phi\phi}$

Polarizing Signals: $V_{PX} = (V_{\phi\phi 1} - I_{\phi\phi 1}Z'_{R1})_M$

$V_{PY} = I_{\phi\phi}Z_{R1}$

where: $\phi\phi$ = AB, BC or CA

1 = positive sequence

Z_R = relay reach

Z'_R = relay offset (forward)

M = memory

Listed in Table I are the characteristics that are formed from these signals. The phase distance functions are always applied with all three characteristics in service.

TABLE I

CHARACTERISTIC	SIGNALS USED
Variable mho	V_{OP} and V_{PX}
Reactance	V_{OP} and V_{PY}
Directional	V_{PX} and V_{PY}

GROUND DISTANCE FUNCTIONS

The following signals are used in the ground distance functions:

Operating Signal: $V_{OP} = (I_\phi - I_O)Z_{R1} + K_O I_O Z_{RO} - V_\phi$

Polarizing Signals: $V_{PX} = (V_{\phi 1} - I_{\phi 1}Z'_{R1})_M$

$V_{PY} = I_{\phi 2}Z_{R1}$

$V_{PZ} = I_O Z_{R1}$

where: ϕ = A, B or C

0 = zero sequence

2 = negative sequence

Listed in Table II are the characteristics that are formed with these signals:

TABLE II

CHARACTERISTIC	SIGNALS USED
Variable mho	V_{OP} and V_{PX}
Negative Sequence Reactance	V_{OP} and V_{PY}
Zero Sequence Reactance	V_{OP} and V_{PZ}
Directional	V_{PX} and V_{PY}
Directional	V_{PX} and V_{PZ}
Negative/Zero Sequence Phase Selector	V_{PZ} and V_{PY}

The ground distance functions can be operated in the reactance mode by taking the variable mho out of service. When the ground functions are operated as reactance functions, they must be supervised by the overreaching functions that are required as part of the pilot/stepped distance scheme.

REVERSE REACHING (BLOCKING) FUNCTIONS

Two types of blocking functions are used in the TLS1000 system.

The first blocking function is a variation of a positive sequence polarized mho ground distance function. Three of these functions are used - one for each phase. The following signals are used to derive this function.

Operating Signal: $V_{OP} = -I_{\emptyset}Z_{R1} - K_0 I_0 Z_{R0} - V_{\emptyset g} + K(V_{\emptyset 1} - I_{\emptyset 1}Z'_{R1})_M$

Polarizing Signal: $V_P = (V_{\emptyset 1} - I_{\emptyset 1}Z'_{R1})$

These blocking functions are designed to operate for all fault types, however, they may be slow to operate for some phase-to-phase faults. To provide for this contingency, a second blocking function is included.

This second function uses negative sequence quantities operating through an amplitude comparator to provide a negative sequence directional characteristic. The signals used to derive this characteristic are as follows:

Operating Signal: $V_{OP} = V_2 + KI_2Z_{R2}$

Restraining Signal: $V_R = I_2Z_{R2}$

ADDITIONAL FEATURES

A number of other features are used to improve the performance of the functions. Following is a brief description of these features. Their use will be discussed at appropriate points throughout this bulletin.

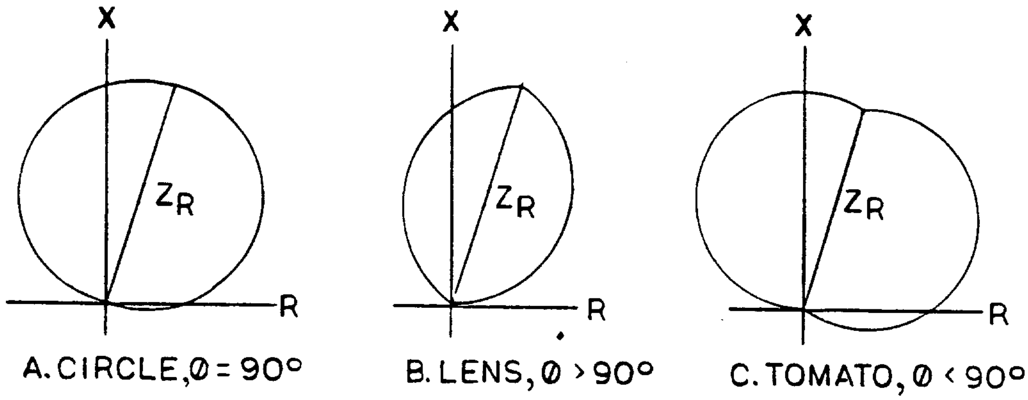


Figure 3 (0285A8942-0, Sh. 3) Characteristic Timer Adjustment

Characteristic Timer Angle Adjustment

Adjustment of the characteristic timer allows the shape of the characteristic to be changed as shown in Figure 3, thus increasing the versatility of the function by allowing the area covered by the function to be easily changed.

Adjustable Phase Shift

Circuitry is provided in the voltage polarizing circuit (V_{PX}) of the phase functions that allows the polarizing signal to be phase shifted from its normal position. The phase shift is made in the leading direction, and produces a change in the variable mho characteristic as shown in Figure 4.

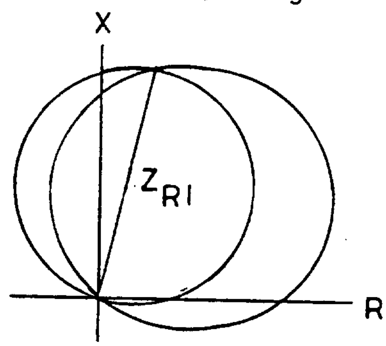


Figure 4 (0285A8942-0, Sh. 3) Polarizing Phase Shift

Phase shifting circuits are also provided in the negative sequence (V_{PY}) and zero sequence (V_{PZ}) polarizing signals of the ground distance functions. One effect of these shifts is to tip the negative or zero sequence reactance characteristic as shown in Figure 5.

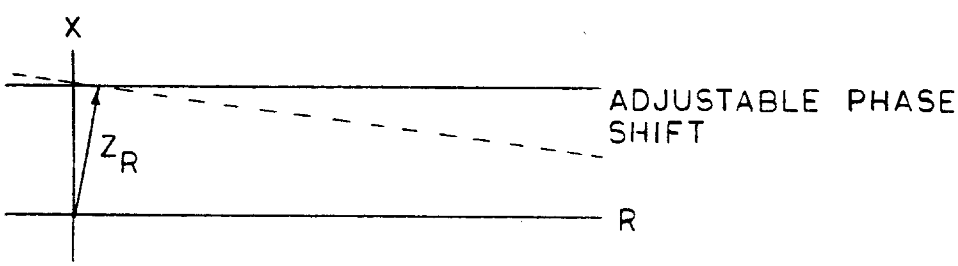


Figure 5 (0285A8942-0, Sh. 4) Negative or Zero Sequence Reactance

Zero Suppression

The phasors of the operating and polarizing signals are converted to blocks before being applied to the comparator as shown in Figure 2. When zero suppression is used, the width of the blocks will be proportional to the suppression level setting as shown in Figure 6.

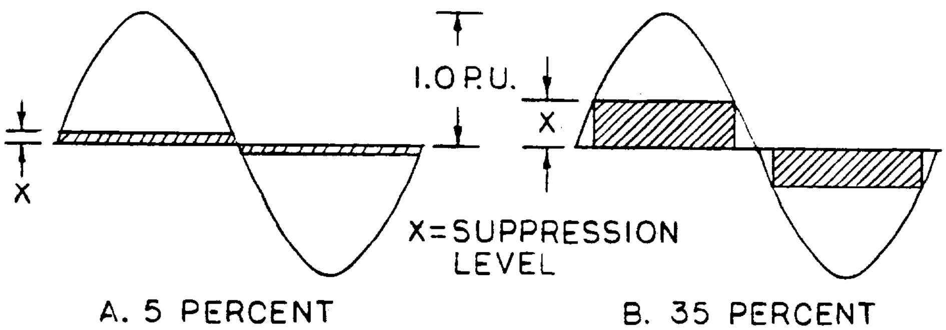


Figure 6 (0285A8942-0, Sh. 4) Effect of Zero Suppression

For a given signal level, zero suppression reduces the width of the blocks as the suppression level is increased. Conversely, the width of the block will vary in proportion to the signal level changes if the suppression level is held constant.

Level Detector

The operate circuit in the forward reaching functions is equipped with an adjustable level detector that can be used to change the mho function into a hybrid distance/overcurrent function. With this feature in service, the operating signal must reach a preset level before the function is allowed to operate.

Zero Sequence Current Restraint (phase functions only)

The phase functions are provided with zero sequence current restraint that is designed to prevent them from operating during single line to ground faults, but to have little effect during double line to ground faults.

APPLICATION CONSIDERATIONS

Because of the features described above, the distance functions are very flexible and can be applied with different characteristics to meet varying application requirements. They can be applied simply as a variable mho function, which will probably be preferred in most applications; or they can be applied as a hybrid distance/overcurrent function to give very fast operating time. They can be adjusted to optimize their performance on very long lines or on very short lines, and the ground distance functions can be applied in the reactance mode to provide increased fault resistance coverage.

OPERATING TIME

The operating time of the distance functions can basically be related to the following:

1. The reach setting
2. The characteristic timer angle setting
3. The amount and type of filtering
4. The method in which the function is operated

The reach setting of the distance function helps establish the magnitude of the operating quantity (IZ-V), which in turn is instrumental in determining the operating time. This is so because large operating signals will either bypass the normal filtering in the function, or pass through the filtering much quicker than will signals of lower levels; i.e., the filtering becomes more effective as the signal level decreases in magnitude. Thus larger operating signals will tend to produce faster operating times than will signals of lesser magnitude.

Since the operating signal is dependent on current, voltage and reach setting, its magnitude will change as follows:

1. It will become larger as the fault is moved towards the relay location because the current will increase and the voltage will decrease.

2. It will become larger as the source impedance behind the relay location decreases.

3. It will become larger as the reach is increased.

The conclusion can therefore be drawn that the fastest operating time will occur for the most severe faults and that the operating time can be optimized by using the largest possible reach consistent with secure operation.

It was pointed out earlier that the shape of the characteristic could be changed by changing the characteristic timer angle setting. Longer timer settings produce more lenticular characteristics and minimize the effects of load flow. Unfortunately, longer settings also produce slower operating times. Shorter timer settings (tomato characteristic) will produce faster operating times, but will also increase the area of coverage and so increase the exposure to load flow. It might seem logical to use short timer settings on short lines where load impedance may be negligible, and in that way get faster operation. However, this is not a viable approach because the tendency to overreach will be increased and directional integrity may be jeopardized. It is possible to reduce the timer setting to get faster operation, but other steps must also be taken to provide secure operation in conjunction with the faster times. These steps are described next.

Filtering

A simplified diagram of the operate circuit for the distance functions used in the TLS system and the filtering used therein is shown in Figure 7.

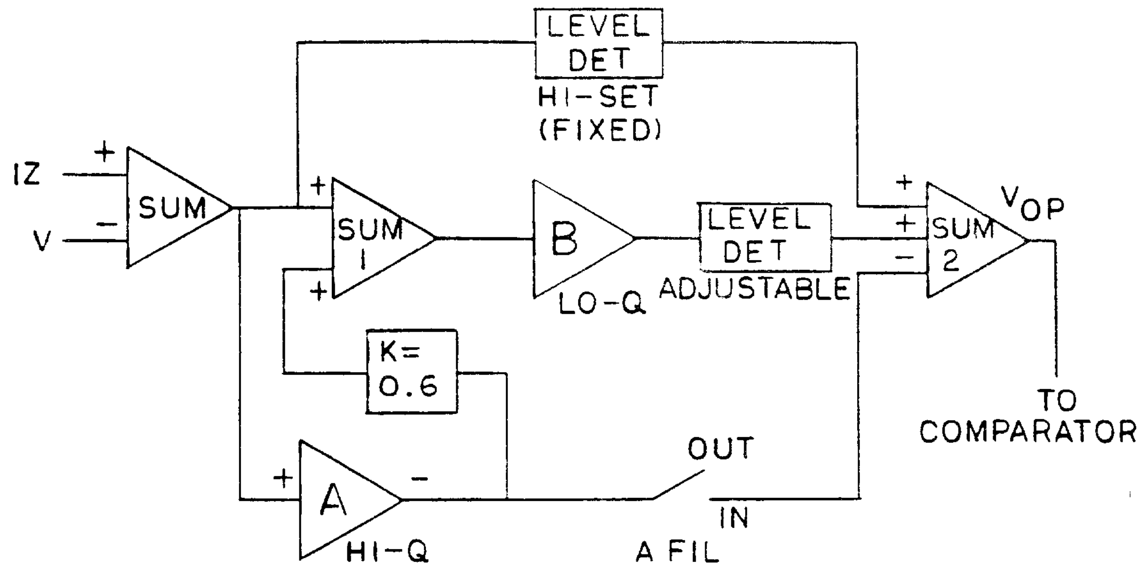


Figure 7 (0285A8942-0, Sh. 5) Simplified Operate Circuit

In simple terms, the operate circuit can be thought of as being composed of three sections.

1. The high set (bypass) fixed level detector section

2. The Lo-Q, B filter section (with adjustable level detector)

3. The Hi-Q, A filter section.

The high set fixed level detector section allows the operate signal to be bypassed around the A and B filter sections for very high signal levels. In this way, faster operation is obtained because the normal filter delays are minimized. The high set level detector setting is fixed and has been empirically selected to eliminate the adverse effects of transients normally encountered on the power system.

With the A FIL link in the "out" position, the output of the A filter is removed from the number 2 summing amplifier. The A filter output is still used, however, to cancel a portion of the operating signal before it is fed into the B filter. On a steady-state basis, the B filter will see only 40 percent of the operating signal because of the output of the A filter. The intent here is to lessen the energy stored in the B filter. Now, when an internal fault occurs, the operate signal will pass through the B filter much faster because the signal will have less stored energy to overcome. Furthermore, at the inception of an internal fault, the output of the A filter tends to add to the operate signal during the first half cycle of input to summer number 1. This dynamic addition increases the magnitude of the operating signal, thereby permitting it to pass through the B filter even faster. Also, with the A filter out, and with the level detector set as proposed, the reach of the zone 1 functions can be increased beyond the normal settings. These modifications will reduce the operating time, but not to the extent possible. Further reduction in operating time can be achieved by reducing the characteristic timer angle setting, but forward offset and/or zero suppression must also be employed in the voltage polarizing circuit to provide security.

Forward Offset

Forward offset is produced in the voltage polarizing circuit and changes the characteristic by lessening the area of steady-state coverage as shown in Figure 8.

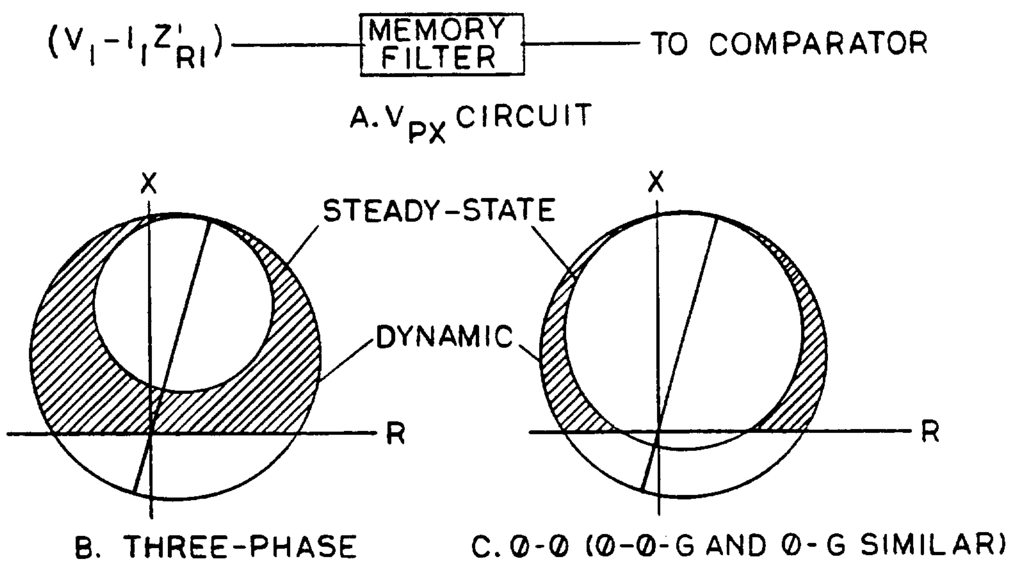


Figure 8 (0285A8942-0, Sh. 5) Offset Mho Characteristic

The exact amount of offset will be a function of the fault type and fault current level.

For load flow and low level three phase faults, the offset will be equal to the offset reach, Z'_{R1}. As the three phase fault level is increased, the offset will be less because of a clipping circuit in the function that keeps the offset voltage ($I_1Z'_{R1}$) from exceeding a fixed level. Clipping is used to prevent the offset voltage from becoming so large that it would override the remembered voltage and cause the output of the memory filter to change so quickly that it would adversely affect the dynamic performance of the function. It is necessary to maintain correct dynamic performance so that the function will operate for faults within the shaded areas shown in Figure 8.

For unbalanced faults, the effect of offset is much less than that experienced for balanced conditions and the steady-state area of coverage is larger. This is so because the positive sequence voltage which is used in polarizing the function will be less affected during unbalanced fault conditions than during balanced fault or load conditions. Here too, the effect of clipping will become more pronounced as the fault current level is increased.

To summarize, offset is greatest for load flow conditions and becomes less for heavy faults and/or unbalanced fault conditions. Therefore, the effect of load impedance is minimized and the characteristic timer can be set with a shorter setting than normally would be used. As a consequence, faster operating times can be achieved but at the expense of steady-state coverage. The function effectively becomes a transient fault detector for some faults and the dynamic performance must be relied on for those faults when forward offset is used. There will, however, be no sacrifice in security. For example, consider the system shown in Figure 9.

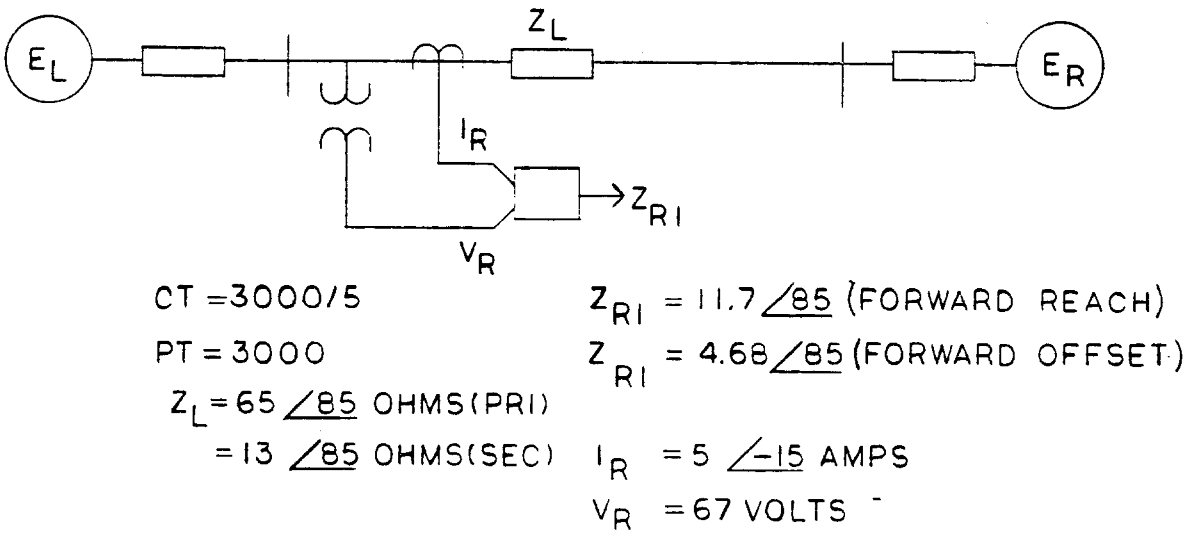


Figure 9 (0285A8942-0, Sh. 6) Simple Power System

For this system, the zone 1 functions are set to reach 90 percent of the line impedance, and an offset reach of 40 percent of the forward reach has been selected. In a typical application where very fast operating time is not required, the function would be applied as a variable mho without offset and with a characteristic timer setting of 4.2 milliseconds. Figure 10 shows the phasor diagrams for the non-offset and the offset mho function for the conditions of Figure 9.

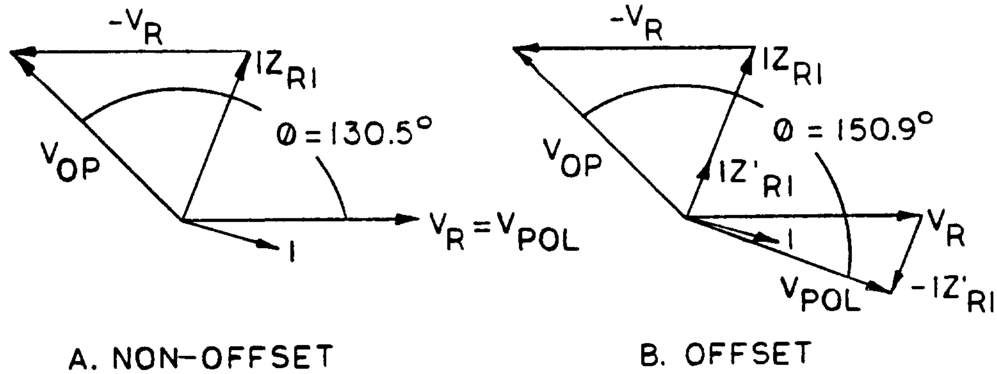


Figure 10 (0285A8942-0, Sh. 6) Effect of Offset

Of interest in Figure 10 is the angle (Ø) between the operating (V_{OP}) and polarizing (V_{POL}) quantities. From this angle the coincidence angle (180 - Ø), and hence the coincidence time, can be calculated. If a mho function is to be secure from the effects of load flow, a margin (M) of about two milliseconds should be maintained between the pickup time (P) of the function and the coincidence time (C) of the blocks produced with load flow; i.e., (M = P - C). For the phasors shown in Figure 9, the coincidence times are about 2.3 and 1.3 milliseconds for the non-offset and offset mho functions, respectively. Since the non-offset mho has a characteristic timer setting of 4.2 milliseconds, a margin of 1.9 milliseconds is obtained. If this same margin is to be maintained in the offset mho function, it can be achieved with a characteristic timer setting of 3.2 milliseconds. Thus, the offset mho function allows a shorter characteristic timer setting to be made without reducing the margin and hence maintaining the security of the function.

Zero Suppression

Zero suppression in the polarizing circuit also allows shorter time settings to be made, but in a different manner. Assume the same system shown in Figure 9, but that a zero suppression level of 35 percent is used, rather than an offset of 40 percent. The phasor diagram of Figure 10a still applies, and is shown again in Figure 11a, but in sinusoidal form.

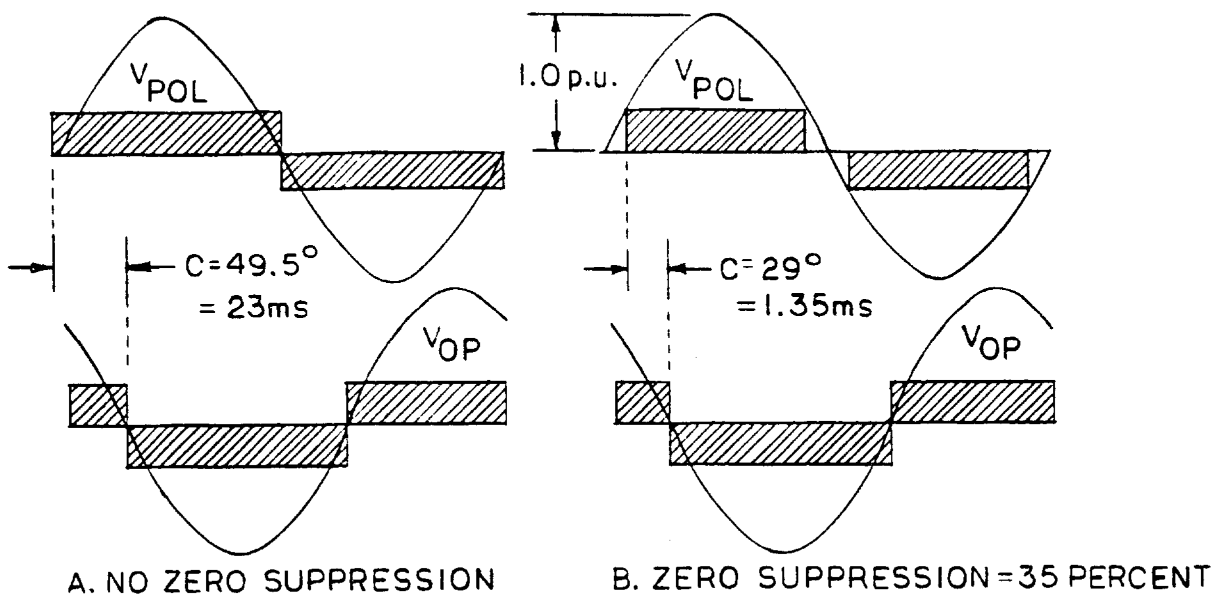


Figure 11 (0285A8942-0, Sh. 7) Effect of Offset - Sinusoidal Form

Figure 11b shows the effect of 35 percent zero suppression in the polarizing circuit. The effect is to reduce the coincidence time by approximately one millisecond so that the characteristic timer can be reduced accordingly, just as when offset was used. It must be noted that zero suppression also affects the steady-state operation of the function, and that the steady-state area of coverage will be reduced proportionately.

Although zero suppression and forward offset have similar advantages and disadvantages, they are different in nature and, depending on fault type, each affects the performance of the function differently. Because the voltage component of the polarizing signal will be less affected during an unbalanced fault than during a balanced three phase fault, the effect of forward offset and zero suppression will be much less for an unbalanced condition than for a balanced condition.

For three phase faults the amount of line not covered steady-state with forward offset is fixed at the magnitude of the offset (up to the clipping level described earlier). On the other hand, the amount of line not covered steady-state with zero suppression will depend on the source to line impedance ratio. The steady-state coverage will be practically non-existent for large source to line ratios, whereas practically all of the line will be covered as the source to line ratio gets very small. It is preferable to use zero suppression in applications involving small source to line ratios, whereas forward offset is preferred when the source to line ratio is large.

In summary, forward offset and/or zero suppression can be used to reduce the coincidence angle of the inputs to the characteristic timer during load flow and so allow the timer angle to be reduced while still maintaining a secure margin. With this reduced timer setting, with the A filter out, and with the reach and level detector set as proposed, very fast operating times can be achieved for heavy faults close to the relay location. The following times were measured on the Model Power System Simulator (60 hertz times; multiply by 1.2 for 50 hertz times).

A. 4 milliseconds for three phase faults.

B. 4-8 milliseconds for single line to ground faults.

If very fast operating time is not a requirement in the application, the variable mho function characteristic should be employed to provide maximum steady-state coverage. To operate as a variable mho, all three sections of the operate circuit are used. With this configuration, the output of the A filter tends to dominate at the input to summer number 2 by virtue of its high Q and stored energy. This prevents the output of the A filter from changing too quickly during the dynamic period immediately following a fault. When the A filter is used, the level detector following the B filter is set equal to 0.1 per unit voltage to prevent operation on capacitor voltage transformer (CVT) transients. Note that CVT transients will be innocuous with the A filter out because of the high level detector setting in the B filter section. The fixed high set level detector will still be active and it will provide an improvement in operating time for the more severe faults, but still not as fast as that obtained with the A filter out.

ARC/FAULT RESISTANCE

In discussing the effect of resistance in the fault on the performance of a distance function, it is necessary to also consider the type of fault.

In faults not involving ground, the resistance is made up of the arc products. It is generally accepted that the voltage drop across the arc is constant and equal to about five percent or less of normal system voltage. The resistance therefore, is non-linear and inversely proportional to the magnitude of the total fault current. A rough approximation is to assume that the arc resistance is equal to about five percent of the impedance from the fault to the source behind the distance function (see Figure 14).

In faults involving ground, there is a linear component of resistance in addition to the non-linear component introduced by the arc. This linear component may be introduced by tower footing resistance, ground wire resistance, trees growing into the line, etc. For ground faults, therefore, the voltage drop across the fault resistance will not be fixed, and will be directly proportional to the total fault current. The linear component can be quite large, such as when a tree touches a conductor at mid-span, and may prevent any type of ground distance function from operating. For this reason, other forms of relaying, such as negative sequence directional overcurrent functions, are often used for ground fault protection.

For a homogeneous system with single-end infeed, the resistance seen by a distance function appears to be purely resistive; i.e., there is no reactive component and the resistance adds to the line impedance as shown in Figure 12a.

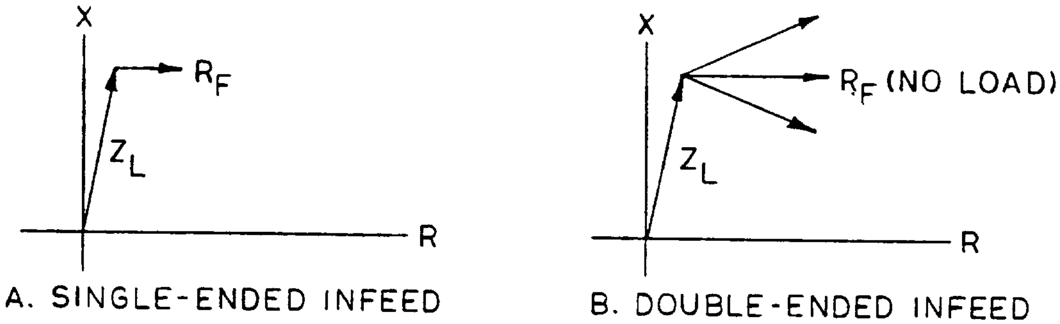


Figure 12 (0285A8942-0, Sh. 7) Effect of Infeed on Fault Resistance

On a double-ended system, the effect of load flow causes the fault resistance to appear to also have a reactive component as shown in Figure 12b.

Another effect of infeed is to magnify the resistive drop for ground faults because of the linear component of resistance, whereas the resistive drop for phase faults will be unaffected by infeed. Thus as far as ground faults are concerned, the resistive component of the fault will appear to be larger to a ground distance function than it actually is. The effect is such that the resistance will appear to be largest to the function at the location with the smallest contribution of fault current.

Because of the magnification of the ground fault resistance and the shift in phase caused by load flow, the performance of some types of ground distance functions could be severely affected. For example, Figure 13 shows that a quadrilateral characteristic has a significant tendency to overreach as opposed to a variable mho of the type used in the TLS system (and in other General Electric ground mho distance functions).

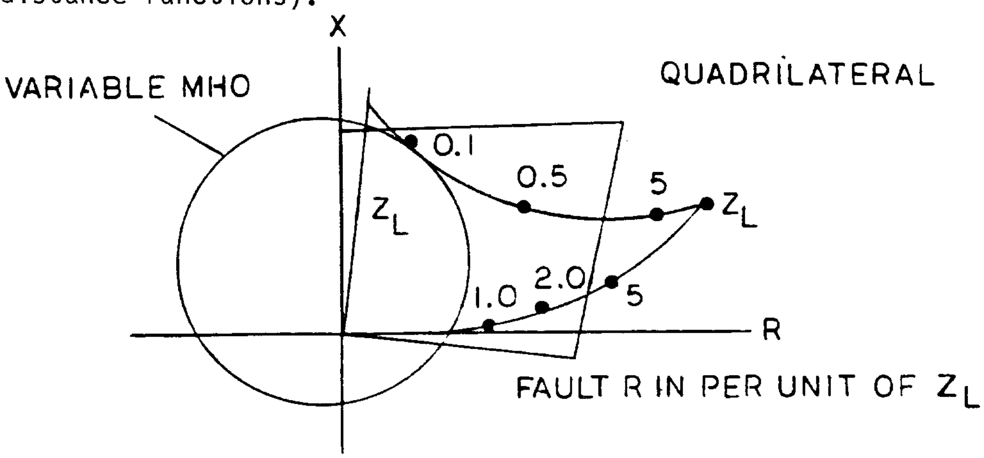


Figure 13 (0285A8942-0, Sh. 8) Variable Mho vs Quadrilateral

If resistance coverage greater than that offered by the variable mho is required, the ground distance functions in the TLS system can be operated in the negative and zero sequence reactance mode. These reactance functions have an adaptive characteristic that adjusts to load flow, thus preventing the overreaching/underreaching tendencies displayed by the quadrilateral functions shown in Figure 13.

The performance of a ground distance function may be affected by ground fault resistance regardless of line length because the resistance can be significant or appear to be significant, because of magnification. On the other hand, the effects of fault resistance on a phase distance function will in many cases be innocuous. For example, consider the system shown in Figure 14.

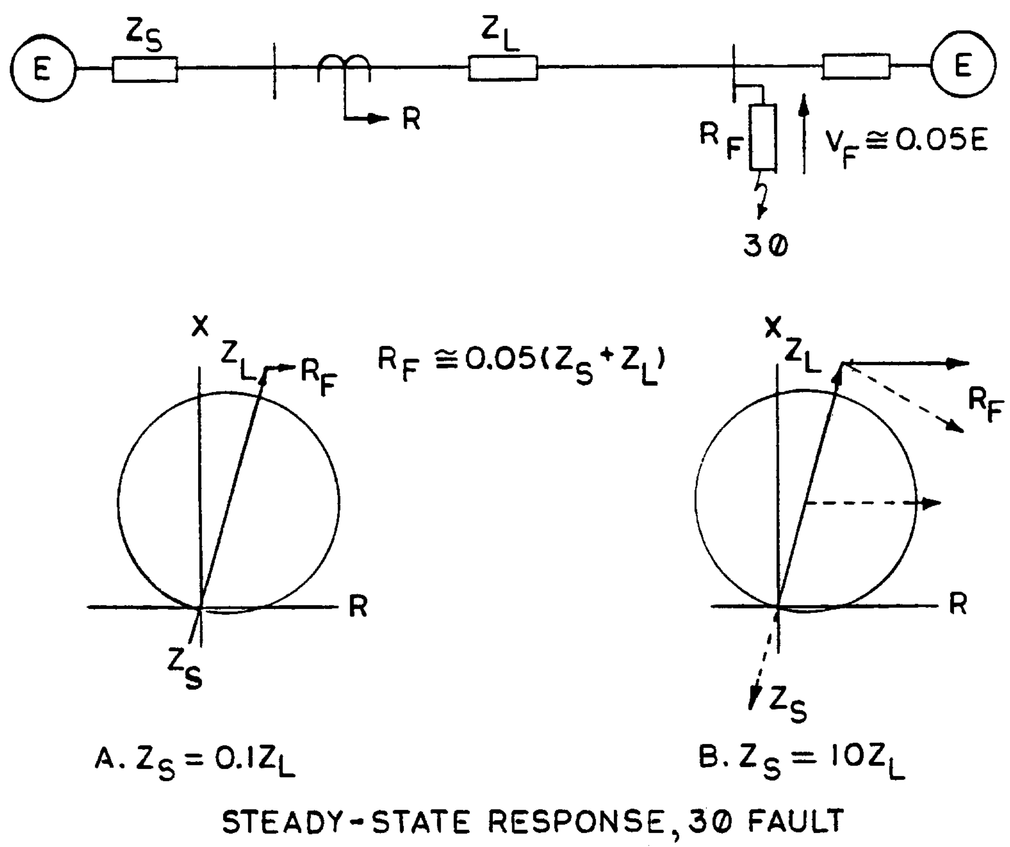
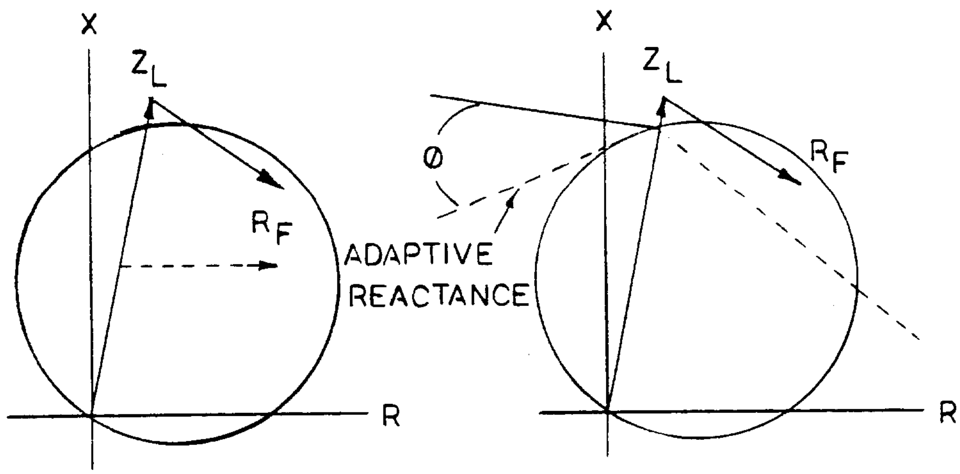


Figure 14 (0285A8942-0, Sh. 8) Effects of Arc Resistance

In this system, the first zone functions are set to reach 90 percent of the line impedance. For low to moderately low source to line impedance ratios (Figure 14a), the arc resistance is small compared to the line impedance, thus the possibility of overreaching is virtually non-existent (even with load flow). On the other hand, for very high source to line impedance ratios, the possibility of overreaching is increased (Figure 14b). Another problem exists in that the function may not operate for any internal faults because the arc resistance may fall outside of the characteristic.

It is possible to provide an increase in the arc resistance coverage by phase shifting the function as shown in Figure 15a.



A. 20 DEGREE PHASE SHIFT

B. PHASE SHIFT PLUS ADAPTIVE REACTANCE

Figure 15 (0285A8942-0, Sh. 9) Effect of Phase Shift

Unfortunately, this will further increase the tendency to overreach (depending on amount and direction of load flow). To overcome this application difficulty, the current supervision (V_{PY}) in the phase functions combines with the voltage polarizing signal (V_{PY}) to form the adaptive reactance characteristic shown in Figure 15b. This characteristic has an adaptive quality because of the zero suppression circuitry that is used in the current supervision signal. At low levels of current, zero suppression will be very effective in reducing the width of the blocks applied to the comparator, and the angle Ø will be quite large. On the other hand, the blocks will increase in width as the signal level is increased (heavier fault current) and the angle Ø will reduce accordingly. Thus, to provide a secure application for the situation depicted in Figure 14b (Z_S/Z_L very large), the zero suppression level should be set on the basis of maximum source impedance (weakest source). With this setting, the function will not overreach for external faults with arc resistance. As the source gets stronger, the current level, and hence the current polarizing signal, will increase and the reactance characteristic will open up to provide increased coverage. Note that the fault resistance will reduce in magnitude as the source impedance decreases, thus the security will not be jeopardized. If the special conditions shown in Figure 14 can never be realized on the line to be protected, the zero suppression level in the current supervision signal should be set to minimum.

Arc resitance and load flow for certain system conditions may also introduce another problem for phase mho distance functions. The steady-state security may be jeopardized for a three phase fault directly behind the function, but the function will be quite secure dynamically. Please note that this situation arises only under certain specific conditions. To increase the security, it is proposed that the zero suppression level in the voltage polarizing circuit (V_{PX}) be set at the five percent level. With this setting, the steady-state polarizing voltage (which is equal to the arc drop) will not exceed the zero suppression level, thus the function cannot operate. It is also possible to increase the security by phase shifting the voltage polarizing signal in the leading direction, by increasing the characteristic timer pickup setting (make the characteristic lenticular), by using forward offset or by adding blocking functions to the scheme.

SERIES COMPENSATED LINES

The TLS1000 system can be applied on lines with series compensation or on lines adjacent to compensated lines. This is made possible through a judicious choice of:

1. design of the distance functions, and
2. the settings used on the functions.

One of the basic problems that can occur on a compensated line is that the voltage at the relay can be reversed from the normal position because of the series capacitor. Consider the situation shown in Figure 16.

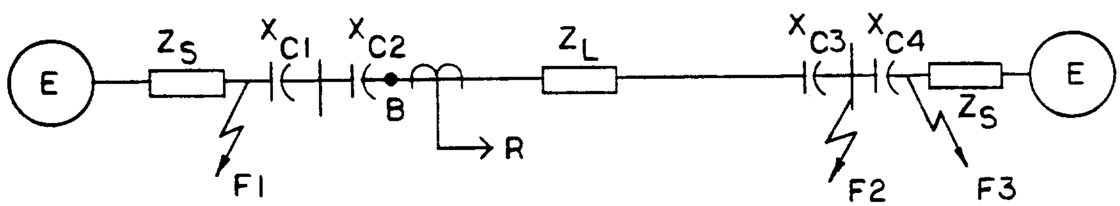


Figure 16 (0285A8942-0, Sh. 9) Typical Series Compensated System

For a fault at F1, the voltage applied to a relay with its potential source located on the line side of capacitor C2 will reverse if the protective gaps do not operate to remove the capacitors from service. The effect of the reversal on a distance function that uses this voltage for polarization is to cause the fault to appear to be internal to the line rather than external as it actually is (on a steady-state basis). If the function has its potential source on the bus side of C2 (location C), an internal fault at F4 will appear as an external fault (steady-state). If the function has a memory circuit in the voltage polarizing signal, it will perform correctly on a dynamic basis regardless of the location of the potential source; i.e., the voltage will not reverse immediately because of the memory action.

The distance functions in the TLS system use positive sequence voltage as the polarizing quantity and are provided with memory circuits. The positive sequence voltage will reverse for three phase faults, but on many systems it will be less likely to reverse for unbalanced faults. Therefore, the function must be relied on to operate dynamically for three phase faults, but it will respond correctly on a dynamic basis, and in many cases, on a steady-state basis for unbalanced faults. Thus, the distance functions in the TLS system will respond correctly to initiate high speed tripping (direct or pilot) regardless of the fault type or fault location relative to the series capacitor and potential source location.

Although the TLS distance functions with their potential source located at B in Figure 16 will provide a correct dynamic response for a fault at F1, this response may not be long enough to prevent tripping in the event of a breaker failure, or inordinately long breaker times in the adjacent line sections. To overcome this limitation, the blocking functions must be used in all applications involving series capacitors. The blocking functions will operate correctly dynamically, and possibly steady-state, to establish a blocking condition; and they are provided with adjustment in the dropout time to allow their output to last long enough to allow fault clearing by the breakers in the adjacent line sections.

Because the capacitive reactance of the series capacitor cancels the inductive reactance of the line, zone 1 functions cannot be set to protect 90 percent of the line when the capacitors are located in front of the relay location - either in the line itself or in adjacent line sections. It is also recommended that zone 1 functions not be set to reach 90 percent of the compensated line impedance; i.e., $[0.9(Z_L - X_C)]$. This is so because of the low frequency transients that are introduced by the series capacitors which can cause a zone 1 function to overreach significantly. The zone 1 functions in the TLS system can be used to initiate direct tripping on series compensated lines, but they must be operated in the B filter/level detector mode. When applied in this way, the level detector can be set on the basis of the gap flashing level when protective gaps are used around the capacitors; or if zinc oxide protectors are used, the level detector setting can be based on the peak voltage that can be tolerated across the zinc oxide before the capacitor bank is shorted. When set in this way, the zone 1 functions cannot operate for faults beyond the remote line terminal, but will operate for heavy faults close to the relay location. If more than one set of capacitors are located in front of the relay, it may be necessary to set the level detector on the combined gap flashing level. If it can be shown that the gaps on a bank in an adjacent line section will always operate to remove that bank from service, then the level detector setting can be based on the gap flashing level on the bank(s) in the line. As an example, consider a fault at F3 in Figure 16. For this fault, infeed at the bus remote from the relay may be sufficient to assure that capacitor bank C4 will always be removed from service. In that case, the gap flashing level of the capacitors located in the line itself (C3 in this example) need only be considered in determining the level detector setting in the zone 1 functions at location B.

Note that the zone 1 functions act as hybrid overcurrent/distance functions when applied in this manner and will suffer some pullback in reach. They will, however, provide high speed direct tripping for severe faults close to the function without risk of overreaching for external faults.

If the series capacitors are all located behind the relay (C1 and C2 in Figure 16), the zone 1 functions can be applied as a variable mho function, but the reach setting must be reduced by another ten percent below the setting normally used on uncompensated lines; i.e., 80 percent versus 90 percent.

It is not necessary to make any special settings in the overreaching functions when applied on series compensated lines, but some modifications will be required in the settings of the blocking functions.

First, a 20 degree phase shift must be introduced to the polarizing signal in the MB functions. This phase shift was determined empirically and is used to facilitate coordination with the tripping functions in the presence of the transients introduced by the series capacitors.

When series capacitors are located between the potential sources used to supply the tripping and blocking functions at each end of the line, the impedance seen by the tripping functions for a fault beyond the remote terminal may be reduced because of the capacitors, but the impedance seen by the blocking functions will not. For this reason, the reach of the blocking functions will have to be increased to insure that they will operate for all faults that the remote tripping functions can see.

The negative sequence blocking function uses negative sequence voltage and current to form a directional characteristic via an amplitude comparator. The following quantities are used:

$$V_{OP} = V2 + KI_2Z_{R2}$$

$$V_{REST} = I_2Z_{R2}$$

The function operates when the magnitude of the operating quantity is greater than the magnitude of the restraining quantity. It is possible for the negative sequence voltage to be reversed from normal for some system conditions. For example, V_2 will be reversed from the normal position when the sum of the capacitive reactance of C1 and C2 is greater than the negative sequence source impedance (Z_S) behind the capacitors (see Figure 15). The effect of this reversal would cause the function to operate for internal faults were it not for the compensation factor (K) in the operate signal. Therefore the compensation factor, K, must be set differently when the line, or an adjacent line is compensated. The exact setting to be made will be a function of the system parameters.

SINGLE POLE TRIPPING

The TLS system can be used to initiate single pole tripping when such operation is required. Only a few modifications are required in the settings.

One problem arises because the phase distance functions can operate for some single line to ground faults. If this were allowed to happen, a three pole trip would be initiated when a single pole trip is really required. To prevent this from happening the following is done:

1. The first zone phase functions have zero sequence overcurrent restraint built in. This restraint is such that the function will be prevented from operating for single line to ground faults, but the effect will be minimized on double line to ground faults. This restraint must be switched in when single pole tripping is required.

2. The logic is set up so that the ground distance overreaching functions take priority over the phase distance overreaching functions during single line to ground faults. Thus, the phase distance functions will be prevented from initiating a three pole trip. No special settings are required to implement this feature.

The first zone ground distance functions are provided with zero sequence current supervision. On systems using three pole tripping this supervision is set at the minimum level to provide the most sensitive protection. When single pole tripping is used, the setting for this supervision should be based on the minimum zero sequence current for a fault at the end of the line remote from the function. This setting is proposed to prevent overreaching by the first zone ground distance functions in the unlikely event that a phase to phase fault were to occur on an adjacent line at the same time that a pole was open (during a single pole trip) in the line being protected by the zone 1 functions.

It was noted earlier that the ground distance functions use signals derived from the negative and zero sequence current. These two signals form an excellent phase selector in addition to combining with the operating signal to form the negative and zero sequence reactance characteristics described earlier. This type of phase selection assures that the ground distance function associated with the faulted phase only will operate during single line to ground faults. Provisions are included for removing these inputs, so it must be assured that these signals are in when single pole tripping is required.

SCHEME AND CHANNEL CONSIDERATIONS

The TLS system has a common logic module that allows any of the following modes of operation:

1. Stepped distance scheme
2. Zone acceleration
3. Directional comparison blocking scheme
4. Permissive tripping scheme

    a. Overreaching
    b. Underreaching

5. Hybrid scheme

Stepped Distance Protection

Stepped distance protection can be obtained in two ways:

1. Three independent zones if three zones of protection are required.
2. Two independent zones when only two zones of protection are required.

The second method is provided with the means to extend the reach of the first zone function to second zone reach following a time delay that is started by the operation of the overreaching functions. Therefore, three zones of protection can be provided via two zones of equipment. Whether or not second or third zone timing is to be implemented is up to the user. When second zone timing is to be used, it is proposed that the switched first zone method be used to implement it, rather than using the overreaching functions as the second zone function. In this way, it may be possible to set the overreaching functions longer than a normal second zone reach and so optimize the operating time as described earlier. The normal second zone reach can then be obtained with the switched zone 1 function.

It is also possible to extend the reach of the zone 1 function by external means via a contact converter provided in the system. The input to the contact converter can come from a channel trip signal thus allowing the system to be applied in a zone acceleration scheme. This type of scheme is typically applied when overreaching functions are not available for use.

Pilot Protection

The remainder of this discussion on schemes and channels pertains to the tripping, blocking and hybrid type directional comparison schemes.

In earlier days of directional comparison relaying, most schemes used with power line carrier (PLC) were blocking schemes with an OFF-ON channel, and most schemes used over microwave (MW) were tripping schemes with a frequency shift (FSK) channel. With only these two choices, tripping or blocking was sufficient to describe the complete protective scheme.

The introduction of frequency shift channels on PLC, with the unblocking mode of operation, made it possible to provide either a tripping or a blocking scheme over PLC or MW, depending on which frequency (trip or guard) is transmitted in standby. In addition a third relay scheme, called a "hybrid" scheme was developed, which offers some of the advantages of a blocking scheme (trip at one end with weak infeed at the other) but operates basically as a tripping scheme.

In the tabulation of relay schemes and pilot channels given below, the following definitions are used:

Tripping Scheme - requires operation of the local trip functions and receipt of a trip signal from the remote terminals before tripping will be initiated. Scheme contains tripping functions only.

Blocking Scheme - requires operation of the local trip function and the absence of a blocking signal from the remote terminals before tripping will be initiated. Scheme contains both blocking and tripping functions.

Hybrid Scheme - requires operation of local trip function and receipt of a trip signal from remote terminals before tripping will be initiated, but trip signal may be "repeated" from remote terminal if a blocking function has not operated at that terminal. Scheme requires both tripping and blocking functions.

The various combinations of relay schemes and pilot channels are described below:

1. Tripping scheme, FSK tripping channel. Permissive overreaching transfer trip (POTT), transmits the guard frequency in standby condition, and the relay trip functions key the channel to trip frequency. Tripping is blocked on loss of channel. Receipt of trip frequency gives trip permission to local relay.

2. Tripping scheme, FSK unblocking channel. Permissive overreaching transfer trip, transmits guard frequency in standby condition; relay trip functions key the channel to trip frequency and permit trip for short duration if the signal is attenuated by a fault, then block tripping. Receipt of an unblock signal gives trip permission to local relay (note that an unblock signal can be the receipt of the trip signal from the remote terminal or the loss of signal (LOS) output from the local receiver).

3. Blocking scheme, OFF-ON power line carrier. No signal transmitted in standby condition. Relay blocking functions start carrier transmission and relay tripping functions stop carrier transmission. Receiver output blocks tripping by local relay. Tripping functions initiate tripping independently at each terminal in the absence of a blocking signal.

4. Blocking scheme, FSK tripping channel. Transmitter keyed to trip frequency in standby, relay blocking function at one terminal keys transmitter to guard frequency for external fault. Tripping blocked for loss of channel. Receipt of trip frequency gives trip permission to local relay.

5. Blocking scheme, FSK unblocking channel. Transmitter keyed to trip frequency in standby, relay blocking function at one terminal keys transmitter to guard frequency for external fault. Permits tripping for a short duration if the signal is attenuated by a fault. Receipt of unblock signal gives trip permission to local relay.

6. Hybrid scheme, FSK tripping channel. Transmits guard frequency in standby condition. Relay tripping function keys transmitters to trip frequency. In addition, receipt of a trip frequency plus no blocking function output will key the transmitter for short duration to "repeat" trip signal back to transmitter location. Tripping is blocked for the loss of channel. Receipt of trip frequency gives trip permission to local relay.

7. Hybrid shceme, FSK unblocking channel. Transmits guard frequency in standby condition. Relay tripping function keys transmitter to trip frequency. In addition, receipt of a trip frequency, plus no local blocking function output, will key the transmitter for short duration to "repeat" the trip signal back to the transmitter location. Permits

tripping for a short duration if the signal is attenuated by a fault. Receipt of an unblock signal gives trip permission to the local relay.

The following application guidelines should be considered when selecting a relaying scheme and a channel.

1. The blocking scheme with OFF-ON carrier will trip the local breaker for any internal fault whether or not the remote tripping function operates and is therefore suitable for applications with a weak infeed terminal. The channel is not continuously monitored, and is therefore subject to overtripping if the channel fails. A failed channel can go undetected until tested manually or by an automatic checkback scheme.

2. Frequency shift (FSK) tripping channels would normally be used with microwave. FSK unblocking channels would be used with power line carrier to allow tripping on internal faults that cause excessive attenuation in the channel.

3. Where frequency shift channels are used, tripping schemes tend to be more secure because relay tripping functions at both ends of the line must see the fault. They are generally applied where there are good sources of fault current at both ends of the line.

4. Where the source at one end of a line is much weaker than that at the other end, a blocking scheme will permit faster tripping of the heavy infeed end since tripping is not delayed because of slow operation of the tripping function at the other end.

5. For fast tripping of a weak infeed terminal, a hybrid scheme with a weak infeed trip option is preferred.

6. If two FSK channels are used for direct transfer tripping for equipment failure, one of the two channels can be used for the directional comparison relaying. This would be a reason for choosing a tripping or hybrid type scheme rather than a blocking scheme.

OTHER FEATURES

The TLS system contains other functions and features in addition to those previously described.

FAULT DETECTOR

A fault detector function is used to provide supervision of the trip outputs, and is intended to reduce the possibility of misoperation due to either potential or component failure. The function is a sensitive, high speed current operated function, that uses negative sequence current or the change of positive sequence current. It has an adaptive pickup level that is increased automatically, after a time delay, when a continuous input is applied to it. This feature is intended to prevent operation of the fault detector on negative sequence current caused by unbalances in the load current. The function will perform properly on low level fault currents because the adaptive feature is provided with a long time constant. If the fault detector function is not desired, it can be taken out of service via option links provided in the equipment.

LINE PICKUP (CLOSE INTO FAULT)

Line pickup circuitry (close into a fault protection) is included in all TLS systems. Circuitry is provided for three pole and single pole tripping schemes.

The line pickup circuitry is implemented via current and voltage functions that operate through the logic to initiate tripping when energizing a line. Basically, the current and voltage functions are used to form open pole detectors to determine that the line is dead by sensing the lack of voltage and current. If a dead line condition persists for nine cycles, the logic is arranged to permit direct tripping by a positive sequence overcurent function provided for this purpose. If there is no fault when the breaker is closed, the positive sequence overcurrent function will not operate, and the line pickup protection will be removed from service when all three phase voltages return to normal.

Similar type logic is used when single pole tripping is required, but in this case line pickup will only be energized during the period that the faulted phase is open. If a breaker is reclosed into a fault, three pole tripping will be initiated through the operation of the ground distance function associated with the faulted phase. If there is no fault, the line pickup circuitry will be removed from service following restoration of the phase voltage.

If the line pickup protection is not desired, it can be taken out of service via an option link.

RECLOSING CONTROL

Reclose initiate outputs are provided for three pole reclosing and single pole reclosing (when used). Option links are provided in the logic to block the reclose initiate outputs for any, or all, of the following conditions.

1. Operation of an external contact (via a contact converter)

2. Following a zone 3, or zone 2 and 3 time delayed trip.

3. Following a zone 4 time delayed trip.

4. Following an operation of any one of the MT functions, thus blocking reclosing for all multi-phase faults, but allowing reclosing for single line to ground faults (used in three pole tripping schemes).

5. Following a trip initiated by an out-of-step swing.

SEQUENTIAL RECLOSING

Sequential reclosing logic is provided in the TLS system. It is provided to control an independent recloser/reclosing system, and it may be used to prevent reclosing into a severe fault. The reclosing logic is arranged to recognize the severity of the fault by operation of certain of the tripping functions, and to provide an inhibit output to block reclosing at the terminals where those functions have operated. The inhibit output will persist until the line voltage returns to normal to indicate that the line is healthy. If a severe fault is not indicated, reclosing will be permitted at that terminal, and if successful, the voltage on the line wil return to normal to remove any inhibit outputs that may have been produced. If none of the fault detectors indicate a severe condition, high speed reclosing will be initiated at all terminals of the line. If a severe condition is indicated at all line terminals, then reclosing will be inhibited at all line terminals. For the latter condition, reclosing will have to be performed manually, or a long time delay is often recommended to produce an automatic reclose and so minimize the shock to the system.

An inhibit output may be initiated for the following conditions:

1. Operation of any of the first zone functions within 0.4 cycle of the time that the fault detector operates.

2. Operation of any of the phase distance functions, thus inhibiting reclosing for all multi-phase faults on the line.

3. Operation of all three phase distance functions, thus inhibiting reclosing for all three phase faults.

Option links are provided whereby these features can be inserted/removed from service.

PT FUSE FAILURE

Circuitry is included in the TLS system to detect failure of a fuse in the potential supply of the system. The alarm circuit operates when all three of the following conditions are met.

1. Loss of any phase voltage.
2. Any phase current above the IØ TRIP level detector setting.
3. No output from the fault detector.

The fuse alarm output is sealed in once it operates, and remains sealed in until all phase voltages return to normal. The output from the fuse failure alarm may be used to block tripping, sound an alarm, etc. The alarm will not operate if the phase current is not above the IØ TRIP pickup, but the distance units cannot produce any tripping for this loss of potential because they are supervised by IØ TRIP. If the current should then increase above the pickup level, the fuse failure circuit will operate before the distance functions, thus preventing any trip outputs. Note that the fuse failure alarm circuit will be blocked during a single pole trip when such tripping is employed.

OUT-OF-STEP BLOCKING

Out-of-step blocking is provided on both the phase and ground overreaching functions. The ground functions are provided with out-of-step blocking to prevent operation of the ground overreaching functions in applications involving single pole tripping and parallel lines. With one pole open in one of the lines, it is possible for the ground distance function on the same phase in the parallel line to operate during a swing before the phase out-of-step blocking can be set up. The ground out-of-step blocking is set to prevent this. If single pole tripping is not employed, the ground out-of-step blocking is not required and is taken out of service.

DESIGN FEATURES

PACKAGING

The TLS system is contained in a modular design package consisting of two separate cases. The printed circuit boards, transformers, transactors and output relays are contained in pluggable modules. Multi-conductor cables provide the interconnections between the two cases. Each case includes two 14-point test/disconnect plugs. A single regulated DC-DC power supply module provides the DC supply voltages to both cases. The modular design offers the advantages of reduced size, reduced cost, and ease of installation.

SETTINGS

All of the TLS settings and adjustments are digital and are made using rotary switches, miniature toggle switches (DIP) or printed circuit board-mounted links. The increments used in these settings have been chosen to provide good resolution, thus eliminating the need for vernier adjustments which would require the use of potentiometers. Many adjustments, such as the characteristic angle, the reach and some overcurrent levels are conveniently located on the front panel of the modules. Switches are provided in the logic modules to program the system for various schemes and optional features which are available in the system.

CIRCUITRY

The TLS system includes innovative circuitry which incorporates proven state of the art electronics into traditional relaying functions. The TLS system, like other General Electric Co. relays, uses only hermetically sealed and burned-in semiconductors. The TLS system may be used in an environment where the ambient temperature is between minus 20 degrees and plus 65 degrees Centigrade. The following are examples of the new circuit techniques used in the TLS design.

Timing Circuits

The measuring unit characteristic timers and a majority of the logic timers are digital; that is, the time is established by counting a series of reference or clock pulses. These pulses are provided by a highly stable, continuously running crystal oscillator. A second oscillator, of a different design, is included as backup to the primary crystal oscillator. In the event that the frequency of the crystal oscillator goes outside prescribed limits, a monitoring circuit will switch to the backup oscillator and energize an alarm circuit.

These digital timers are a marked improvement over the resistor-capacitor timers used in previous systems. Performance variations with changes in component values, temperature and age are minimized. The digital timers also provide greater accuracy and ease of setting.

An integrated circuit package was developed to provide all of the special features required by a measuring unit characteristic timer. The tripping unit characteristic timers are adjustable from 64 to 128 degrees in one degree steps. Because of the special features in this timer chip, it is also used for many of the logic timers.

Operate Circuits

The mho distance functions used in the TLS system are of the phase angle comparator type used in previous designs. There are, however, several significant innovations in the operating circuits of the functions.

In earlier designs, the reach of the function was adjusted by selecting an appropriate tap on the restraint voltage, and using base reach taps in the current circuits to make major changes in the range of adjustment, i.e., 1 to 10 or 3 to 30 ohms. In the TLS system, on the other hand, voltage taps are used to select ranges of reach adjustment (0.1 to 2.5 vs 1 to 25 for example), and the reach is adjusted by changing the replica impedance in the current circuits. The approach provides improved performance by producing a more uniform energy level in the operating circuit filters over a wide range of reach settings. By varying the IZ quantity, the resolution of the reach is made uniform and improved over that which can be obtained with voltage restraint taps, especially at low tap settings (higher reaches).

TARGETS

Light emitting diodes (LEDs) are used as trip targets in the TLS system. The LEDs are energized by latching reed relays. These relays are set at the time of tripping and remain latched until reset manually via a front panel reset pushbutton or remotely via an external input to a contact converter. The reset circuit also provides a means of checking the LEDs by momentarily lighting all of the targets when the pushbutton is depressed. If the station battery control power is removed for any reason when a target is lit, the associated reed relay will remain latched so the same target(s) will be displayed when the control power is reapplied. The following LED targets are provided:

A	Phase A trip*
B	Phase B trip*
C	Phase C trip*
I	Zone 1 trip
II	Zone 2 trip
III	Zone 3 trip
IV	Zone 4 trip
CT	Channel trip
LP	Line pickup trip
WI	Weak infeed trip
TT	Transfer trip
MOB	Out-of-step blocking**

*Light individually in single pole tripping schemes, whereas all three light in three pole tripping schemes

**Does not seal-in

SETTINGS GUIDE

I. STANDARD SETTINGS

* The settings described in this section apply to transmission lines 10-200 miles in length without series compensation or weak infeed conditions, and where single-pole tripping and ultra-fast tripping is not required.

Settings are provided for the following schemes:

1. Permissive tripping scheme
2. Blocking scheme
3. Hybrid scheme

The settings given for each function apply to all schemes except where specific differences exist. In those cases, the settings will be given for each scheme accordingly. The following settings must be determined using the instructions given below:

I.1 Voltage Functions:

	Setting
V_{nom}	Select 107.5 or 115, whichever is closest to nominal

I.2 Overcurrent Functions:

Function	Setting* Permissive	Hybrid	Blocking
IØ Trip	0.1	0.15	0.15
IØØ	0.1	0.15	0.15

*In per unit of rated I_N

I_1 Set to two-thirds of minimum current for a three-phase fault just in front of relay, or 125 percent of maximum load current, whichever is less

* Revised since last issue

NOTE: If minimum current for an internal fault is less than the pickup settings given for the IØ Trip or IØØ functions, refer to Section II on "Weak Infeed Tripping."

I.3 Distance Functions:

	Replica Impedance Angle
ϕZ_1 [a]	Set nearest to positive sequence line angle
ϕZ_0 [a]	Set nearest to zero sequence line angle
/ZRO	Supplement to ϕZ_0 and independent for each zone. For zero sequence line angles greater than 50 degrees, set /ZRO = 0 and use ϕZ_0 to set replica impedance angle. For line angles less than 50 degrees, use the difference of ϕZ_0 and /ZRO to set replica impedance angle

(a) Common to all zones

First Zone Distance Functions
(optional) - M1, MG1

	Setting M1	Setting MG1
Reach[b]	0.9 (Z_{1L})	0.9 (Z_{1L})
MULT[b] (Reach Multiplier)	See Table IV	See Table IV
K_0, zero sequence current compensation	N/A	0.95 (Z_{0L}/Z_{1L})
VP SENS (zero suppression in Vpol)...	0.05[c]	

(b) Common setting for M1 and MG1

(c) Set to zero if minimum voltage at relay for a three-phase fault at remote terminal is less than ten percent.

	MG1 Only Variable Mho	MG1 Only Reactance
Vp..............................	in	out
MG1 Supervision..................	Mho	Reactance

Overreaching Functions - MT and MTG

	Setting MT	Setting MTG
Reach[(e)]	See Table III	See Table III
MULT[(e)] (Reach Multiplier)	See Table IV	See Table IV
Characteristic Timer Angle	See Table III	See Table III
MOB	See SEC I.6	
VP SENS (zero suppresion in Vpol)..	0.05[(f)]	
K_O, zero sequence current compensation	N/A	(Z_{OL}/Z_{1L})

(e) Common setting for MT and MTG

(f) Set to zero if minimum voltage at relay for a three phase fault at remote terminal is less than ten percent.

NOTE: Two methods are given in Table III for selecting the reach and characteristic timer angle setting of the overreaching functions.

Method 1 is based strictly on line length with reaches selected to provide security, but with no attempt to optimize the setting to give the fastest possible operating time. With this method it is only necessary to know the length of the line to be protected.

Method 2 takes into account the source impedances to establish a setting. With this method, longer reach settings than those obtained with Method 1 may result for a given line length. The effect of the longer reach setting will result in somewhat faster operating times. It should be noted that when this method is used. the maximum fault current should be based on future system operating conditions, taking into account the strongest source conditions. If these conditions are known or can be assumed, or if there is no anticipated change in the system in the future, this method will provide overall better performance with respect to operating time. If these conditions are not known, it may be best to use Method 1 in establishing a setting.

If the system conditions are known, it is possible to check the operating times for the two reaches determined with Method 1 and Method 2, respectively, by using the operating time curves given in Figure 18.

*Zero Suppression Setting

The setting of the zero-suppression level (0 SUPP) on the phase and ground distance units (M1, MG1, MT, & MTG) must be set based on the reach-multiplier setting (MULT) of the associated zone of protection. The zero-suppression levels on the AFM boards must be set equal to 0.1/MULT, where MULT is the reach multiplier set on the front panel of the AFM101/104 or AFM102/105 module.
For example, if the reach multiplier is set to 0.25, the zero-suppression level must be set equal to 0.1/0.25 or 0.4. The nearest available setting is 0.41.

*S Signal

The recommended setting for the S signal on the phase and ground distance units (M1, MG1, MT, & MTG) is OUT. If the reach multiplier is set less than 1.0, the S signal **must** be in the OUT position to ensure proper operation of the distance functions.

*IO Restraint Signal

The IO Restraint signal on the VMM101/102 module is used to prevent the TLS phase units from operating on heavy close-in single-line-to-ground faults in single-pole tripping applications. When the TLS is applied in a three-pole tripping scheme the IO REST link should be in the OUT position. When the TLS is applied in a single-pole tripping scheme, it should be in the IN position.

Blocking Functions - MB and NB

	MB
Characteristic timer angle ...	Pickup: 10^{o} less than MT pickup at remote end of line

	MB
K, zero sequence current compensation	$(Z_{0L} - Z_{1L})/Z_{1L}$

The MB reach setting (Z_R) is partially dependent on the reach of the MT function at the remote line terminal.

1. If the MT reach is less than twice the positive sequence line impedance, Z_L,

$$Z_R = (\text{MT reach})(1 - KV1) \quad (1)$$

2. If the MT reach is greater than twice the positive sequence line impedance, Z_L

$$Z_R = (2)(\text{MT reach} - Z_L)(1 - KV1) \quad (2)$$

* Revised since last issue

In either case, start with the largest KV1 (KV1 = 0.45, 0.3, 0.15, 0) and then check for the following:

$$KV1 \leq \frac{Z_R}{\frac{E}{I_R} - Z_L} \qquad (3)$$

where: Z_R = MB reach from (1) or (2) above

E = Normal system voltage

I_R = Minimum current for a three-phase fault at remote end of line from where MB is located

Z_L = Positive sequence line impedance

If equation (3) is not satisfied with the KV1 selected, reduce KV1 until satisfaction is achieved. If the minimum I_R is not known, set KV1 = 0.

I.4 Logic Timers

Timer	Function	Setting
TL1	Comparator	Blocking scheme: Set pickup equal to channel time plus propagation time plus 2.0 millisecond margin. Tripping and Hybrid schemes: Use a 3.0 millisecond minimum pickup. May be set longer to provide additional security against spurious outputs from receiver.
TL2	Zone 2	Set these timers
TL3	Zone 3	to appropriate
TL4	Zone 4	backup tripping times
TL6	Out-of-step	See section I.6
TL16	Week infeed delay	Hybrid scheme only: Set long enough to provide security against spurious outputs from receiver.
TL13	Direct transfer trip	Tripping and Hybrid schemes only: Used with shared channels. Set long enough to provide security against receiver output from direct transfer trip receiver when relaying receiver is producing trip output.
TL22	Direct transfer trip reclosing control	Tripping and Hybrid schemes only: Used with shared channels. Set long enough to differentiate between an equipment transfer trip and a line transfer trip.

I.5 Stepped Distance Protection

A. Second Zone Protection:

The reach settings given in the previous sections for the permissive functions apply to a pilot relaying scheme when used with a suitable channel. The permissive functions can be used to energize a timer (included in the logic) and thus provide time-delayed backup protection. However, the reach may not be correct to coordinate with distance functions in adjacent line sections if the above outlined settings are used. If such coordination is required, three alternatives are available:

1. Pull back the reach of the permissive zone. If this alternative is selected, a degradation in operating time can be expected as a consequence of the reduced reach.

2. Use the zone switching feature (included in logic) to extend the reach of the zone 1 function to zone 2 following zone 2 time, which is controlled by the overreaching function.

3. Add a dedicated zone 2 tripping function.

If alternative 1 or 3 is selected, choose a second zone reach that meets the needs of the system (typically 110 to 125 percent of the line length). Set the permissive overreaching functions as described earlier.

If alternative 2 is selected, follow the settings for the zone 1 and permissive functions and select a zone 1 reach multiplier to give the desired zone 2 reach.

B. Third Zone Protection:

Third zone protection, when provided, is implemented in one of two ways:

1. With a dedicated third zone function, or,

2. With the overreaching function of the pilot scheme also used to:

   a. provide third zone tripping, and,

   b. to control switching of the zone 1 function to provide second zone protection.

In selecting a reach setting for the third zone function, the following points should be kept in mind.

The effect of infeed at the remote terminal of the protected line will cause the distance functions to see an impedance that can be much larger than the actual impedance as measured from the relay location to the fault. To overcome this increase in apparent impedance, an inordinately long reach setting may be required on the third zone function. Before making such a setting, the effects of load flow (both emergency, and that occurring during swings) must be considered. It is also necessary to consider any future changes that may be made in the power system which could cause the third zone functions to operate on load flow after these changes are made. A margin of 40 degrees must be maintained between the pickup time of the third zone function (characteristic timer setting) and the coincidence time of the blocks produced with load. It may be necessary to make the third zone function lenticular to maintain this margin. If these points are not considered, the result may be incorrect operation of the third zone functions which could have a serious effect on the operation of the power system.

In blocking and hybrid types of relaying schemes, the overreaching functions must be set to coordinate with the remote blocking functions. When the overreaching functions are also used as the third zone functions, extremely long settings may be required on the blocking functions to achieve coordination. Here too, the effects of load must be considered for the blocking functions must not be allowed to operate on load, otherwise tripping will be delayed during legitimate fault conditions.

When a dedicated third zone function is used, a switch is provided in the scheme logic wherein either the second zone function, or both it and the third zone function, can be used to initiate pilot tripping and to control keying of the transmitter. If the second zone functions alone are used for pilot tripping and transmitter keying, some degradation in overall operating time may be experienced because of the minimum amount of overreach obtained with second zone protection. The security of the system will be quite good, however, because of the limited exposure to external faults. If the third zone function is used in conjunction with the second zone function for pilot protection and transmitter control, overall operating times may be improved because of the increased overreach provided by the third zone function, but security will be reduced because of the increased exposure to external faults.

In summary, selection of a reach setting for a third zone function should be made with extreme care so as not to degrade the protection and jeopardize the integrity of the power system.

I.6 Out-of-Step Blocking

This scheme is equipped with out-of-step blocking on both the phase and ground functions (required on ground functions in single-pole tripping schemes).

Phase Out-of-Step Blocking - MOB

The reach of the phase out-of-step blocking functions is the same as the phase MT functions, but separate settings are required on the MOB characteristic timer and on timer TL6 (time delay) in the scheme logic.

The characteristic timer setting is based on the reach of the MT functions and the minimum expected load impedance for maximum load flow across the protected line. With reference to Figure 20, the MT reach and minimum expected load impedance are laid out on an R-X diagram. The angle A shown in Figure 20 is then measured and a 20 degree margin is added to this to establish the MOB setting. In Figure 20, the angle A is 40 degrees; therefore, the MOB timer setting should be 60 degrees, thus producing the MOB characteristic shown. In no case should the MOB characteristic timer angle setting be less than 50 degrees.

From system swing studies, the minimum time for the impedance locus to traverse the distance between the MOB characteristic and the MT characteristics can be established. Timer TL6 should be set with a pickup 0.5 cycles less than this time.

The pickup time of TL6 should never be set less than two cycles. If necessary, increase the MT characteristic timer pickup setting to produce a more lenticular characteristic on MT and so allow TL6 to be set to meet the two cycle minimum.

Ground Out-of-Step Block - MOBG

The ground MOBG timer should be set with the same setting as the MTG characteristic timer, thus effectively removing the MOBG from service since it is not required in three-pole tripping schemes.

I.7 Effects of Non-Homogeneity

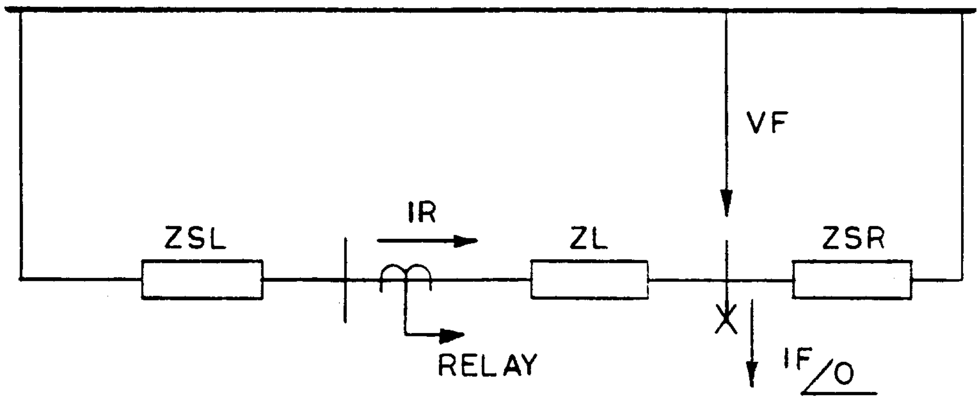
The term, homogeneous, is used to describe a system in which the angle of all of the system impedances are equal. A non-homogenous system is therefore one in which the impedances have different angles. Non-homogenity in a system can cause a negative sequence or zero sequence reactance function to overreach unless provisions are included in the function to prevent this. The phase shift circuits in the negative and zero sequence polarizing signals are provided to prevent overreaching. To determine the amount of phase shift required, it is necessary to know the system as shown in Figure 17.

The tendency for the function to overreach will depend on whether the relay current leads or lags the total fault current. Overreaching can occur for leading currents, whereas underreaching can occur for lagging currents. The amount of lag/lead will depend on the system impedance angles. For example: assume that I_F is at zero degrees as shown in Figure 17. Then,

$$V_F = (Z_F \angle \theta_F)(I_F \angle 0)$$

$$I_R = \frac{V_F}{Z_T} = \frac{(Z_F \angle \theta)(I_F \angle 0)}{Z_T \angle \theta_T} = \frac{Z_F I_F}{Z_T} \angle \theta_F - \theta_T$$

Thus, the relay current leads the fault current when $\theta_T < \theta_F$, and lags the fault current when $\theta_T > \theta_F$.



$ZT = (ZSL + ZL) = ZT\angle\phi T$

$ZSR = ZSR\angle\phi R$

$ZF = ZT$ IN PARALLEL WITH $ZSR = ZF\angle\phi F$

Figure 17 (0285A8942-0, Sh. 10) Negative or Zero Sequence Network

To prevent overreaching when the current is leading, set the phase shift in the negative and zero sequence circuits equal to or greater than the maximum amount of lead that is expected for various system operating conditions.

SAMPLE CALCULATION AND SETTING CHECKLISTS

* The following pages provide a sample calculation and checklists for the settings that must be made on the measuring and timing functions in the TLS1000 System. Many of the settings (for lines 10-200 miles in length, without series compensation or weak infeed conditions, and where single-pole tripping and ultra-fast tripping is not required) require no calculations. The sample calculation which follows demonstrates the calculations for those settings that must be determined. A checklist for the settings is given prior to the sample.

The checklists contain a functional listing of the adjustments to be made, the name of the adjustment as it appears on the respective module, the name of the module on which it is located, and a place to fill in the actual setting (when not given). Where modules are listed with two numbers separated by a slash (AFM102/105 for example), the first number refers to 60 hertz modules, whereas 50 hertz modules are represented by the second number.

* Revised since last issue

TLS SETTINGS SHEETS

FUNCTION	ADJUSTMENT	MODULE	SETTING
IO TRIP	I_T	ISM101/102	
IO BLOCK	I_B	ISM101/102	0.1
REPLICA IMPEDANCE	øZ1	ISM101/102	
REPLICA IMPEDANCE	øZ0	ISM101/102	
M1/MG1 REACH	r	AFM101/104	
M1/MG1 REACH MULT	MULT	AFM101/104	
MG1 A FILTER	A FIL	AFM101/104	IN
MG1 B FILTER	B FIL	AFM101/104	IN
MG1 0 SUP	O SUP	AFM101/104	0.1/MULT*
MG1 S SIGNAL	S	AFM101/104	OUT
IOZR1 CLIP LEVEL	MULT	AFM101/104	
MG1 I0 CURR. COMP.	K0	AFM101/104	
MG1 ∠ZR0	∠ZR0	AFM101/104	
M1 A FILTER	A FIL	AFM201/202	IN
M1 B FILTER	B FIL	AFM201/202	IN
M1 O SUP	O SUP	AFM201/202	0.1/MULT*
M1 S SIGNAL	S	AFM201/202	OUT
3I0 SENS	I0 SENS	ETM101	0.05
MG1 VP SENS	VP SENS	ETM101	0.05
M1 VP SENS	VP SENS	ETM101	
IOO (M1 SUP)	IO-O	ETM101	
MG1 VP	VP	ETM101	
MG1 I2	I2	ETM101	
MG1 I0	I0	ETM101	
MT/MTG REACH	r	AFM102/105	
MT/MTG REACH MULT	MULT	AFM102/105	
MTG A FILTER	A FIL	AFM102/105	IN
MTG B FILTER	B FIL	AFM102/105	IN
MTG 0 SUP	O SUP	AFM102/105	0.1/MULT*
MTG S SIGNAL	S	AFM102/105	OUT
IOZR1 CLIP LEVEL	MULT	AFM102/105	
MTG I0 CURR. COMP.	K0	AFM102/105	
MTG ∠ZR0	∠ZR0	AFM102/105	
MT A FILTER	A FIL	AFM201/202	IN
MT B FILTER	B FIL	AFM201/202	IN
MT O SUP	O SUP	AFM201/202	0.1/MULT*
MT S SIGNAL	S	AFM201/202	OUT
MG1 VP SENS	VP SENS	ETM102	0.05
M1 VP SENS	VP SENS	ETM102	
IOO (M1 SUP)	IO-O	ETM102	

* See instructions

* Revised since last issue

*

ZONE 1 REACH EXT.	I1	VMM101/102	
NB REACH	NB	VMM101/102	60
NB CURR. COMP.	KI2Z	VMM101/102	1.0
IOZ RESTRAINT	IOZ REST	VMM101/102	
M1/MG1 OFFSET	OFFSET M1/MG1	VMM101/102	0
MT/MTG OFFSET	OFFSET MT/MTG	VMM101/102	0
MG1 PHASE SHIFT	VP ANG	VMM101/102	0
M1 PHASE SHIFT	M1 VP	VMM101/102	NOT SHIFT
I2	I2LD	VMM101/102	0.05
I0 ZERO SUPP	MULT	VMM101/102	
MB REACH	r	ABM101/102	
MB I0 CURR COMP	K	ABM101/102	
MB VOLT COMP	KV1	ABM101/102	
I1	I1	ABM101/102	
I2 SHIFT	I2 SHIFT	ABM101/102	0
I0 SHIFT	I0 SHIFT	ABM101/102	0
MB OFFSET	OFFSET	ABM101/102	IN
MB POL PHASE SHIFT	POL	ABM101/102	0
TIMER TL13	TL13	ULM111	
MOB TIMER	MOB O	ULM121	
MOB G TIMER	MOB G	ULM121	90
TIMER TL6	TL6	ULM121	
NB CHAR TIMER	NB	ULM131	90
TIMER TL4	TL4	ULM131	
NB DROPOUT	TL24	ULM131	0.5
MB DROPOUT	TL25	ULM131	3
TIMER TL1	TL1	ULM141	
TIMER TL2	TL2	ULM141	
TIMER TL3	TL3	ULM141	
TIMER TL15	TL15	ULM141	2.0
TIMER TL16	TL16	ULM141	
TIMER TL22	TL22	ULM141	
M1 CHAR TIMER	M1	UTM101	90
MG1 CHAR TIMER	MG1	UTM101	90
MT CHAR TIMER	MT	UTM101	
MTG CHAR TIMER	MTG	UTM101	
MB CHAR TIMER	MB	UTM101	
MG1 SUPERVISION	MG1 SUPERVISION	UTM101	
M1 SUPERVISION	M1 SUPERVISION	UTM101	

* Revised since last issue

SAMPLE CALCULATION

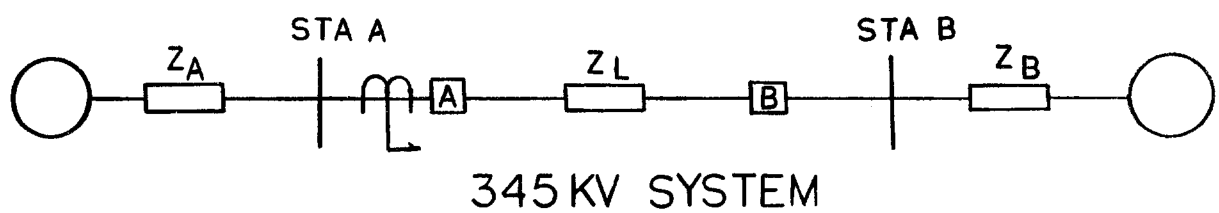
INTRODUCTION

Many of the settings required on the TLS1000 System are similar to those required on any system using distance relays. These settings relate to reach, angle of maximum reach, characteristic shape (mho, lens), etc. In addition to these settings, the TLS1000 System has been provided with other features to increase its flexibility and make it usable for almost any transmission line relaying application. Fortunately, many of these features are required only for special conditions, thus the settings required to implement them require no calculations. It may be necessary to deviate from these fixed settings only for the following conditions:

1. Lines outside of 10-200 miles (16-320 kms) in length.
2. Series compensated lines.
3. Lines with single-pole tripping.
4. Lines where ultra-fast operation is required.
5. Lines with weak-infeed conditions.

SYSTEM

This sample calculation (made for the relays at Station A) will illustrate the settings to be made and the method for determining them for a line wherein none of the above 5 conditions are encountered. The following system is assumed.



Source A

Minimum (maximum impedance)

Z_{A1}, Z_{A2} = 18 ohms

Z_{A0} = 6 ohms

Maximum (minimum impedance)

Z_{A1}, Z_{A2} = 10 ohms

Z_{A0} = 6 ohms

Source B

Minimum (maximum impedance)

Z_{A1}, Z_{A2} = 50 ohms
Z_{A0} = 25 ohms

Maximum (minimum impedance)

Z_{A1}, Z_{A2} = 25 ohms
Z_{A0} = 8 ohms

TRANSMISSION LINE

Z_{1L} = 45 /85 ohms
Z_{0L} = 130.5 /75 ohms
CT RATIO = 2000/5 = 400
PT RATIO = 345000/115 = 3000
Length = 75 miles
Maximum load = 3 amperes
Scheme type = blocking

SETTINGS

The settings to be determined are given in the text starting on page 31. A checklist for these settings starts on page 40. They are:

VOLTAGE FUNCTIONS (page 31)

V_{nom} = 115

OVERCURRENT FUNCTIONS (page 31)

IØ Trip = 0.15
IØØ = 0.15 (for M1 and MT)

To determine the I1 setting, calculate the minimum current for a three-phase fault just in front of the terminal. From the assumed system parameters, this is:

I_{min} = 345000/(3*18*400) = 27.7 amperes

Two-thirds of this value is greater than 125 percent of the maximum load current (3*1.25 = 3.75), therefore,

I1 = 3.75/5 = 0.75 per unit

DISTANCE FUNCTIONS (page 32)

Angle of maximum reach

ØZ1 = 85 degrees
ØZ0 = 75 degrees
/ZR0 = 0 degrees

FIRST ZONE FUNCTIONS, M1 and MG1

Reach setting

$Z_{R1} = 0.9*Z_{1L} = 0.9*45*400/3000 = 5.4$ ohms

Reach multiplier

To determine the reach multiplier, see Table IV on page 55 and determine the following:

$I_F > 9/Z_{R1}$ or $I_F < 9/Z_{R1}$

$9/Z_{R1} = 9/5.4 = 1.67$

$I_F = 345000/(\sqrt{3}*63*400) = 7.9$ amperes

7.9 > 1.67 therefore,
MULT = 1.0

Zero sequence current compensation, KO

$KO = 0.95*(Z_{0L}/Z_{1L}) = 0.95*(130.5/45)$

$KO = 2.8$

VP SENS (zero suppression in V_{pol} in M1 function)

For a three-phase fault at end of the line, with maximum source impedance at left end.

$V1 = Z_{1L}/(Z_{1L} + Z_A) = 45/(45 + 18) = 0.71$ per unit

therefore,

VP SENS = 0.05

Variable mho or reactance function for MG1

The system is factory set with MG1 as a variable mho function; to change to a reactance function, make the following changes:

VP = out
MG1 supervision = reactance

OVERREACHING FUNCTIONS - MT and MTG

Reach setting - see Table III, page 54

Method 2 can be used to determine the reach setting because all of the necessary information is known from the assumed (known) system parameters. From Table III, Method 2:

I_F = 345000/($\sqrt{3}$*55*400) = 9.05

I_L = 3

I_F/I_L = 9.05/3 = 3.02

Z_{R1} = 45*400/3000 + 35/9.05

Z_{R1} = 9.9 ohms

Reach multiplier

See Table IV and use I_F = 7.9 as calculated when determining the zone 1 reach multiplier. From Table IV:

$I_F > 9/Z_{R1}$ or $I_F < 9/Z_{R1}$

$9/Z_{R1}$ = 9/9.9 = 0.91

7.9 > 0.91 therefore,

MULT = 1.0

Characteristic timer angle (see Figure 19, page 56)

Determine I_L*Z_{R1} (in per unit on 66.4 volt base):

I_L*Z_{R1} = 3*9.9/66.4 = 0.45 (per unit)

From Figure 19,

Timer angle = 90 degrees

MOB characteristic timer (section I.6, page 37)

Assume out-of-step blocking is not used, set MOB characteristic timer angle equal to MT characteristic timer angle.

MOB = 90 degrees

VP SENS (zero suppression in V_{pol} of MT function)

Set same as VP SENS in M1 function

VP SENS = 0.05

Zero sequence compensation, K0

$K0 = Z_{0L}/Z_{1L} = 130.5/45 = 2.9$

BLOCKING FUNCTIONS, MB (see pages 33-34)

Characteristic timer angle

Assume that remote MT timer is set at 90 degrees.

MB = MT-10 = 90-10 = 80 degrees

Zero sequence current compensation, K

$K = (Z_{0L}-Z_{1L})/Z_{1L} = (130.5-45)/45$

K = 1.9

Reach setting

Use equation (1), page 34. The MB reach setting will depend on the reach of the MT function at the remote terminal. For this example, assume MT reach = 10 ohms. From equation (1):

$Z_R = 10*(1-0.45) = 5.5$ ohms

Checking the equality of equation (3), page 34,

$KV1 \leq Z_R/((E/I_R)-Z_L)$

$0.45 \leq 5.5/((66.4/7.9)-6)$

$0.45 \leq 2.29$

Use the calculated value (5.5 ohms) since the equality holds true.

$Z_R = 5.5$ ohms, KV1 = 0.45

LOGIC TIMERS (see pages 34-35)

Timer TL1

Assume a 2.0 millisecond channel and 0.5 millisecond propagation time:

TL1 = 2.0+0.5+1.0 = 3.5 milliseconds

Timer TL2, 3 and 4

Assume zone 2 backup is used and set to 0.25 seconds

TL2 = 0.25 seconds

Assume zone 3 and 4 backup not used. Timer settings for TL3 and 4 are irrelevant

Timer TL6

Out-of-step not used, timer setting irrelevant.

Timer TL16

Weak infeed not used, timer setting irrelevant

Timer TL13

Direct transfer tripping not used through TLS system logic, therefore timer setting irrelevant.

Timer TL22

Not used, timer setting irrelevant.

REMAINING SETTINGS

* The remainder of the settings require no calculations and are pre-set to specified values. These settings are listed in bold face in the setting check lists.

*

* Revised since last issue

II. WEAK INFEED CONDITIONS

A weak infeed condition exists whenever the fault current for an internal fault on the transmission line falls below the standard settings for the overcurrent trip supervision functions, IØ TRIP and IØØ. It is possible to initiate a trip for this condition, but a blocking or hybrid type of scheme must be used, and one end of the line must have a strong feed.

a. Blocking scheme:

If a blocking scheme is used, the weak infeed terminal will have to be tripped by a direct transferred trip from the strong terminal following a trip there.

b. Hybrid Scheme:

If a hybrid scheme is selected, overcurrent and undervoltage functions located at the weak terminal are used in conjunction with no output from the blocking functions to initiate tripping on receipt of a permissive trip signal from the strong terminal.

Some thought must be given to the settings of the overcurrent tripping and blocking functions when either scheme is employed for weak infeed conditions. With the standard settings, the overcurrent blocking functions are set as sensitively as possible at each terminal, and the overcurrent tripping functions are set less sensitively to assure coordination. This may not be acceptable for a weak infeed condition. Consider the following:

1. The current at the weak terminal is either greater than the setting of the tripping functions or less than the setting of the blocking functions for various source conditions; i.e., the current will never be between the setting of the tripping and blocking functions. For this case, the standard settings may be used. Either scheme will trip normally when the current is greater than the setting of the tripping functions. When the current is less than the setting of the blocking functions, the weak terminal must be direct transferred tripped when a blocking scheme is used, or weak infeed tripping will be initiated when a hybrid scheme is used.

2. The current at the weak terminal can fall in between the settings of the tripping and blocking functions. For this condition, the standard settings cannot be used because the blocking functions may operate at the weak terminal to block tripping at the strong as well as the weak terminal. To overcome this condition, the following settings are proposed.

STRONG TERMINAL:

IØ TRIP	= 0.3 I_N
IØØ	= 0.3 I_N
IØ BLOCK	= 0.1 I_N
I_2	= 0.05 I_N

WEAK TERMINAL:

$I\emptyset$ TRIP = 0.15 I_N
$I\emptyset\emptyset$ = 0.15 I_N
$I\emptyset$ BLOCK = 0.2 I_N
I_2 = 0.15 I_N

With these settings, the tripping functions are set to coordinate with the blocking functions at the remote terminal of the line just as in the standard settings. However, the blocking functions at the weak terminal are set above the tripping functions at the same terminal thus eliminating the situation where the blocking functions could operate to block tripping for a weak feed condition. It must be noted that the tripping functions at the strong terminal must of necessity be set less sensitively (with higher settings) than those proposed in the standard settings. Consequently, conditions at the strong terminal must be sufficient to support the settings there for all operating conditons.

It was stated earlier that at least one terminal must be a strong terminal for these settings to work. If the situation can reverse, so that the strong terminal becomes the weak terminal and vice versa for varying system conditions, it is proposed that two hybrid schemes be used with one scheme at each line terminal set up for weak conditions and one set up for strong conditions.

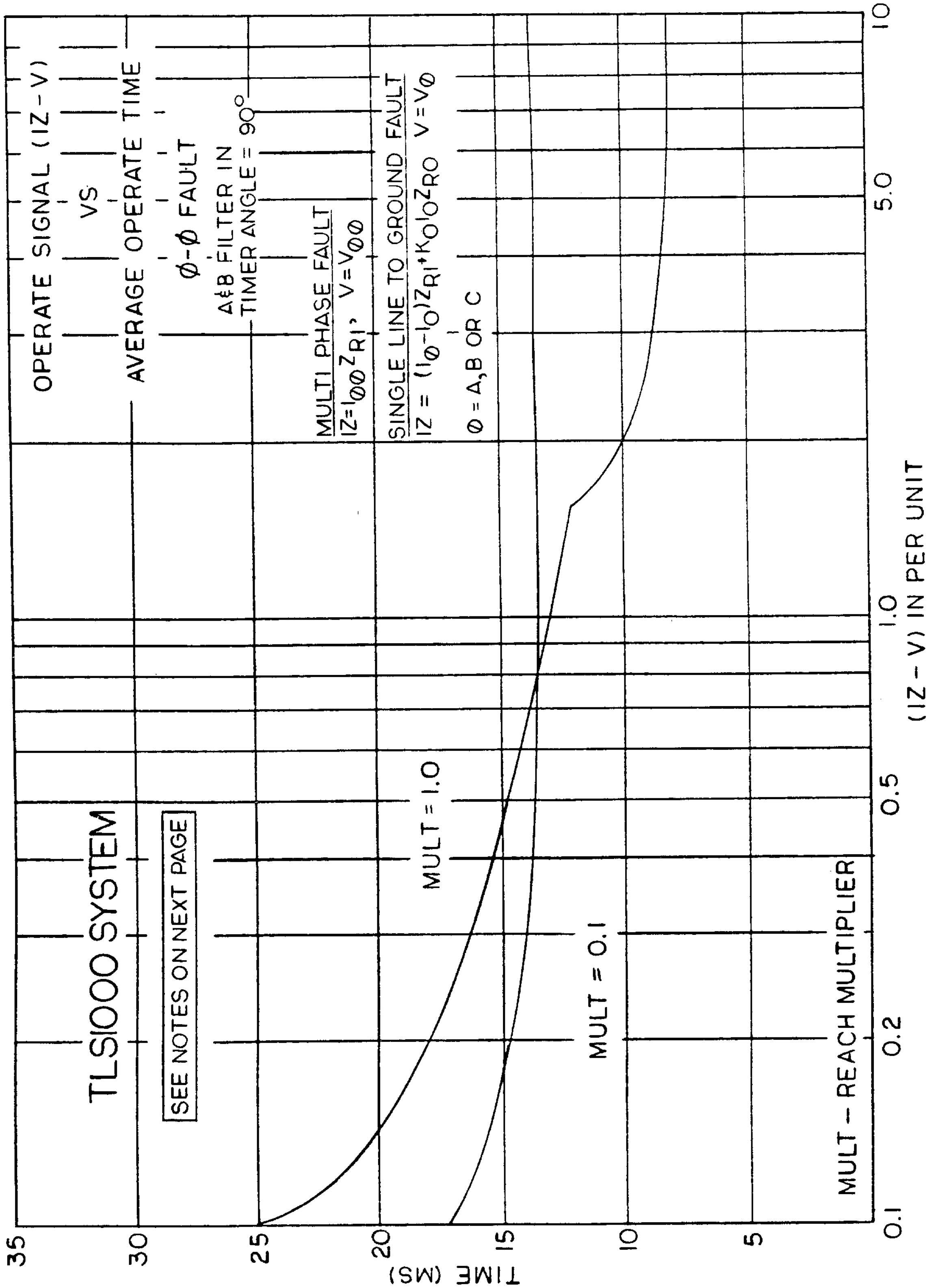


Figure 18 (0285A8942-0, Sh. 11) (IZ-V) in Per Unit vs. Operating Time

NOTES ON FIGURE 18:

The operating time for any one of the distance functions in the TLS1000 system is dependent on the reach setting of the function, the magnitude of the fault current and the incidence angle of fault occurence. The overall average operating time for any type of fault will be dependent on the number of functions that operate for a given fault type. For three phase faults, all three of the phase functions (AB, BC and CA) will operate, and the average operating time will be approximately equal to the minimum operating time of any one of the functions. This is so because the effect of incidence angle is nearly eliminated by the fact that the fault will occur at an incidence angle that is favorable to at least one of the three phase functions. For near end phase-to-phase-to-ground faults (Ø-Ø-G), three functions will also operate - two ground functions and one phase function - so here too, the average operating time will be approximately equal to the minimum operating time of any one of the three functions. On the other hand, only one function will operate for phase-to-phase (Ø-Ø), remote phase-to-phase-to-ground and phase-to-ground (Ø-G) faults, so the average operating time will fall somewhere between the minimum and maximum operating time for that single function.

The time curves of Figure 18 show the average time for a Ø-Ø fault, therefore, the above comments should be kept in mind when using these curves. For three phase and near end Ø-Ø-G faults, the operating time will be about two milliseconds less than the time shown. For Ø-Ø and Ø-G faults, the operating time will be equal to the time shown plus or minus about two milliseconds.

The times given are for electronic outputs. When contact outputs are used, add four milliseconds to the given times.

TABLE III
MT AND MTG REACH

Method 1:

CHARACTERISTIC TIMER ANGLE AND REACH SETTING			
LINE LENGTH MILES/KILOMETERS	REACH SETTING, Z_{R1} PERCENT OF LINE	PICKUP DEGREES	DROPOUT* DEGREES
0-50/0-80	200	90	128
50-100/80-160	175	90	128
100-150/160-240	150	105	128
150-200/240-320	135	120	128

*Not adjustable, fixed at 128 degrees

NOTE 1: See Table IV for reach multiplier (MULT) selection

Method 2:

	REACH			
IF/IL =	< 1.5	1.5 - 3	3 - 6	> 6
Z_{R1} =	$Z_L + \frac{15}{I_F}$	$Z_L + \frac{25}{I_F}$	$Z_L + \frac{35}{I_F}$	$Z_L + \frac{50}{I_F}$

where: I_F = maximum current for a three phase fault at remote end of line

I_L = maximum load current

Z_L = positive sequence line impedance

Z_{R1} = relay reach setting

NOTES:
1. See Figure 19 for characteristic timer angle setting
2. See Table IV for reach multiplier (MULT) selection

TABLE IV
REACH MULTIPLIER SELECTION

A. First Zone Functions:

REACH RANGE	REACH MULTIPLIER (MULT)*	
6.25 to 25	Use MULT = 1.0	
2.5 to 6.5	$I_F > 9/Z_{R1}$ $I_F < 9/Z_{R1}$	Use MULT = 1.0 Use MULT = 0.25
1.0 to 2.5	$I_F > 9/Z_{R1}$ $I_F < 9/Z_{R1}$	Use MULT = 1.0 Use MULT = 0.25
0.25 to 1.0	$I_F > 2.25/Z_{R1}$ $I_F < 2.25/Z_{R1}$	Use MULT = 0.25 Use MULT = 0.1
0.1 to 0.25	Use MULT = 0.1	

B. Overreaching Functions:

REACH RANGE	REACH MULTIPLIER (MULT)*	
12.5 to 50	Use MULT = 1.0	
5 to 13	$I_F > 9/Z_{R1}$ $I_F < 9/Z_{R1}$	Use MULT = 1.0 Use MULT = 0.25
2 to 5	$I_F > 9/Z_{R1}$ $I_F < 9/Z_{R1}$	Use MULT = 1.0 Use MULT = 0.25
0.5 to 2	$I_F > 2.25/Z_{R1}$ $I_F < 2.25/Z_{R1}$	Use MULT = 0.25 Use MULT = 0.1
0.2 to 0.5	Use MULT = 0.1	

I_F = minimum fault current for three phase fault at the remote end of the line
Z_{R1} = Relay reach

NOTE: Maximum sensitivity will be achieved if the lowest MULT is used, but better operating time will be obtained if the highest MULT is used. Therefore, always select the highest MULT if sensitivity is not a problem. If the minimum fault current is unknown, select the lowest MULT in the reach range desired.

*Reach Multiplier (MULT) = 0.1, 0.25, 1.0

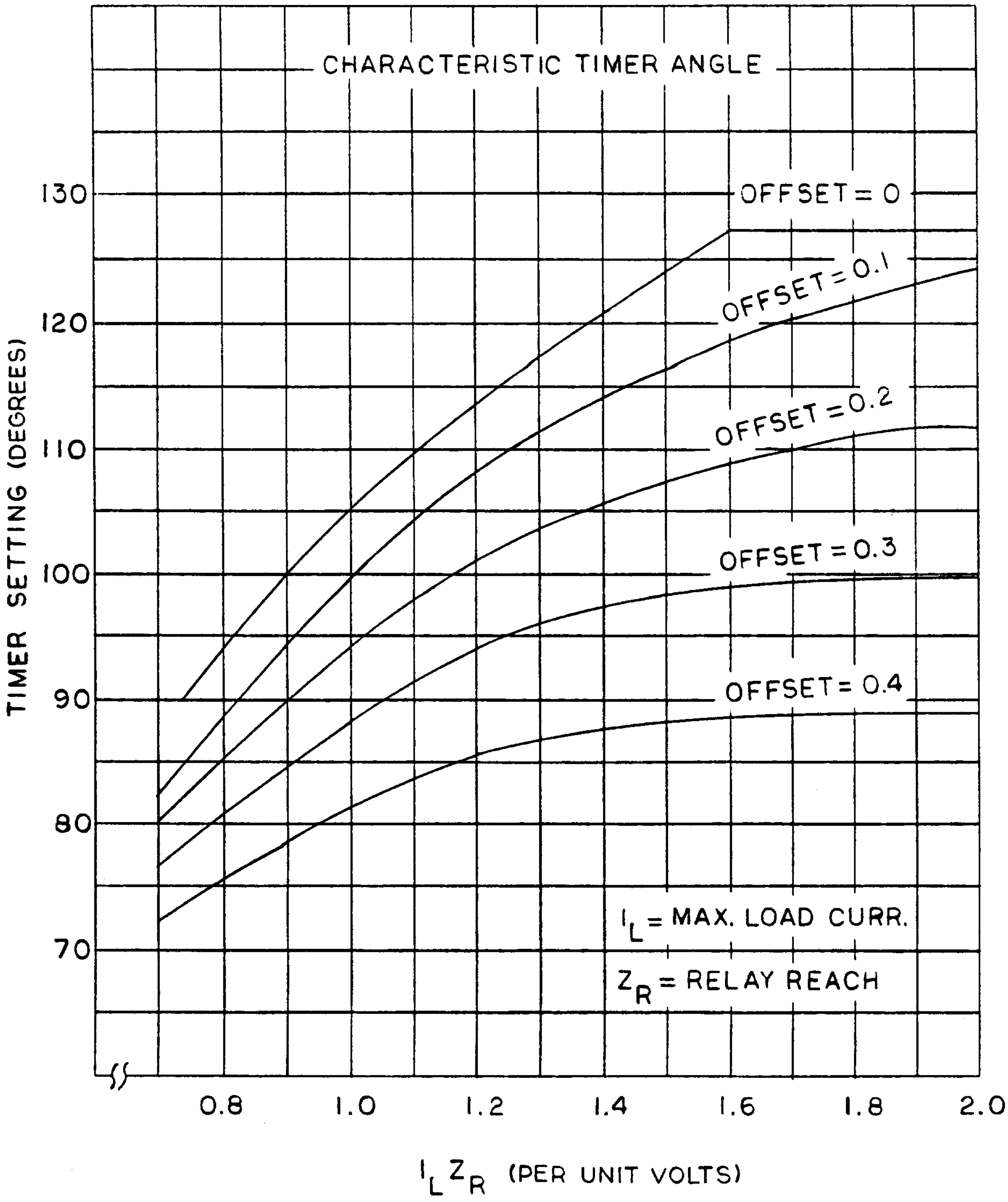


Figure 19 (0285A8942-0, Sh. 12) Characteristic Timer Angle

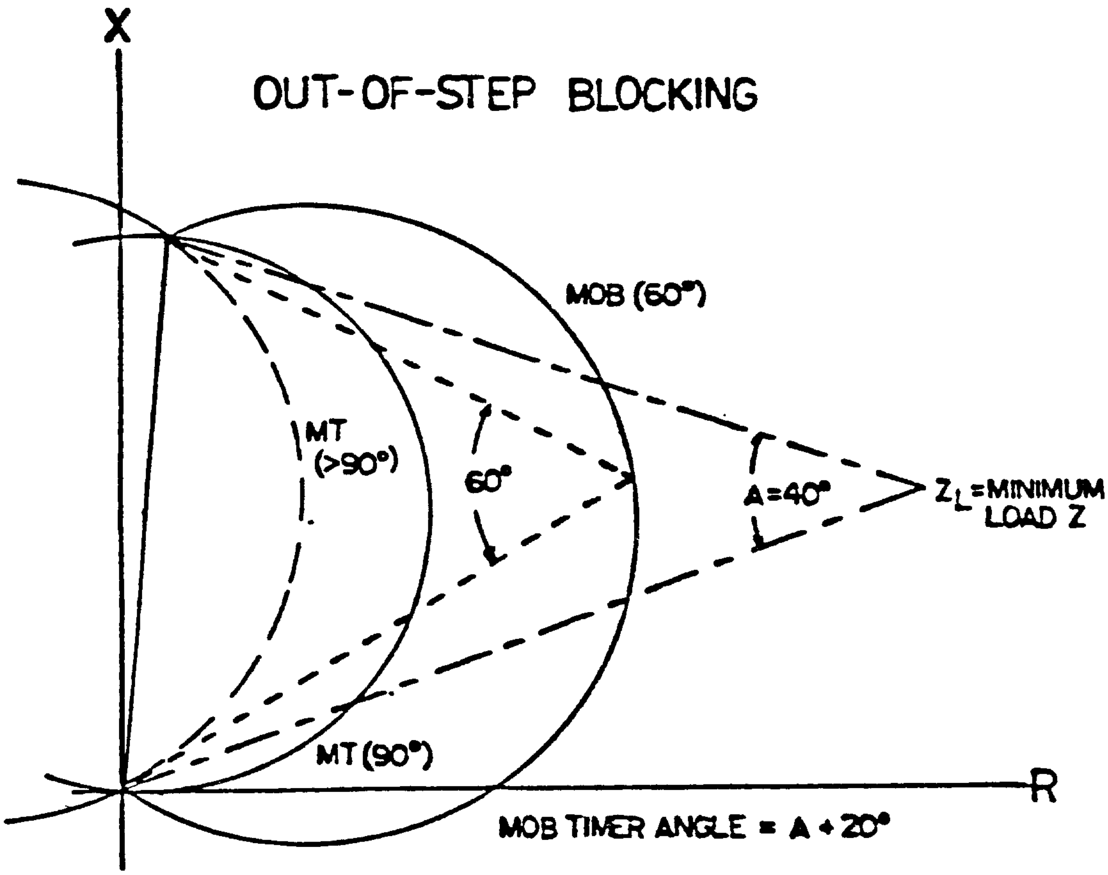


Figure 20 (0285A8942-0, Sh. 13) Out-of-Step Blocking

APPENDIX I

TLS LOGIC AND ELEMENTARY DIAGRAM LIST

SCHEME	TRIP MODE SINGLE POLE	TRIP MODE THREE POLE	CHANNEL	NO. OF FORWARD ZONES	BLKG ZONE	LOGIC DRAWING NUMBER	ELEMENTARY NUMBER
HYBRID	X		FSK	2	YES	0145D8982, SH 1	0138B7776
HYBRID		X	FSK	2	YES	0145D8982, SH 2	0138B7774
PERMISSIVE	X		FSK	2		0145D8982, SH 3	0138B7776
PERMISSIVE		X	FSK	2		0145D8982, SH 4	0138B7774
BLOCKING	X		AM	2	YES	0145D8982, SH 5	0138B7772
BLOCKING		X	AM	2	YES	0145D8982, SH 6	0138B7773

APPENDIX II
GENERAL SPECIFICATIONS

RATINGS

Rated Frequency	o 50 or 60 hertz
Rated Voltage	o 100 to 120 volts AC
Rated Current	o I_N = 1 or 5 amperes
DC Control Voltage	o 48 - Operating Range: 34- 60 VDC 110/125 - Operating Range: 88-150 VDC 220/250 - Operating Range: 176-300 VDC
Maximum Permissible Currents	
Continuous	o 2 x I_N
Three Seconds	o 50 x I_N
One Second	o 100 x I_N
Maximum Permissible AC Voltage	
Continuous	o 2.0 x rated
One Minute (one per hour)	o 3.5 x rated
Ambient Temperature Range	
For Storage	o -40 to +65 degrees Celsius
For Operation	o The TLS has been designed for continuous operation between -20°C and +55°C per ANSI Standard C37.90. In addition, the TLS will not malfunction nor be damaged by operation at temperatures up to +65°C.
Insulation Test Voltage	o 2 kV 50/60 hertz, one minute
Impulse Voltage Withstand	o 5 kV peak, 1.2/50 milliseconds, 0.5 joule
Interference Test Withstand	o ANSI/IEEE C37.90 and IEC 255-5

BURDENS

Current Circuits	o 0.03 ohm $\angle$ 5 degrees, I_N = 5 amps o 0.14 ohm $\angle$30 degrees, I_N = 1 amp
Voltage Circuits	o 0.2 VA $\angle$49 degrees, 60 hertz o 0.24 VA $\angle$48 degrees, 50 hertz

DC Battery (for contact converters)	o 1.4 milliamperes each	
DC Battery (for Power Supply and Telephone Relays)	Normal	Tripped
ALL VOLTAGE RATINGS	13 watts	40 watts

Contact Data

Trip Outputs

- o Continuous rating = 3 amperes
- o Make and carry for tripping duty (per ANSI C37.90) 30 amps
- o Break 180 VA resistive at 125/250 VDC
- o Break 60 VA inductive at 125/250 VDC

Auxiliary Outputs (including Alarms)

- o Continuous rating = 3 amperes
- o Make and carry for 30 seconds 5 amperes
- o Break 25 watts inductive at 125/250 VDC
- o Make and Carry continuously 50 watts
- o Maximum of 250 volts or 0.5 amp

DLA and Channel Control Contacts

- o 10 watts
- o 250 VDC maximum
- o 0.5 amp maximum

ACCURACY

Distance Measuring Units

- o Reach: plus and minus five percent of setting at angle of maximum reach
- o Angle of Maximum Reach: plus and minus three degrees of setting

Zone Timers

- o Plus and minus three percent of setting

Characteristic Timers

- o Plus and minus one degree

DIMENSIONS

Standard rack mounted unit:

- o 6-15/16 inches (176 millimeters) high
- o 19-1/16 inches (484 millimeters) wide (standard 19-inch rack)
- o 14 inches (356 millimeters) deep (including terminal blocks)

WEIGHT

Standard rack mounted unit weighs approximately 33 pounds (15 kilograms) net.

APPENDIX III
TLS MEASURING UNIT SETTING RANGES

I. OVERCURRENT FUNCTIONS

Function	Range	Resolution	Location* 60 Hz/50 Hz
IØ Trip	0.1 to 1.0 I_N	0.05 I_N	PC-ISM101/2
IØ Block	0.1 to 1.0 I_N	0.05 I_N	PC-ISM101/2
IØØ*	0.1 to 1.0 I_N	0.05 I_N	FP-ETM101 (M1)
			FP-ETM101 (M1)
I_1	0.2 to 3.2 I_N	0.2 I_N	PC-ABM101/2
I_2	0.05 to 0.5 I_N	0.05 I_N	PC-VMM101/2
3ĪØ**	0.05 to 0.65 I_N	0.20 I_N	PC-ETM101
I_2Z Ø SHIFT***	0 to -15° (lag)	5°	PC-ABM101/2
3ĪØZ Ø SHIFT***	0 to -15° (lag)	5°	PC-ABM101/2
Fault Detector	0.02 I_N	--	PC-ABM101/2

*Separate adjustment for each zone
**Zone one; MTG fixed at 0.05 I_N
***MG1, MG2, MTG

II. UNDERVOLTAGE FUNCTIONS

Function	Range	Resolution	Location
VA, VB, VC	0.65 V_N	V_N = 107.5 or 115 V	PC-ISM101/2

III. DISTANCE FUNCTIONS

A. REPLICA IMPEDANCE ANGLE

Function	Range	Resolution	Location
Z_{R1}	50° to 85°	5°	FP-ISM101/2
Z_{R0}	50° to 85°	5°	FP-ISM101/2

NOTE: ONE REPLICA IMPEDANCE ANGLE ADJUSTMENT IS USED FOR ALL ZONES OF PROTECTION

B. FIRST ZONE DISTANCE RELAYS: M1 AND MG1 (OPTIONAL)

1. Common Phase and Ground Adjustments

Function	Range	Resolution	Location
M1/MG1	(1-25)x(MULT)x5/I_N	0.1 ohm x 5/I_N	FP-AFM101/4
FWD OFFSET	0 to 0.4 PU	0.1	PC-VMM101/2
Multiplier (MULT)	0.1, 0.25, 1.0	--	FP-AFM101/4

*PC = On printed circuit board, FP = On front panel

2. Phase Zone 1 - M1

Function	Range	Resolution	Location* 60 Hz/50 Hz
Char. Timer	64^o - 127^o	1^o	PC-UTM101
Pol. Volt. Sensitivity	0, 0.05, 0.35 V_N	--	PC-ETM101
Pol. Volt. Phase Shift	0^o or same as MG1	--	PC-VMM101/2
Oper. Ckt. Level Det.	0.1 to 1.5 V_N	0.03 V_N	PC-AFM201/2

3. Ground Zone 1 - MG1

Function	Range	Resolution	Location
Char. Timer	64^o - 127^o	1^o	PC-UTM101
Pol. Volt. Sensitivity	0, 0.05, 0.35 V_N	--	PC-ETM101
Pol. Volt. Phase Shift	0^o to $+45^o$ (LEAD)	5^o from 10-35^o	PC-VMM101/2
Oper. Ckt. Level Det.	0.1 to 1.5 V_N	0.03 V_N	PC-AFM201/2
K_0	1 - 7	0.1	PC-AFM101/4
V_1 Pol.	IN, OUT	--	PC-ETM101
$3I_0Z$ Pol.	IN, OUT	--	PC-ETM101
I_2Z Pol.	IN, OUT	--	PC-ETM101
Z_{RO} Angle Adj.	0 to -75^o (LAG)	25^o	PC-AFM101/4

C. PERMISSIVE ZONE DISTANCE RELAYS: MT AND MTG

1. Common Phase and Ground Adjustments

Function	Reach Range	Resolution	Location
MT/MTG:			
Standard	(1-25)x(MULT)x5/I_N	0.2 ohm x 5/I_N	FP-AFM102/5
Optional	(3-75)x(MULT)x5/I_N	0.3 ohm x 5/I_N	FP-AFM102/5
Fwd Offset	0 to 0.4 PU	0.1	PC-VMM101/2
Multiplier (MULT)	0.1, 0.25, 1.0	--	FP-AFM102/5

2. Phase - MT

Function	Range	Resolution	Location
Char. Timer	64^o - 127^o	1^o	PC-UTM101
Pol. Volt. Sensitivity	0, 0.05, 0.35 V_N	--	PC-ETM102
Oper. Ckt. Level Det.	0.1 to 1.5 V_N	0.03 V_N	PC-AFM201/2
MOBØ Char. Timer	32^o - 126^o	2^o	PC-ULM121

*PC = On printed circuit board, FP = On front panel

3. Ground MTG

Function	Range	Resolution	Location* 60 Hz/50 Hz
Char. Timer	64^o - 127^o	1^o	PC-UTM101
Pol. Volt. Sensitivity	0, 0.05, 0.35 V_N	--	PC-ETM102
Oper. Ckt. Level Det.	0.1 to 1.5 V_N	0.03 V_N	PC-AFM102/5
MOBG Char. Timer	32^o - 126^o	2^o	PC-ULM121
K_0	1 - 7	0.1	PC-AFM102/5
Z_{RO} Angle Adj.	0 to -75^o	25^o (from Z_{RO} Angle)	PC-AFM102/5

D. DEDICATED ZONE 2 DISTANCE RELAYS: MG2 AND MG2 (Optional)

1. Common Phase and Ground Adjustments

Function	Reach Range	Resolution	Location
M2/MG2:	(2-50)x(MULT)x5/I_N	0.2 ohm x 5/I_N	FP-AFM102/5
Fwd Offset	Uses MT/MTG offset)	--	--
Multiplier (MULT)	0.1, 0.25, 1.0	--	FP-AFM102/5

2. Phase - M2

Function	Range	Resolution	Location
Char. Timer	64^o - 127^o	1^o	PC-UTM102
Pol. Volt. Sensitivity	0, 0.05, 0.35 V_N	--	PC-ETM102
Oper. Ckt. Level Det.	0.1 to 1.5 V_N	0.03 V_N	PC-AFM201/2

3. Ground MG2

Function	Range	Resolution	Location
Char. Timer	64^o - 127^o	1^o	PC-UTM102
Pol. Volt. Sensitivity	0, 0.05, 0.35 V_N	--	PC-ETM102
Oper. Ckt. Level Det.	0.1 to 1.5 V_N	0.03 V_N	PC-AFM201/2
K_0	1 - 7	0.1	PC-AFM102/5
Z_{RO} Angle Adj.	0 to -75^o (from Z_{RO} Angle)	25^o	PC-AFM102/5

*PC = On printed circuit board, FP = On front panel

E. SWITCHED ZONE 2

Function	Range	Resolution	Location* 60 Hz/50 Hz
M2/MG2 Reach	1 to 10 times M1/MG1 Reach	0.05	FP-VMM101/2

IV. BLOCKING FUNCTIONS (Optional)

A. PHASE BLOCKING UNITS - MB

Function	Range	Resolution	Location
MB Reach	(2-50 ohms)x5/I_N	0.2 ohm x 5 I_N	FP-ABM101/2
K	1 - 7	0.1	PC-ABM101/2
Fwd. Offset	0, 0.1 PU	--	PC-ABM101/2
Char. Timer	64^o - 127^o	1^o	PC-ABM101/2
Dropout Timer	0.5 to 7.5 cycles	0.5 cycle	PC-ULM131
Pol. Volt. Phase Shift	0, +20^o (LEAD)	--	PC-ABM101/2
KV1	0 to 0.45 V_N	0.15 V_N	PC-ABM101/2

B. NEGATIVE SEQUENCE DIRECTION BLOCKING UNIT - NB

Function	Range	Resolution	Location
NB Reach	(5-80 ohms)x5/I_N	5 ohms x 5 I_N	PC-VMM101
K_2I_2 Z Comp.	0.5 - 1.0 PU	0.05 PU	PC-VMM101
Char. Timer	64^o - 94^o	2^o	PC-ULM131
Dropout Timer	0.5 to 7.5 cycles	0.5 cycle	PC-ULM131

V. ZONE TIMERS

Function	Range	Resolution	Location
Zone 2	0.2 - 3.15 sec.	0.05 sec.	ULM141
Zone 3	0.4 - 6.3 sec.	0.10 sec.	ULM141
Zone 4	0.4 - 6.3 sec.	0.10 sec.	ULM131

*PC = On printed circuit board, FP = On front panel

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