FUNDAMENTALS OF TRANSMISSION LINE RELAYING SELECTION

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6/69 - 2/70	Cadet Engineer - Louisiana Power & Light Company
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Past Chairman of Protective Relaying Performance Criteria Working Group [winner of outstanding working group award for 1994]
Past Chairman of Effectiveness of Distribution Protection Working Group
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Member of planning committees for, Texas A&M Conference for Protective Relay Engineers, Texas A&M Substation Automation Conference, Georgia Tech Protective Relaying Conference, and Western Protective Relay Conference
1997-8 Chairman of Western North Carolina Section of IEEE
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Introduction

The selection and application of protective relaying is often referred to as an art. At no time is this reference more true than in the selection and application of the relaying for protection of transmission lines. A Working Group of the IEEE Power System Relaying Committee has completed the task of producing an extensive document entitled "**Guide for the Protection of AC Transmission Lines**." This guide is a compilation of the knowledge of more than 50 protective relay engineers. Included in the guide are definitions, terminology, fundamentals of selection and application, descriptions of the multitude of different line configurations, discussions of relaying and pilot relaying schemes, and tutelage on how to avoid many of the mistakes and omissions that have plagued past installations.

This paper is based on some of the materials developed for part of the introductory sections of the guide that deal with the fundamentals of transmission line protective relaying.

Relaying Evaluation Criteria -- Reliability

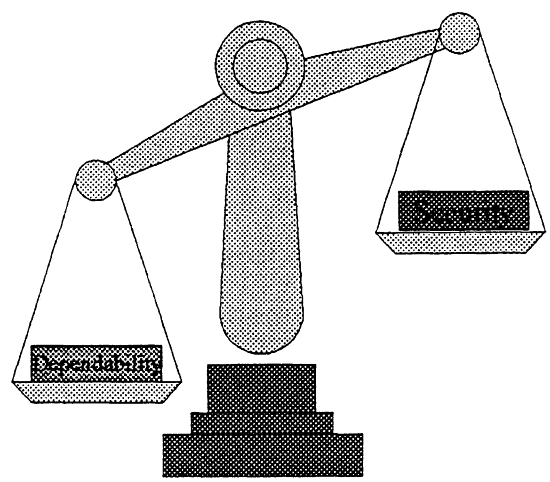
The term "reliability" is frequently used in analysis or evaluation of a relay or relaying system. Relaying reliability is often defined by defining its two components, dependability and security. Relaying **dependability** is defined as "the degree of certainty that a relay or relay system will operate correctly." Relaying **security** "relates to the degree of certainty that a relay or relay system will not operate incorrectly." Both of these definitions come from the standard, IEEE C37.2-1979. Paraphrasing these definitions, dependability is a measure of the relaying's ability to operate when it is supposed to operate and security is a measure of the relaying's ability to avoid operation for all other conditions for which tripping is not desired.

Of these two components of reliability, dependability has traditionally been considered to be the most important. This importance is based on the consequences of uncleared faults in terms of equipment damage and effect on the overall power system. Fortunately, methods to achieve dependability, especially at the transmission level, have been well established and proven. All these methods provide some means to deal with single failures and are often referred to as redundancy. An important concept to apply in all protection designs is the ability to accommodate **single point failures**.

Redundancy, as it applies to the protection of the transmission system, can be provided by a number of different methods, each with varying levels of complexity, benefits, and costs. Some redundancy concepts:

- Two, or more, protective relaying systems
- Two, or more, relaying communication systems or channels
- Local backup
- Remote Backup
- Duplicated dc sources
- Duplicated cts
- Duplicated vts
- Duplicated breaker trip coils

When two relay systems are provided, **independence of operating principles** of these different protection systems is often considered to be important. The precept followed by this independence is to avoid **common mode failure**. Common mode failures would include failures of different pieces of the protective system caused by the same stimulus.



Even though dependability has traditionally been considered the more important element of reliability, modern power systems are requiring that security be given considerable emphasis also. Higher loading of generators and transmission lines leave less tolerance for inadvertent or unnecessary tripping.

Achieving security in transmission protective relaying is more challenging and less established than achieving dependability. For a protective relaying system to be secure, it must be capable of tolerating mechanical stresses, electrical transients, fingers in the wrong place, and even the human errors of application and settings.

Dependability can be achieved with equipment and techniques; security requires the art and guile and total diligence of the protective relaying staff--the designers, the installers, and those that commission, operate, and maintain.

Relay Evaluation Criteria -- Selectivity

The protective relay engineer must also consider the concept of selectivity. Selectivity is the ability of the relay or relaying systems to isolate a problem while minimizing the area taken out of service. The most effective means of achieving selectivity is to apply differential relays. These relays measure the currents supplied by the sources and compare them to the currents leaving into the loads. Faults are detected by the differences in these currents.

Transmission lines, because of their length, make the application of traditional differential concepts difficult. If reliable high speed communications is available for the terminals of the line, current differential or pilot relaying, using either directional comparison or phase comparison techniques, can provide effective selectivity with no significant time delays required.

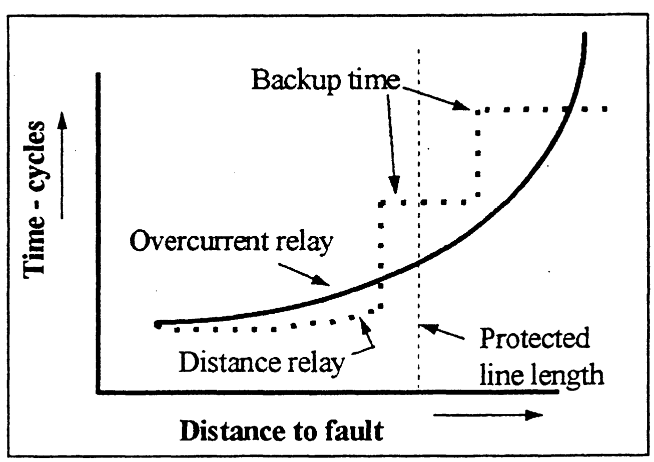
If the communications capability is not available or if an independent second form of protection is required, selectivity can be achieved using methods that allow the preferred relays to operate faster than other relays that detect the same fault. These methods include step distance protection, which uses impedance relays, and coordinated overcurrent relays. Both of these methods are capable of providing high speed tripping for faults close to the relays, but may introduce time delays ranging upwards from a few tenths of a second for faults located farther out on the line.

Relay Evaluation Criteria -- Speed

Perhaps the easiest understood design consideration is speed of relaying response. Slow relaying response may cause excessive equipment damage, adverse effects on customer service, or even loss of system stability. Any additional delay in tripping a fault will increase the risk of exacerbating these problems. On the other hand, increasing the speed of the protection may increase its costs or may compromise either the security or the selectivity of the protection.

Although the speed of the primary protection is given the most thought and debate among the protective relaying community, perhaps of more significance should be the speed of the backup systems. Even the best of primary protection systems can only provide 1/2 to 1 cycle relay operations. The others may be 1 to 3 cycles slower. Yet backup relay operations, either local backup or remote backup, may provide relay times from 10 to more than 30 cycles.

One or two cycles improvement in primary relay response time may be significant and must be evaluated. However, the time delays applied to implement backup protection must also be carefully evaluated and minimized. If the effects of backup tripping time delays are not tolerable, it may be necessary to apply two sets of relays using independent or separated pilot communications.



Relay Evaluation Criteria -- Sensitivity

Sensitivity of protection refers to the minimum operating quantities required by the relay to detect a fault. Modern relays require less energy to operate and therefore tend to have lower sensitivity limits. However, ground faults with high impedances, high source-to-line impedance ratios, and inherent system voltage imbalances still create challenges to the sensitivity of the relays.

Relay Evaluation Criteria -- Simplicity

Albert Einstein once said something to the effect that a difficult situation should be made as simple as possible, but not simpler. So it is with the design of protection. Solutions to every imaginable problem or combination of problems may be possible and are often interesting fodder for debate and discussions. Quite often though, the probability and consequences of human error in application or operation of the complex solutions is far greater than the problems they are designed to handle. So here's the challenge: design the protection to be as simple as possible, but not simpler!

Relay Evaluation Criteria -- Economics

As relay design engineers, we all know that the costs are not important. In fact, the costs are only a small fraction of the equipment they protect. As employees with bosses, we all know that costs are the most important consideration of your every working minute. So which concept is correct?

A prudent design engineer will evaluate more than the initial costs. Initial costs, installation and commissioning costs, and the costs of unreliable performance should be considered. In addition, features that may result in improvements in operations, service restoration, and post-fault analysis can be considered in a complete economic evaluation.

Selection of Protection

So now that you know all of the textbook criteria that can influence your decisions on what protection to select and apply, let's get more specific and talk about your system. The following factors will influence your choices.

Selection of Protection -- Criticality of Line

Always an important influence on what protection is applied is the criticality of the protected line to the system. This criticality judgment is subjective and could be based on voltage level, line loading, line length, proximity to generating sources, stability studies, or customer service considerations. Whatever influences this determination, more critical lines may justify the increased costs of speed and high reliability. Lesser critical lines may be adequately protected at lower costs.

Selection of Protection -- Line Configuration

Another consideration that may dictate some of your choices for protection is the characteristics of the line. Very long or very short lines may require special protection solutions. Multi-terminal and lines tapped with loads also can restrict choices. Other possible line design complications include the use of cables for all or parts of the line, the application of series capacitors or shunt reactors, and the availability of positive and/or zero sequence sources on the line or at the terminals.

Selection of Protection -- Communications

Since many protective relaying options for transmission lines involve the use of station to station communications, it is important to determine whether the tail wags the dog or vice versa. If the choice of the communications is directed by factors independent of the relaying, it may be necessary to select the relaying to be compatible with the communications that is available. Otherwise, relaying and communications can be selected as a team based on other factors, such as line length or criticality.

Selection of Protection -- Past Practices

Past practices and the familiarity of the responsible personnel with these practices will often override other considerations when protection is being selected for a transmission line. New concepts, equipment, or applications of equipment usually require development of new documentation, commissioning procedures, test methods, and also require personnel training and indoctrination.

However, before the protection engineer should default to past practices, it is important the reasons those practices were implemented are well understood. It is not uncommon for companies to continue to apply protection based on designs from the past even though the reasons for those practices are either no longer appropriate or, worse, are not known.

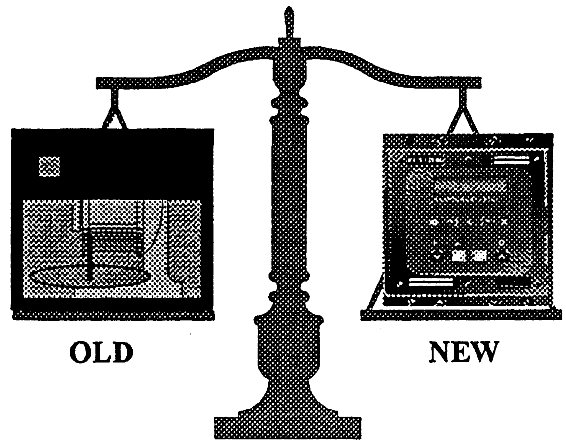
Fear of change should not hide behind the excuse, “we’ve always done it that way.”

Selection of Protection -- Old Versus New Technologies

The debate over continuation of the old tried and proven technologies versus implementation of new technologies has become more necessary and more important with the significant changes brought on by microprocessor technology. More often than not, the benefits and advantages provided by the new technologies are quite significant. They include:

- self-check, self test capabilities

- lower ct burdens
- better sensitivities
- wider setting ranges
- easier setting changes
- greater application flexibility
- increased operation data
- improved and increased post-fault analysis information
- remote access through communications interfaces



Compromises

What makes the design of protective systems an art is the requirement for compromise. Reliability of protection is always to some extent a compromise between the degree of dependability and the degree of security required. Other compromises often include reliability versus cost, speed versus either cost or security, simplicity versus complex solutions, independence of design and manufacturer versus standardization, and old technologies versus new.

All of these decisions and countless more make up the design decision. It is vitally important the design engineer document the reasons certain compromises are made. This documentation process provides management with the information needed to evaluate the protection decisions in a technically less complex format. The documentation is also important to allow better understanding by future generations of protection personnel of why certain practices were implemented.

Often the very act of documenting the reasons for choices and compromises may reveal other solutions and will generally result in a better final design.

Summary

The selection of protection for a transmission line usually presents to the design engineer a myriad of interdependent variables. Careful design should consider all or most of the design criteria and influencing factors presented in this paper. In the real world, however, it is important to recognize that the protective systems are similar to insurance policies. They cost money and you only need them when you need them and you only need the ones you need.

The protection design engineer must be open minded and flexible, pragmatic and well-informed. He must understand protection equipment and techniques, but he must also be familiar with the failure modes and characteristics of the protected equipment or lines.

Proper and correct operation of protection is expected. The success of a protective relay engineer is measured by the degree to which he does not fail.