

APPLICATION CONSIDERATIONS OF CGR BROKEN CONDUCTOR DETECTION RELAY

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INTRODUCTION

Four wire distribution circuits present a challenge to protection engineers. Inherent in the concept of line-to-neutral connection of single-phase load is the likelihood of long-time residual current flow. The need to permit this condition to persist restricts the setting permissible for a conventional ground overcurrent relay used to protect such a circuit. This, in turn, makes the relay less responsive to open phase conditions and to high resistance ground faults.

Serious studies of methods of improved detection of open and downed conductors on 4-wire distribution circuits have been made over the years. In 1949 an AIEE Power System Relaying Committee Working Group concluded that there was at that time, no successful solution to this problem. Methods under trial at that time included "arc frequency relaying" and "high frequency current" relaying. Efforts continued over the years to find an improved concept for use on distribution circuits.

Following extensive investigation by the Westinghouse Advanced Systems Technology Group under the sponsorship of Pennsylvania Power and Light, the search for a more effective practical, economical open-conductor relaying concept was narrowed to one that offers considerable promise. It is called a ratio ground relay.

It is evident that the traditional devices, applied in their normal manner will provide the poorest sensitivity of detection for those faults which occur on the "MAIN" because this is the most heavily loaded part of the distribution circuit. Most undetected downed conductors have been on the "MAIN" for this reason. The CGR relay offers improvement in this area.

RATIO GROUND RELAY, CGR

The basic concept of the CGR Relay is shown in figure 1. It is a single disc electromechanical relay using $|3I_0|^2$ (i.e. sum of the three phase currents squared) as an operating quantity and $|I_1|^2 - |I_2|^2$ (difference of the squares of the magnitudes of the positive and negative sequence components of the three phase currents) as a restraint quantity. It is connected as shown in figure 2. Its sensitivity varies as the

load current varies, as described in figure 3. Contrasting this with a relay responsive to $3I_0$ alone, it can be seen in figure 4 that the CGR set for a given $3I_0$ sensitivity at full load is more sensitive to open conductor detection at smaller loads. The comparison is based on the assumption that the ground CO Relay, responding to $3I_0$ -only, is set on the next lowest tap that will provide sensitivity comparable to the CGR at full load. A conventional $3I_0$ -only relay will, of course, have the same sensitivity at small load as at large load and is unable to detect loss of even 100% of the load on one phase at a load level below its setting.

OPEN CONDUCTOR DETECTION

Since $3I_0$ for an open conductor condition is dependent on the load level in the two unaffected phases (as well as the open phase if only partial load loss occurs) the CGR is expected to detect many open and ungrounded cases that conventional distribution circuit ground relays would ignore.

Figure 5, for example, shows the improvement possible using the CGR relay. Assuming a current transformer secondary current of four amperes full load and adequate circuit balance (under normal unbalanced load conditions and/or with the largest lateral fuse blown) to permit a $3I_0$ zero sequence current setting for the residual relay of 1.5 amperes, the CGR tap 1 setting could be selected.

Throughout this paper, the assumption is made in determining relay response that two balanced currents exist in two phases that are equal in magnitude at a value of I_L and 120 electrical degrees apart. The third phase current is assumed to be 120 degrees from the other two and to have a value of RI_L where R is simply a constant less than or greater than 1. This reasonable assumption constrains the resistance-limited fault current to be in-phase with the load current. Also this assumption considers that load is uniform and partial loss of load does not change the power factor angle of the phase current.

At a load current of 4 amperes, the ability of the CGR and conventional $3I_0$ -only relay would be nearly the same for detecting a broken (open but ungrounded) conductor. Loss in one phase of 1.75 amperes load ($1.75/4=43.8\%$) or greater would be detected by the CGR and because of available taps, the $3I_0$ relay would be slightly more sensitive and would detect 37.5% loss of load. Below a load current of 1.5 amperes, detection of total load loss would be impossible with the $3I_0$ -only relay. On the other hand, the CGR relay (on tap 1) will, at that same 1.5 amperes load level respond to 0.8 amperes $3I_0$. The CGR would then recognize a conductor break that produced the loss of 53% of the load in the opened phase, where the $3I_0$ -only relay would not detect even 100% loss of load. The CGR is able to detect some broken conductor conditions at a feeder load level as low as 0.5 amperes, secondary.

LOAD PATTERNS

In figure 6, an idealized homogeneous distribution area supplied by four feeders is depicted. In such a representation, the load area is triangular in shape. Figure 7 indicates that opening of a phase conductor at a

uniform load level of 25% of the maximum feeder load can be recognized by the CGR, provided the open (with or without a ground on the load side lead) is within the 63% point shown on figure 7. At this load level, no opens can be recognized by the ground CO ($3I_O$ -only) relay.

At 50% load level, both the CGR and the CO will recognize the open but with different "reaches" as described by figure 8.

GROUND DETECTION

Another inherent benefit that accompanies the application of the CGR relay is its ability to recognize very high resistance ground faults. Figures 9 through 11 demonstrate this effect. The fault resistance values of figure 11 are in per unit based on feeder full load current. For example, a 12,470 volt, 480 ampere circuit (600:5 ct and 4 ampere secondary current at full load) would manifest 1 per unit at $7200/480=15$ ohms. A ground fault having 8 per unit or 120 ohms or less fault resistance would be detectable by the CGR while a fault having only 2.66 per unit or 40 ohms or less could be detected by a conventional $3I_O$ relay. The $3I_O$ -only relay is inherently somewhat more sensitive than the CGR at full load.

COORDINATION WITH OTHER DEVICES

The CGR relay is coordinated with other devices in such a way that it will operate only for those opens and/or grounds that will not be detected by the other devices. The CGR relay will, in the usual application, block reclosing through an external auxiliary relay. It should, then, allow other devices to detect all malfunctions they are able to detect.

Coordination is complicated somewhat by the nature of the time variation of the CGR relay produced by the restraint effect of different load levels. Conventional residual relays are not influenced by load level, but are responsive to zero sequence current only.

Figure 11 shows a representative set of curves of operating time for the CGR relay versus R (the per unit current in the "odd" phase as shown in the phasor diagram of figures 3 and 9). For a given R, operating time is dependent on load level. The characteristic of a CO, $3I_O$ -only relay can readily be translated to this same plot by the knowledge that $3I_O=(1-R)I_L$ for R less than 1, and $3I_O=(R-1)I_L$ for R greater than 1. For selected values of R and I_L load current, $3I_O$ current values can be easily determined. Knowing the CO relay tap setting, the multiple of tap value that this current represents can identify the operating time for the CO relay for the particular time dial in use. It is assumed that this ground CO has been previously coordinated with all other current responsive devices on the feeder. In the absence of a ground overcurrent relay, a similar procedure may be used to assure coordination with downstream reclosers and lateral fuses. Phase current for a device in the 3-phase main, is simply RI_L for R greater than 1 and need not be considered for R less than 1. For a lateral protective device, phase current is $(K+R-1)I_L$ where K is the portion (in per unit) of the total load on the lateral.

FEEDER LOADING

Load variations are quite wide on a distribution feeder, considering growth, seasonal influences, and daily load pattern. Figure 13 describes this variation. Over the lifetime a feeder, the time of operation off - peak predominates.

As has been pointed out in this paper, the improvement afforded by the CGR Relay over the $3I_0$ -only Relay is striking at loads appreciably below full loads. It will, then, provide improvement on a probability basis virtually full time.

OTHER APPLICATIONS FOR THE CGR

Though it is tempting to consider the use of the CGR to solve many other of the persistent industry problems, it should be used with caution in other applications. It cannot be used on a three-wire distribution circuit or on a motor circuit to detect open conductors. It requires that a ground "source" exist on both sides of an open. In the case of the 4-wire distribution circuit, line-to-ground connected load provides the return path to the grounded wye of the supply transformer.

CONCLUSION

The CGR relay offers a conceptual breakthrough in the sensitive detection of opens and high resistance ground faults on 4-wire distribution circuits.

ACKNOWLEDGEMENT

Much credit for the innovative analysis for this unique device is deserved by J. E. Hagberg, retired, M. T. Bishop, C. H. Eichler of Westinghouse and R. E. Lee of Pennsylvania Power and Light. Also the diligence and ingenuity of H. J. Calhoun in designing and developing this relay is acknowledged.

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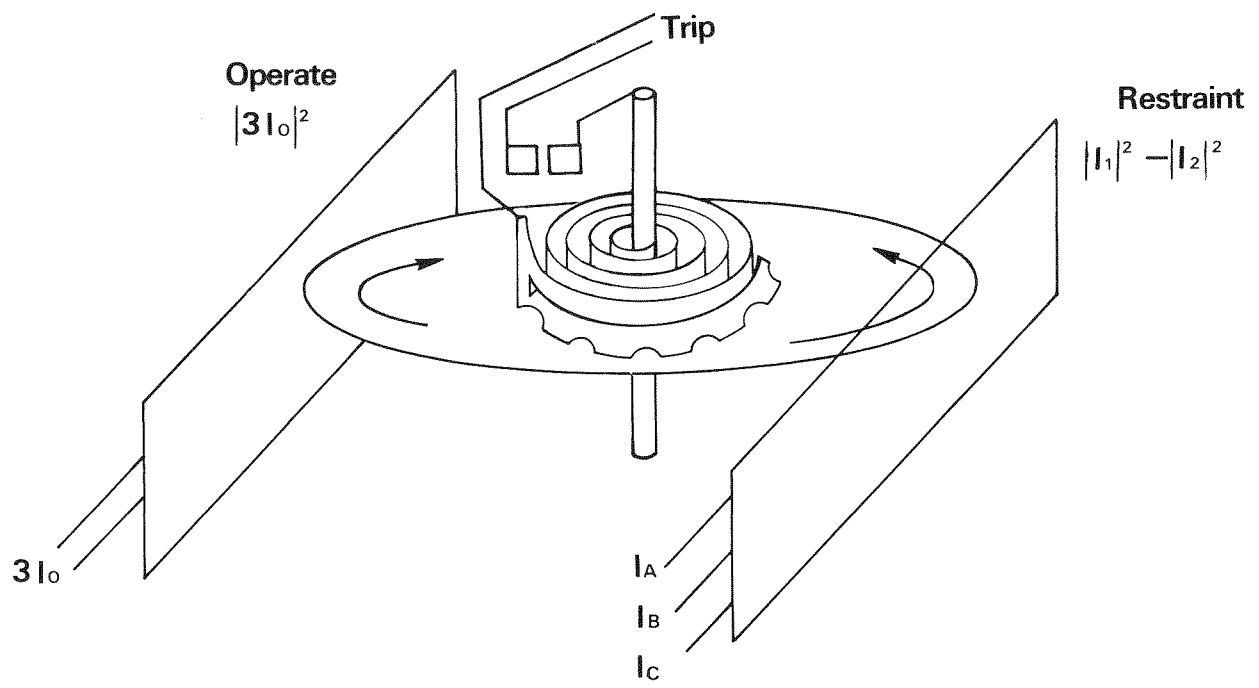


Figure 1 CGR Concept

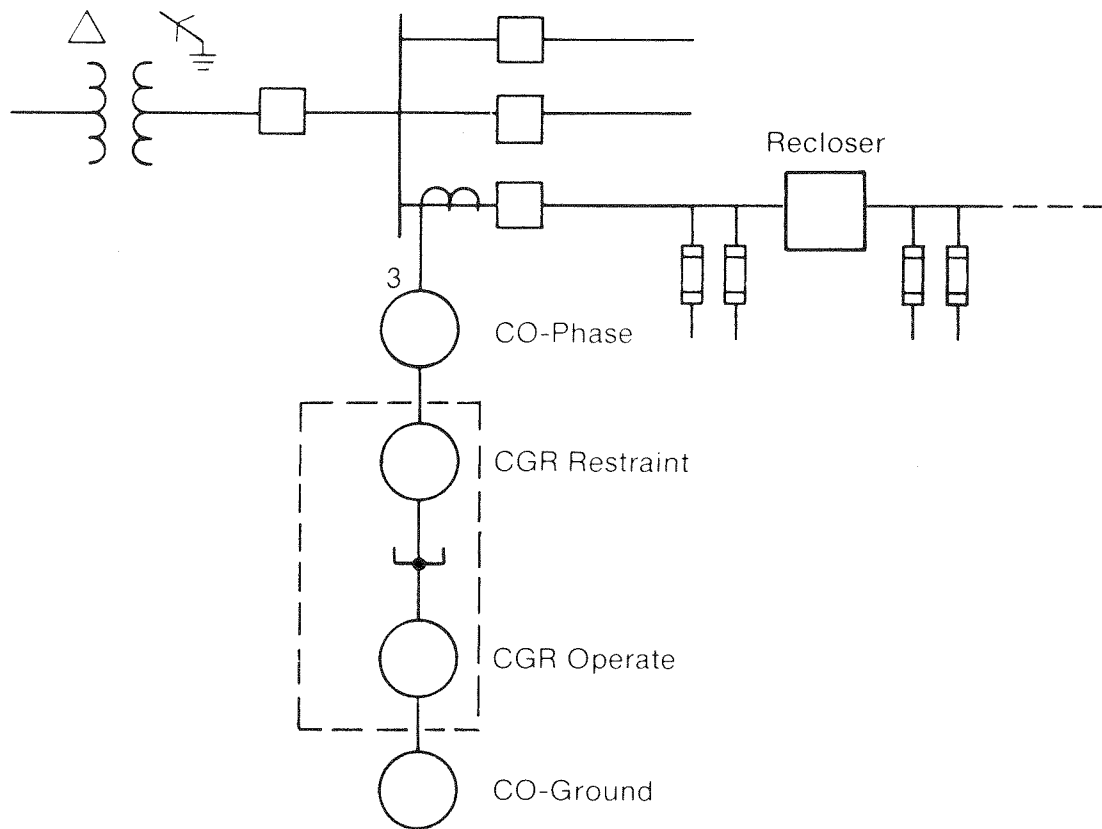
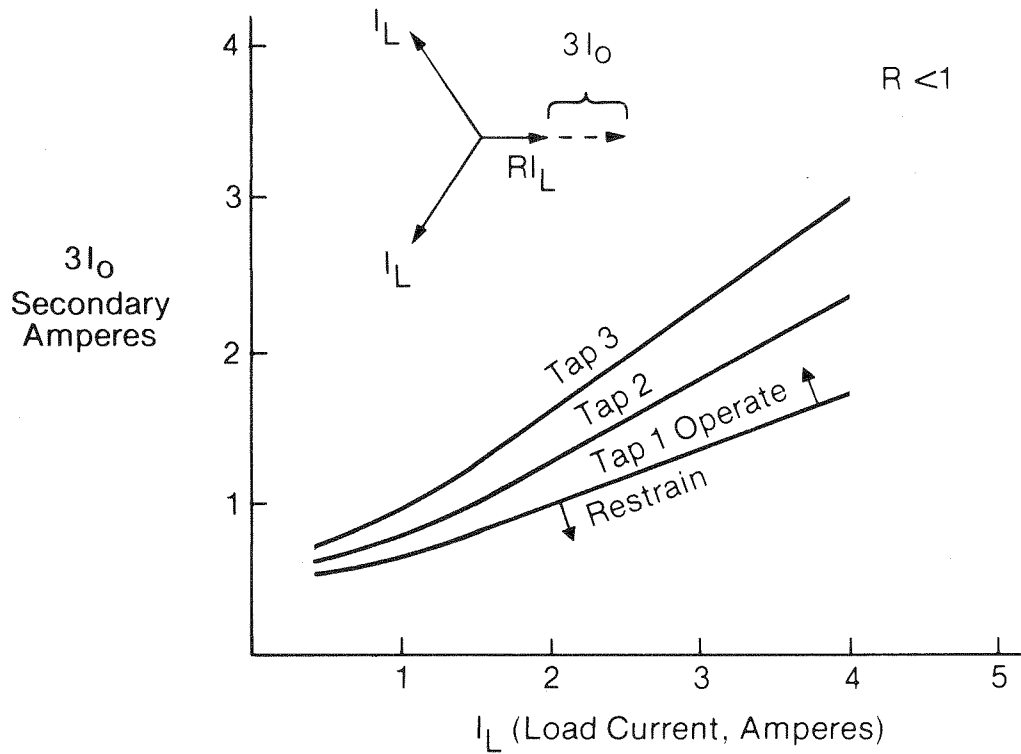


Figure 2 Schematic Diagram of Typical Distribution Substation



Broken Conductor Detection

Figure 3 Characteristics of Type CGR Relay—One Phase Current Low

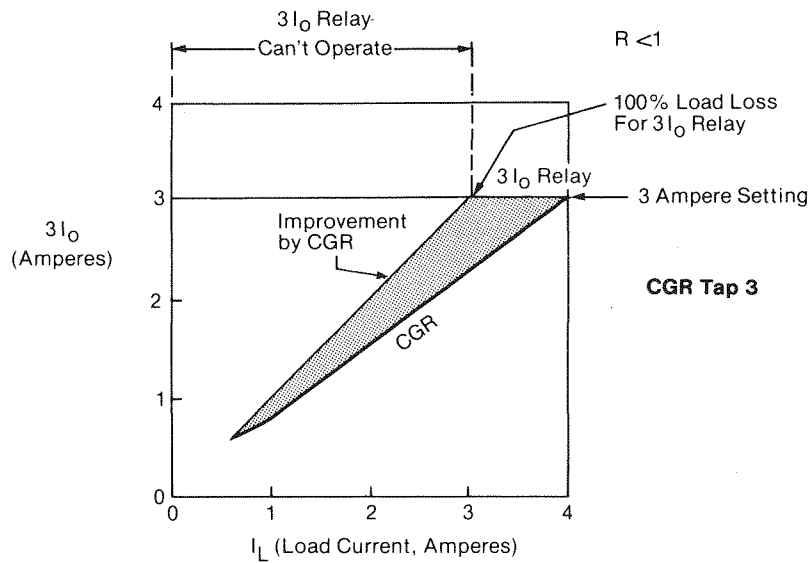
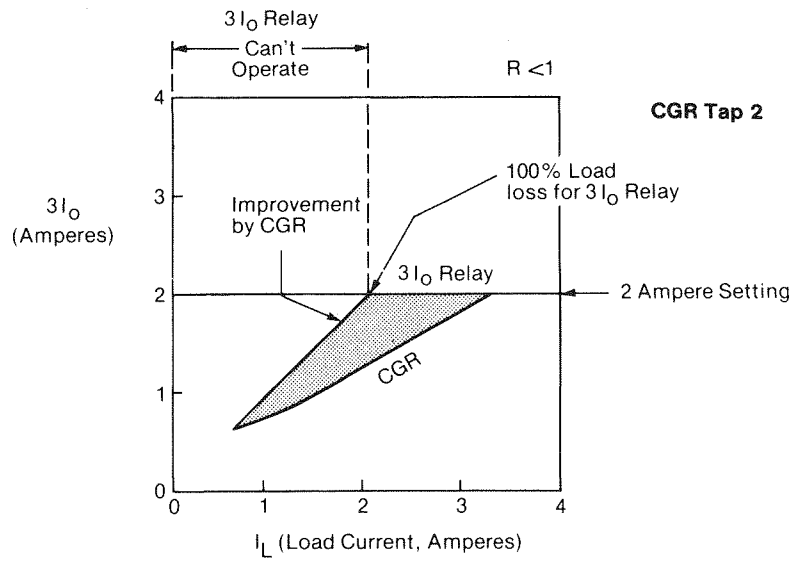
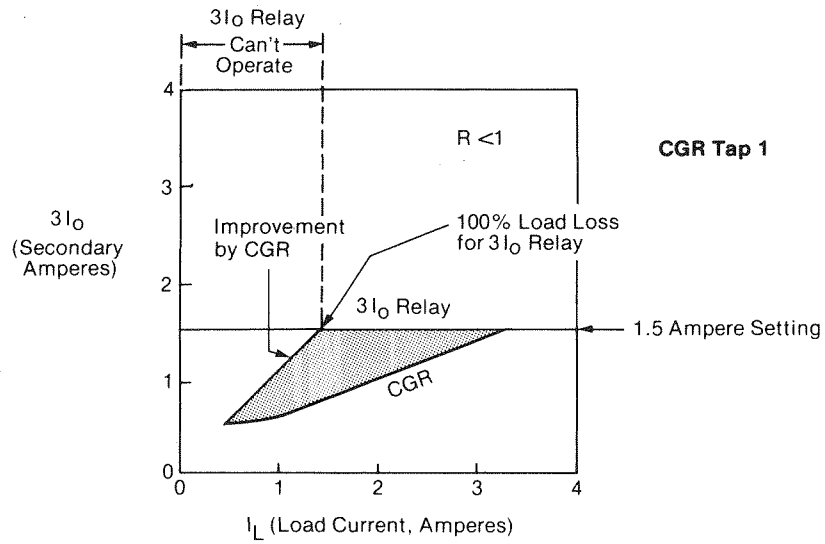


Figure 4 Broken Conductor Detection

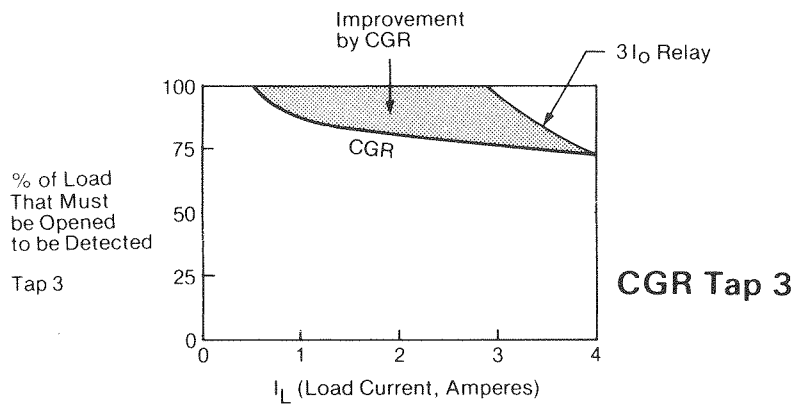
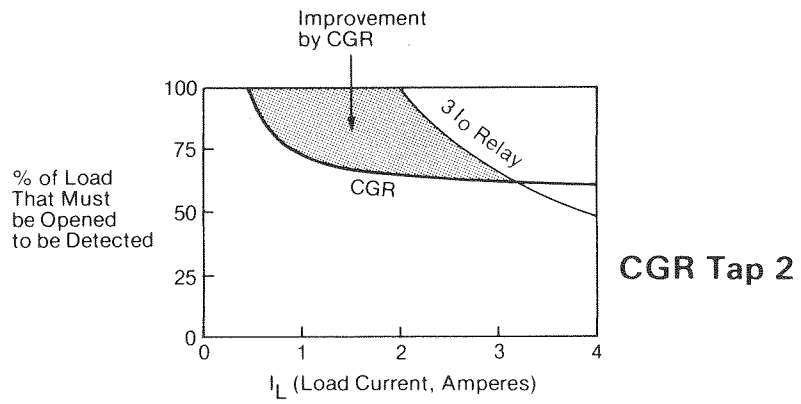
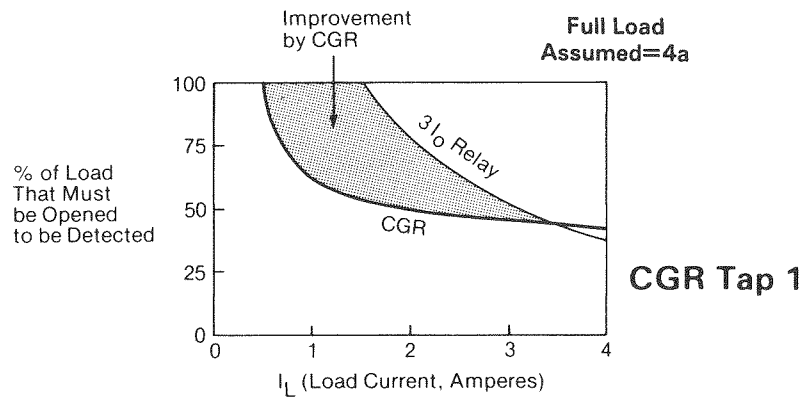


Figure 5 Broken Conductor Detection—Comparison of Effectiveness

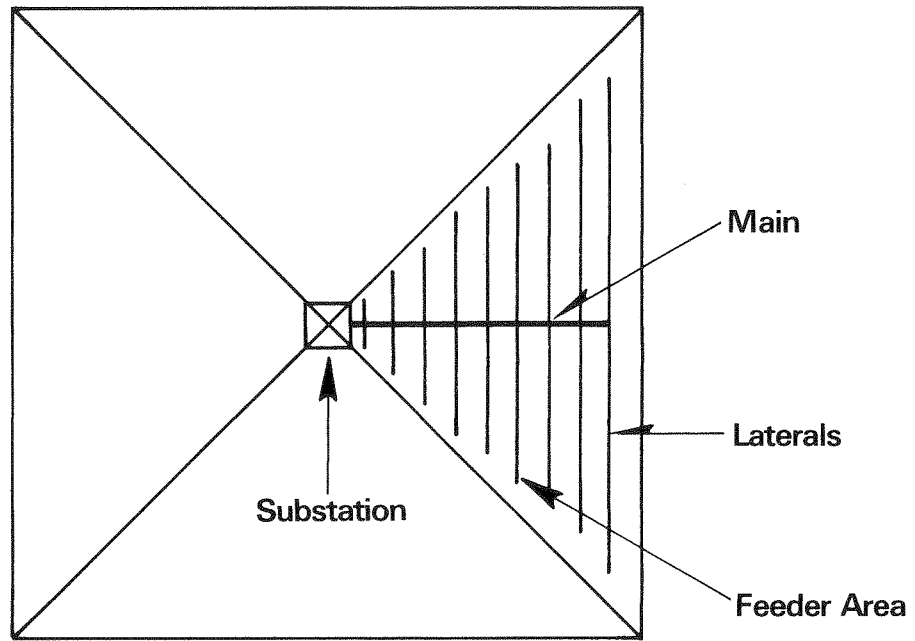


Figure 6 Distribution Substation Area

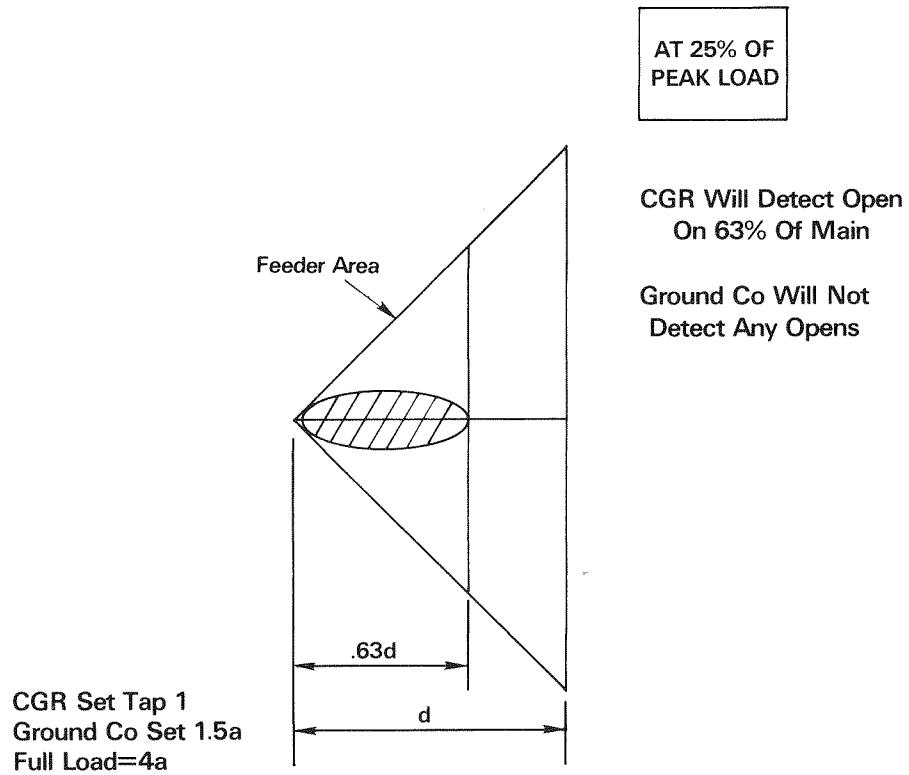


Figure 7 Open Conductor Detection at 25% Load

AT 50% OF PEAK LOAD

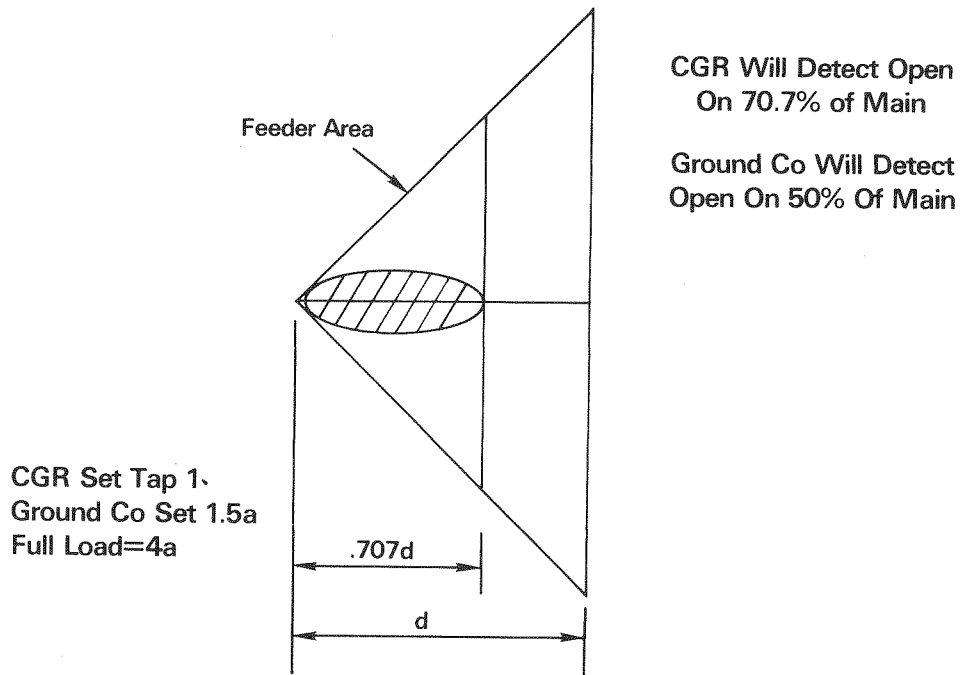


Figure 8 Open Conductor Detection at 50% Load

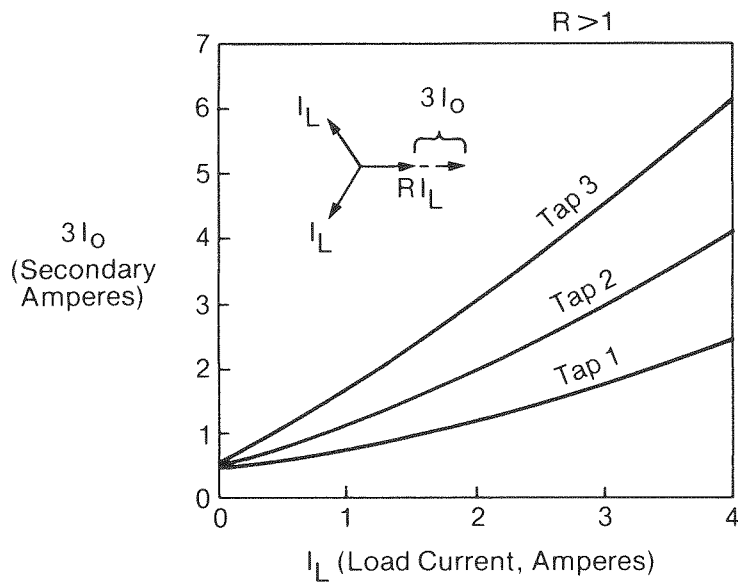


Figure 9 Characteristics of Type CGR Relay—One Phase Current High

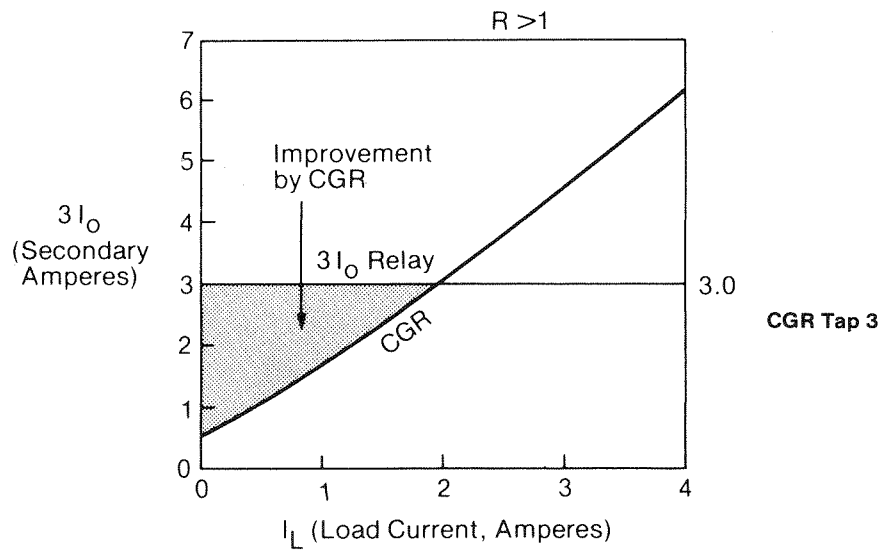
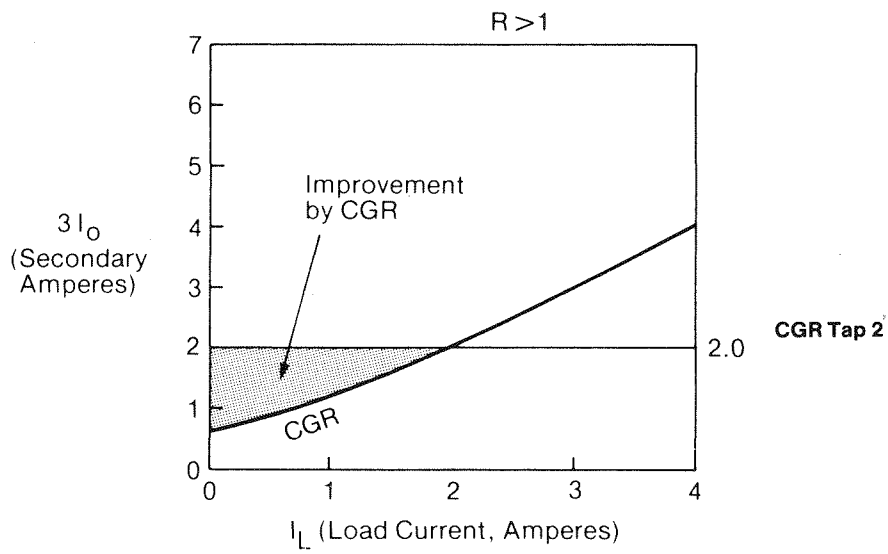
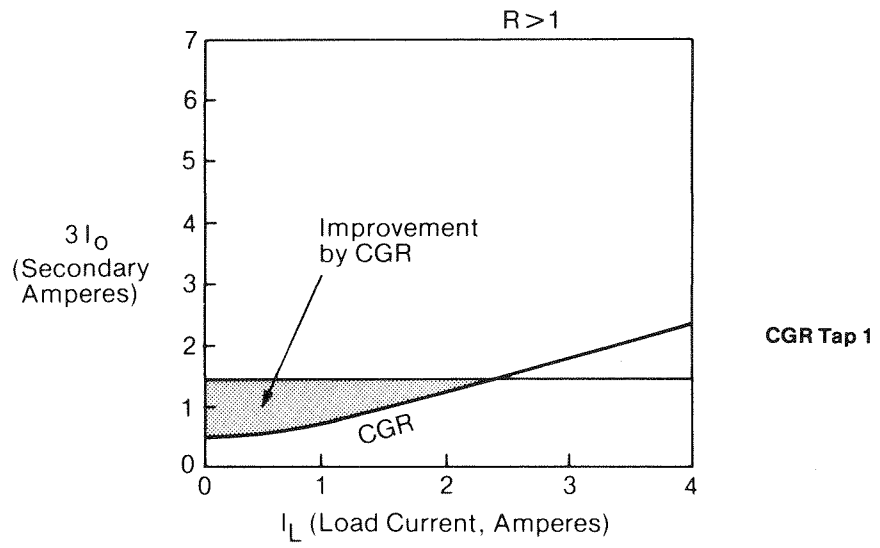


Figure 10 Ground Fault Detection-Relay Response

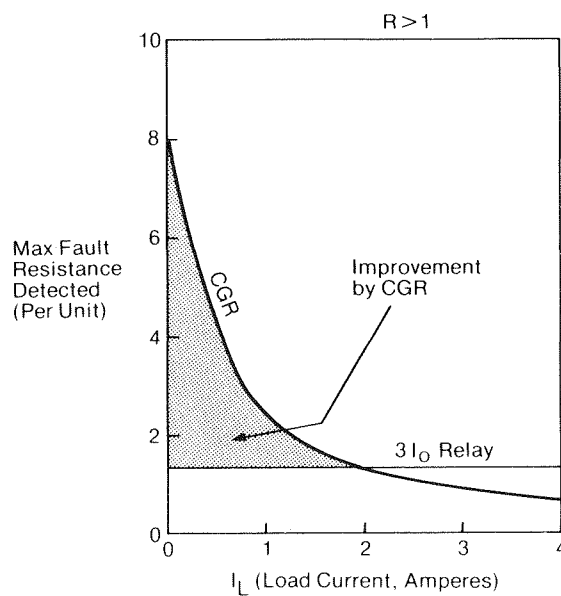
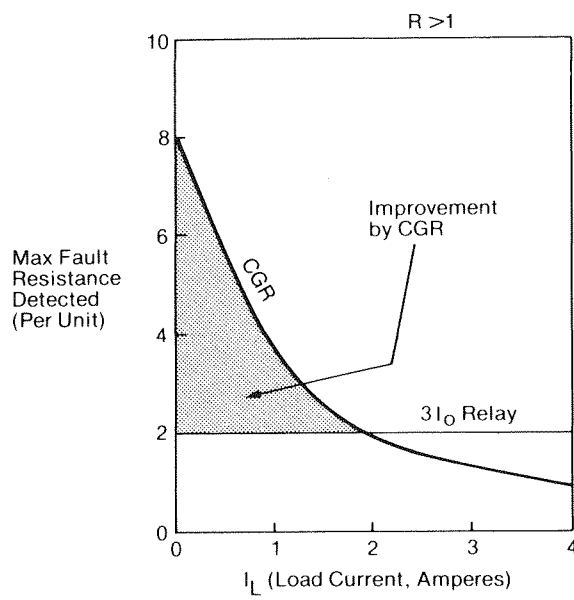
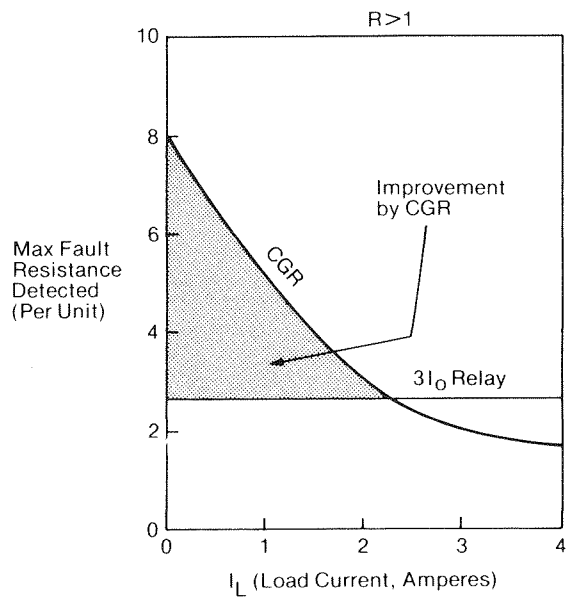
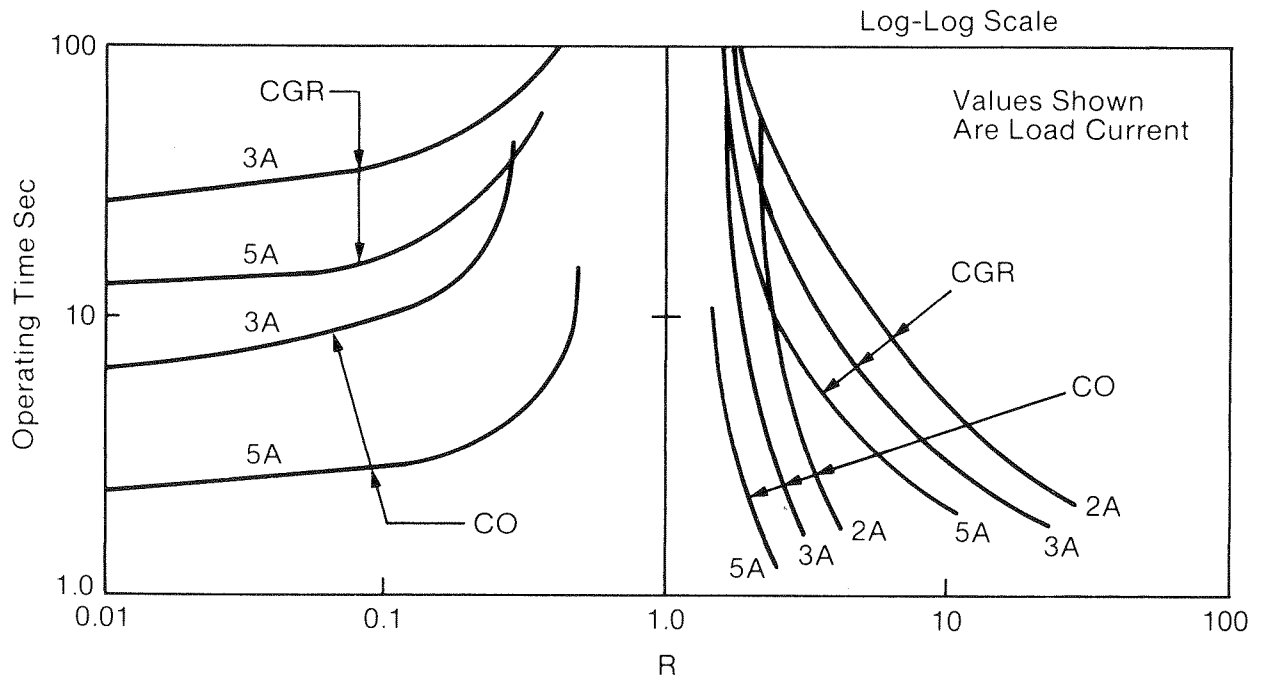


Figure 11 Ground Fault Detection—Comparison of Effectiveness



**Typical Coordination of CGR Relay
with Ground CO (CGR Tap 1, TD 11, CO-9
Tap 1.5; TD 5)**

Figure 12 Typical Coordination Curves of Type CGR and Type CO Ground Relay

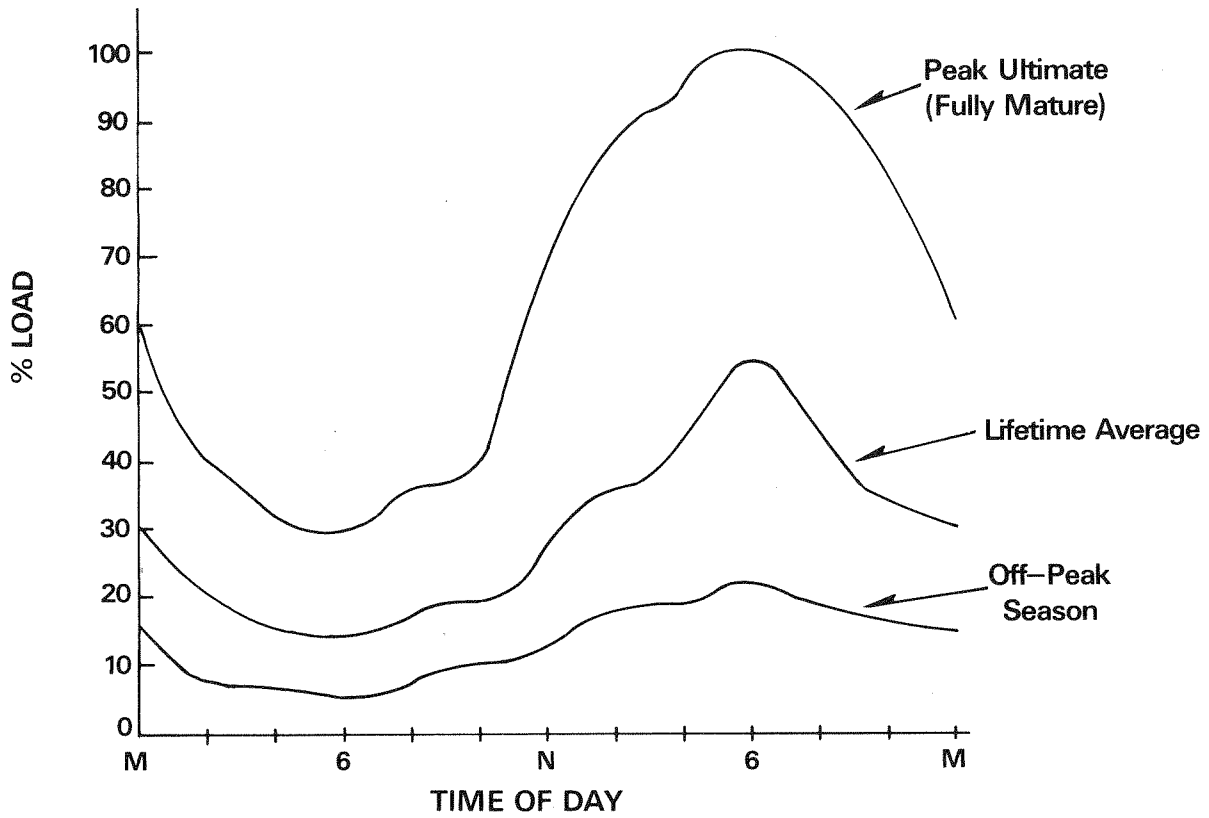


Figure 13 Typical Residential Feeder Loading