Reliability Considerations of Multifunction Protection

INTRODUCTION

Most electric utilities have embraced numeric multifunction protection technology as a means of surviving in an industry that has changed dramatically in the last ten years. Led by restructuring and shrinking resources, protection engineers are continuing the move to communicating, multifunction protection technology as a means of reducing cost and maintaining operating performance with fewer personnel. We are at a point in the evolution of the technology where we need to step back and ask some questions about protection reliability. Our application and maintenance philosophies must be reviewed on a regular basis to ensure that they are meeting long-term protection reliability as well today as they did with predecessor technologies such as electromechanical and solid state devices.

The purpose of this paper is to evaluate the reliability of numerical multifunction protection systems against predecessor technologies. We will define reliability as related to protective relaying, identify a selected group of reliability factors that impact both predecessor and numerical multifunction technologies, discuss each factor in detail, and draw conclusions about the overall reliability of multifunction protection.

DEFINITION

One of the most important design considerations for protective relay engineers, regardless of protection technology, is **reliability**. Reliability means many things to many people, but for protective relay engineers, reliability is defined by two specific performance characteristics:

- DEPENDABILITY
- SECURITY

Dependability is the measure of confidence that a relay or relay system will operate when it is expected to operate.
Security is the measure of confidence that a relay or relay system will not operate when it is not expected to operate.

For a protective relay system to be 100% reliable, it must operate <u>every</u> time it is expected to operate, and <u>never</u> operate when it is not expected to operate. Anything other than perfection in both categories results in less than 100% reliability. In reality, experienced protection engineers understand that 100% reliability is not a realistic goal and even if it were, it could not be afforded.

There are many factors that influence the overall protection reliability equation. The remainder of this paper will be devoted to exploring a selected group of factors that impacts protection reliability, including the influence each had on predecessor technologies versus their impact on the present numerical multifunction technology. We begin by first identifying the reliability factors that influence predecessor technologies and then those that influence multifunction technology.

RELIABILITY FACTORS – PREDECESSOR TECHNOLOGY

Based on industry experience, the following list of factors was identified by the authors as having an influence on static and electromechanical (predecessor technologies) performance reliability:

Power System
Company Organization
Protection Philosophy
New Product Evaluation
Advances in Technology
Protection Product Complexity
Personnel Experience/Training
Design Standards
Ancillary Equipment
Assembly Methods
Installation and Commissioning Tests
Electrical Environment
Maintenance Programs
Record Keeping
Operations Analysis Programs
(feedback to maintenance and design, closes the loop)

RELIABILITY FACTORS – MULTIFUNCTION TECHNOLOGY

Based on industry experience, the following list of factors was identified by the authors as having an influence on numerical multifunction performance reliability:

Power System
Company Organization
Protection Philosophy
New Product Evaluation
Advances in Technology
Protection Product Complexity
Personnel Experience/Training
Design Standards
Ancillary Equipment
Assembly Methods
Installation and Commissioning Tests
Electrical Environment
Maintenance Programs
Record Keeping
Operations Analysis Programs
(feedback to maintenance and design, closes the loop)

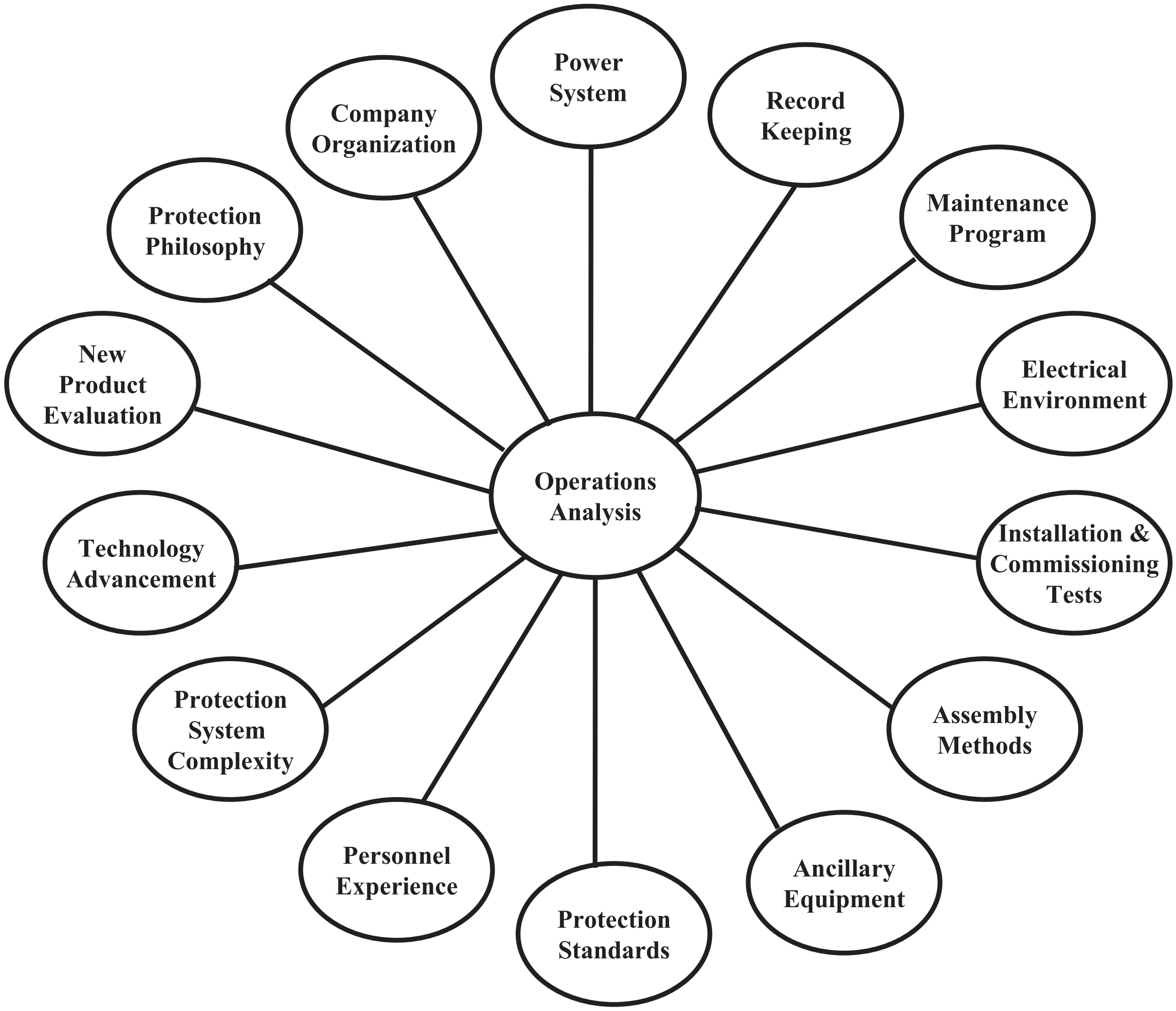

Figure 1: Factors Influencing Protection Reliability

OBSERVATION

As might be expected, the list of factors is the same for predecessor and numerical multifunction technologies. Reliability factors that influence one technology influence all technologies; the question is to what degree. The next section will evaluate the degree or level of influence each factor has on the two technology groups, identifying strengths and weaknesses of each.

DETAILED REVIEW OF RELIABILITY FACTORS

Power System

Protection reliability begins with a thorough understanding of the power system being protected (transmission lines, neighbor interties, generation sources, and loads) and the associated planning and operating guidelines imposed on the system by internal procedures as well as state, federal, and regional agencies.

Based on this knowledge and historical operating experience with similar applications, a particular type (operating principle) of protective relaying can be selected (example: line protection - directional comparison, phase comparison, permissive schemes, etc.). Remember that protection philosophy and most standards in electric utilities are experience based and have evolved over many years.

With a thorough understanding of the planning contingencies used by the planning department, system protection personnel can run their studies and make informed decisions about the level of protection reliability required for a specific application, again factoring in operating history of similar installations. Making the right application choice provides the proper foundation for long-term protection reliability.

Once the decision on type of protection has been made, it may be necessary, depending on the application, to **bias** reliability beyond the inherent bias of the specific type. For example, a “directional comparison normally off blocking scheme” is inherently biased towards dependability. System quantities (volts, amps, angle) required to make a high speed **tripping** decision are derived locally and, if the fault is anywhere in the overreaching zone of protection, will trip unless a blocking signal is received from the remote end of the line. By design, the scheme is slightly less secure than some, and occasionally results in a larger outage area than required to clear the fault; however, there is a high level of confidence that the scheme will trip when a fault is detected.

Continuing the example, two new transmission lines are being added to a bus emanating from a given power station. System parameters indicate that faults on these lines must be cleared high-speed or the units will go unstable. In other words, the units cannot stand a second zone backup clearing time. Therefore, the inherent dependability bias of a single overreaching zone, with step zone backup normally found in directional comparison systems, is not sufficient for this application. This application will require a further **bias** in dependability to meet the specific reliability requirement. This could be accomplished with the addition of a second primary zone or an independent primary package from a different manufacturer.

As mentioned in the introduction, few utilities can afford the cost associated with “gold plating” both security and dependability of their protection systems. Engineering decisions must be made based on the specific application, with an understanding that there is a finite number of dollars that can be invested in the protection system. The protection engineer must have a global understanding of the power system and operating requirements of that system to ensure that application decisions maximize protection reliability.

Technology Observations Associated with the Power System

Misapplication of protection products will have the same impact on protection reliability regardless of the technology. Assuming, however, that the protection engineer has a good understanding of the power system and that the correct application decisions are made, the following observations can be made:

- Predecessor technologies are time tested, require no new standards, and are under stood by all personnel in the engineering, operations, and maintenance loop.
- Obsolescence and cost are slowly but surely eliminating products from the predecessor technology group.
- With expanded range and multiple protection elements, multifunction protection systems provide for more flexibility and precision of setting than predecessor technologies, thus reducing “incorrect” operations resulting from borderline or limited range.
- Lower cost/function, smaller size, and feature/function flexibility of multifunction systems allow the protection engineer more freedom to improve protection reliability with little or no additional cost.
- With self-testing and monitoring, internal sequential events and oscillography, and remote communications, multifunction protection systems are capable of identifying problems, removing themselves from service, and notifying a remote location of the situation. Most situations can be identified and corrected before becoming an “incorrect” operation, thus improving overall protection reliability.

Company Organization

As mentioned in the introduction, we have all been witnesses to many changes in the electric utility industry during the last ten years. Those changes have made it difficult for protection organizations to stay focused on protection reliability.

Forced by federal legislation to evolve from monopolistic entities that controlled generation, transmission, and distribution resources, to competitive entities with separate companies responsible for those same resources, the electric utility industry has been in a state of change, with no end in sight. The Energy Policy Act of 1992 (EP ACT) and the April 1996 FERC issued Orders No. 888 and No. 889 initiated a landslide of federal and state legislation directed at deregulation. Several years ago, California took the lead by implementing the first state level deregulation plan in the country. To put it mildly, the plan has resulted in utter chaos with the most recent developments (January 2001) involving rotating blackouts, utilities that can’t afford the cost of free market generation or the fuel cost (gas) to run their own generation.

Thank goodness not all utilities are experiencing this degree of distraction. However, most electric utility protection organizations have felt the impact of restructuring, reorganization, rightsizing, or downsizing over the years. But the changes have not all been bad. Quite the contrary, protection organizations in the monopolistic electric utility environment always tended to man for peak workload, leaving them overmanned during the valleys. Office automation efforts introduced in the mid 80’s and early 90’s, such as Computer Aided Design and Drafting and various fault study programs began to pay dividends early on and added to the overmanning problem. Thinking more like an owner of a competitive business forced all of us to reevaluate the way we got our work done.

But in recent years, some think the pendulum has swung too far the other way. Focus on both capital and O&M budget cuts has forced utility leaders to think more about short-term cost than long-term reliability. Early out programs have reduced the average experience level in most companies, while at the same time requiring each employee to do more with less experience. Remember that high levels of protection reliability in most companies are based on the experience level of their managers, engineers, and technicians, and effective maintenance programs. Of course, maintenance programs tend to be the first to experience budget cuts when, in reality, they should be the last.

In many companies, the old sages that young engineers used to consult with and learn from are gone, and replaced, if at all, with personnel only a few years older than the questioning engineer. This environment has produced a shortage of technical leadership in many companies and shows no sign of letting up. It bears repeating that short-term financial goals have replaced long-term reliability goals in many companies.

An important part of a protection engineer's professional responsibility is to stay abreast of, and influence change in, organizational issues and management philosophies that could have a negative impact on protection reliability.

Technology Observations Associated with Company Organization
Company organization is a major factor in overall protection reliability. The degree of effect is similar in some ways to predecessor and numerical multifunction technologies but different in others. The following observations can be made:

- Cuts in maintenance budgets resulting in extended or eliminated routine maintenance schedules will degrade protection reliability of predecessor technologies but will have little impact on multifunction systems.

- The elimination of support programs such as new product evaluation can impact reliability of multifunction systems by not allowing the user to learn the details of the product prior to application. This also applies to predecessor technologies but to a lesser degree, because fewer new products are offered in this group and most of the products are already well understood and in use in mature protection schemes.

- Competitive pressures for lower cost installations, reduced maintenance, timely operations analysis and real time metering, remote communications, and increased protection reliability have driven the move to multifunction protection systems.

- Once a design standard has been created, multifunction applications are easily replicated through software. To take full advantage of the technology, testing and commissioning programs must be adapted for numeric products (focus on system testing as opposed to component testing).

- Young protection engineers adapt quicker to multifunction products than predecessor products because they were raised on computer technology.

Protection Philosophy

Protection philosophy consists of global guidelines designed to maintain a high level of protection reliability throughout the range of applications on a given power system. In most companies, this philosophy has evolved based on the complexion of the power system to be protected and operating experience. Also, regional power pool guidelines can influence protection philosophy. As defined by the nature of the business, protection philosophy is very conservative. That is, if the protection system fails to clear a fault, the safety and well-being of the public in general are placed at risk.

A simple analogy of protection philosophy is to think of it in terms of insurance. There are many groups of coverage such as home, auto, and life, in varying degrees of coverage (level of conservatism). First, the individual must choose the right group (don't need auto insurance if you don't own a car) and then the degree or amount of coverage. Conservative individuals usually have more coverage than those who are less conservative. Also, the more coverage an individual has, the more it costs. Paying the monthly premium is analogous to routine maintenance and will be discussed in a later section.

The same applies to protection philosophy. Transmission lines, buses, transformers, and distribution circuits each require a different type of coverage in varying degrees of conservatism (reliability bias is based on a specific application). The scale of conservatism is somewhat unique in each utility and is based on operating history and, to a large degree, on the justification skills of protection personnel. The level of conservatism also has a corresponding level of cost. From a philosophical perspective, protection reliability is influenced by the type of coverage, degree of conservatism, and the overall cost (pressure to lower protection cost by being less conservative).

In recent years, the widespread acceptance of numerical multifunction technology coincident with financial pressures brought on by deregulation and competition have created opportunities for inadvertent violation of basic protection philosophy. With multiple protection elements in one multifunction device, there is a tendency to think that primary and backup protection reliability requirements for a given zone are met by that single multifunction device. Electrically this is true. For the Transformer zone in Figure 2, the same device can provide primary and backup protection. However, from a reliability point of view, a single contingency failure could eliminate primary and backup protection, violating basic philosophical guidelines.

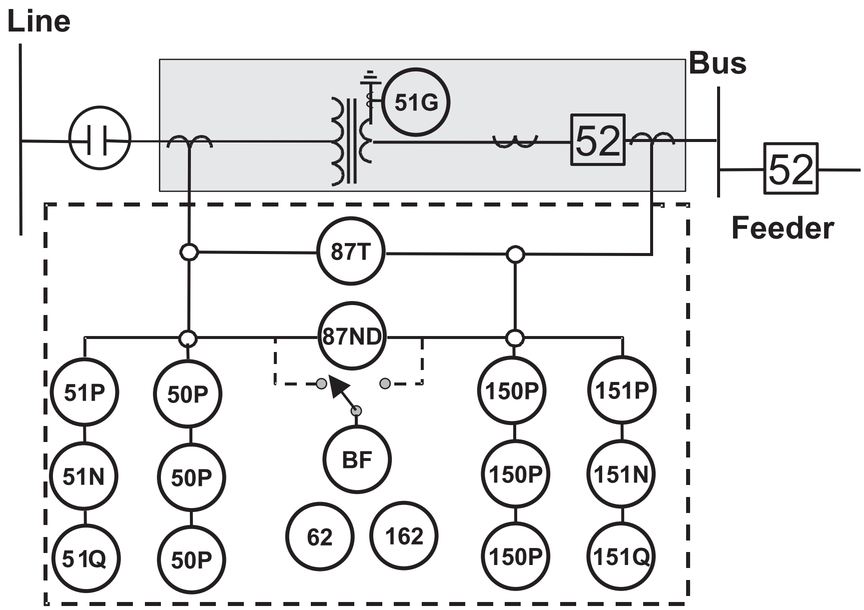

Figure 2: Transformer Zone

The correct way to take advantage of these multifunction capabilities and meet the requirements of protection philosophy guidelines is to use the relay system to provide primary protection for one zone and backup protection for a down stream zone as shown in Figure 3. Backup protection for the primary zone should be provided by a separate device. Further, using backup protection from a separate manufacturer eliminates the reliability concern of common mode failure.

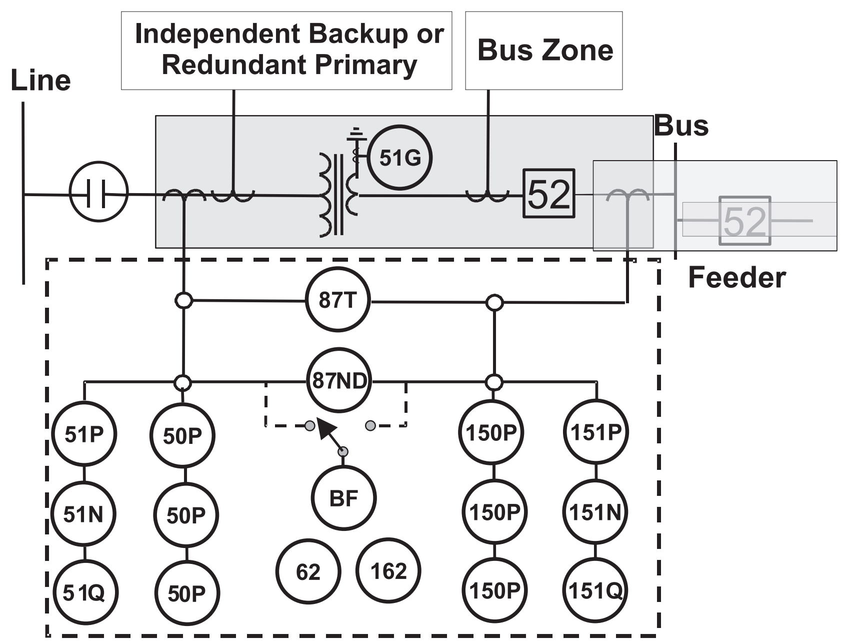

Figure 3: Primary and Backup Protection

Technology Observations Associated with Protection Philosophy
Protection philosophy consists of global guidelines designed to maintain a high level of protection reliability throughout the range of applications on a given power system. Comparisons of predecessor technologies versus numerical multifunction technology reveal some interesting differences related to protection reliability. The following observations can be made:

- Predecessor technologies, if fully operational, provide a high level of dependability resulting from multiple (individual) phase or zone relays and ground relays. When a given protection philosophy is replicated with a three phase device that includes all phases, zones, and ground elements, careful consideration must be given to protection reliability issues such as single contingency failure and common mode failure.

- With self-testing and monitoring, internal sequential events and oscillography, and remote communications, numerical multifunction protection systems are capable of identifying problems, removing themselves from service, and notifying a remote location of the situation. Most situations can be identified and corrected before becoming an “incorrect” operation, thus improving overall protection reliability.

- Protection engineers must guard against inadvertent violation of their company’s philosophical guidelines. For example, the use of a multifunction device to provide primary and backup protection of a given zone could result in a single contingency failure that disables all protection of that zone.

- Philosophical objectives are easier to meet with multifunction technology (multiple elements, multiple setting groups, and more flexibility) and even allow for philosophical enhancements.

- The reliability impact of a common mode failure on multifunction protection systems of a single manufacturer should be considered. Predecessor technologies by a single manufacturer take advantage of multiple (individual) phases, zones, and ground relays to offset common mode failure. With all protection elements and phases in one multifunction device, use of a single manufacturer’s equipment for primary and backup protection of a given zone creates the possibility of a common mode failure that could disable all protection.

New Product Evaluation
For many years, a small group of protection engineers and technicians has been at work in most utilities evaluating new protection and control products before applying them to their power system. Normally an application need would start the evaluation process that consisted of head to head comparison of various manufacturers’ products.

To be on the list of products to be evaluated, the manufacturer would have to meet specific application and reliability guidelines defined by the evaluation personnel. The evaluation program was designed to be fair and objective, with the primary intent of selecting the product that most closely met the specific application and reliability requirements. A secondary but equally important reliability benefit was the intimate product knowledge gained during the evaluation process. Evaluation personnel would pass that knowledge on to standards developers, design engineers, and technical personnel responsible for operations analysis and maintenance procedures, quickly raising the proficiency of all involved. Companies that followed this approach had fewer protection reliability problems than those who had not.

Unfortunately, most utilities have greatly reduced or eliminated their evaluation teams, citing cost benefit as the reason. At the same time, fewer protection engineers and field technicians with less experience are involved with more projects involving the application of multifunction products. These are great products, but in the hands of the uninformed, they can have a major impact on protection reliability.

As a result of competitive pressures, even large electric utilities are slowly moving in the direction of co-ops, municipals, and large industrials relative to in-house product knowledge. That is, they rely more on outside experts such as consultants and manufacturers to supply detailed product knowledge required for application, design, and commissioning. Normally, one or two in-house personnel responsible for long-term operations and maintenance of multifunction systems will attend product schools offered by the manufacturer, thus maintaining a nominal level of product expertise.

An additional concern of too much reliance on outside expertise in evaluating protective relay systems is that the outside expert may be an expert on the protective systems but they will not be an expert on the power system to which the protection is being applied. Nor will they be on the operating practices. This intimate knowledge can only come from long-term study and exposure. The nuances that affect the applicability of a particular system in the overall scheme of things will not be apparent to the outside consultant.

Protection managers must guard against reducing their in-house product knowledge to levels that will negatively impact protection reliability.

Technology Observations Associated with New Product Evaluation

At this point in the evolution of protection technology, new product evaluation or lack thereof has little impact on predecessor technologies because most of these products are part of mature systems. Standards and procedures for predecessor technologies are well documented and protection personnel are familiar enough with the application, commissioning, and maintenance of the systems to maintain acceptable levels of protection reliability. Therefore, the following observations can be made:

- A complete product evaluation prepares the user for the proper application, commissioning and maintenance of the product. Lack of such knowledge increases the risk of protection reliability problems.

- Without detailed product knowledge, protection standards may not take full advantage of the technology, or may include improper application that will be perpetuated with each new installation.

- Lack of detailed product knowledge leads to an applications mentality of "learn as you go". Protection reliability will more than likely suffer.

- Relying too heavily on consultants or manufacturers for detailed product knowledge limits the user's ability to quickly adapt to a new application or respond to operations and maintenance emergencies.

- Detailed product knowledge allows the user to take full advantage of commissioning, self-checking, and operations analysis features of numerical multifunction technology, increasing overall protection reliability.

- Over time, as multifunction technologies replace predecessor technologies, younger protection engineers will become less knowledgeable of older technologies. Protection managers need to recognize the potential impact this could have on long-term protection reliability and act accordingly.

Advances in Technology
Over time, protection system standards have to be updated due to changes in the requirements of the applications, obsolescence of protective products, pressures to take advantage of newer technologies to improve operating practices or reduce costs, etc. Each time a new standard is deployed on the power system, there is usually a learning curve that must be tolerated. Protection system reliability may suffer until all of the "kinks" have been worked out of the application and the organization has worked out all of the requirements for applying, testing, and operating the new protection system.

With predecessor technologies, product designs tended to be fairly stable. The product characteristics tended to remain fixed for long periods of time. The user could expect that the relay that was standardized on and purchased 10 or 20 years earlier would be available and the same as the new one of the same model that he purchased today. Due to the nature of microprocessor technology, the product life cycles have been shortened considerably. Products become functionally obsolete very quickly due to the advances in capability of the underlying technology. The processors become faster and cheaper so capabilities go up and cost goes down. It becomes very easy to be seduced by the new capabilities offered by each new generation of numerical multi-function relays so standards are updated on a much shorter time frame.

Another consideration is that, with numerical multifunction relays, "it is only software." This attitude makes it easy for the functionality of the device to be upgraded often over the product's life cycle. The result can be that otherwise identical relays bought over a period of time may have different capabilities, settings, etc. Luckily, with the advent of flash memory, it is easy to update the firmware of products in the field without dismantling them and changing chips. Thus, the user can keep the fleet up-to-date and similar in operating characteristics for consistency in testing and operations. However, this trend also means that the protection standards require more maintenance to ensure that they keep up with evolution of a numerical relay's functionality.

Technology Observations Associated with Advances in Technology
The main concern with predecessor technologies versus numerical multifunction technologies is with the *pace* of advances in technology. Numerical multifunction designs change much more rapidly than electro-mechanical and solid state analog designs did. The following additional observations can be made:

- The result of this rapid change is that a protection system standard may only be able to be used for 5 years before the products that it is based upon become supplanted by newer designs. In the past, it was not unusual for a protection system standard to be used for 10 to 20 years without significant change.

- With changing standards, there is often a negative impact upon protection system reliability because the learning curve portion becomes a significant part of the overall deployment of the protection system standard on the power system.

- Advances in technology can be very seductive. The user should fully weigh the advantages of the new capabilities against the risk associated with changing standards.

Protection System Complexity
When single function devices are used to create a protection system, the protection system designer has nearly complete freedom in combining these devices in a way that fits the unique application requirements of the power system and the operating norms of the organization operating and maintaining the power system. With multifunction devices, this freedom may be restricted by limitations in the programmability of the multifunction system. As numerical multifunction designs have evolved, great strides have been made in the flexibility of these devices. Advanced programmable logic systems have brought back the previous level of freedom to the protection system designer.

On the other hand, it is a well-understood concept that the complexity of a system made up of discrete components is inversely proportional to the reliability of that protection system. With more sensing relays, more auxiliary relays, more wires and contacts, etc. there are more components that could fail. This tended to be a restraining factor that limited the complexity of the design of the protection system. Also, with increased complexity, there is more room for error at every stage. The persons applying the protection system, the persons maintaining the protection system, and the persons operating the power system that the protection system is applied to are more likely to make mistakes if the system is so complex that it is difficult to understand.

With the fast processors and highly flexible and powerful programmable logic schemes available in numerical multifunction relays, there is no direct penalty in reliability associated with adding complexity to the protection system. It is just computer code running in the device and will be as reliably executed 20 years down the line as it is the day it is placed in service. With this restraining factor removed, the protection system designer (relay manufacturer as well as user) is tempted to design in greater and greater levels of complexity.

Added complexity is good when it increases the ability of the relay to adapt and respond to conditions and abnormalities on the power system that it is intended to protect. However, added complexity can create greater room for error if the product is difficult to understand and apply. If the designer does not adequately document the programmable logic for a specific application, the operating and maintenance personnel may not understand what it is supposed to do.

Technology Observations Associated with Protection System Complexity
Protection systems made up of discrete components tended to be limited in their complexity due to the reliability concerns from having too many components in the system that might fail and render the whole system unreliable. Numerical multifunction devices do not have this restraining factor so they tend to have greater capabilities but with greater levels of complexity. The following additional observations can be made:

- Complex systems tend to be more reliable in a numerical multifunction system than complex systems using predecessor technology.

- More robust protection system designs can be applied with numerical multifunction relays to improve overall protection system reliability.

- The tendency to make the system overly complex must be overcome so that users do not make mistakes that result in reduced protection system reliability.

- The protection system designer must take documentation of the protection system in a programmable logic relay to the same level of detail as was done with predecessor technologies. That is, we would never consider sending out a protection system made up of hard wired contact logic without a schematic diagram for the operating and maintenance personnel to use. Thus, if the schematic diagram is made up of programmable logic inside the "black box," this logic must be documented similarly.

Personnel Experience/Training

A major component of protection reliability is the technical competence of personnel involved with detailed engineering, commissioning, operations, and maintenance. As the pressures of deregulation continue to impact the size and experience level of protection organizations, improving the technical competence of those remaining becomes a priority.

The experienced personnel who remain in the protection groups tend to be more competent with predecessor technologies than numerical multifunction technology. Therein lies the paradox. The proliferation of multifunction technology throughout the industry has created more projects for fewer people with less experience. In many protection organizations, the technical personnel are overwhelmed by the technology, creating multiple opportunities for protection reliability problems.

As we discussed in the section on product evaluation, detailed product knowledge gained through the evaluation process is one key to maintaining high levels of protection reliability regardless of technology. As new multifunction products are evaluated and accepted for application, the accumulated knowledge is distributed throughout the organization.

Evaluation personnel work closely with protection standards and design personnel who, in turn, help the commissioning, operations, and maintenance personnel with product knowledge and procedures. We all know there is no substitute for time and experience in gaining competence with a new technology. However, a good foundation is essential to the process, and having an in-house expert to consult with accelerates the learning process.

In lieu of evaluation experts, standards and design personnel must rely on consultants or manufacturers for detailed product knowledge. In the case of multifunction protection, this process works quite well using two-man teams with one engineer being proficient in predecessor technologies teamed with a recent hire with excellent computer skills. Engineers raised with computers tend to be more comfortable with newer technologies and easily adapt to multifunction technology. The more experienced engineer makes sure that the analog logic of predecessor technologies is replicated with the multifunction systems and meets all the application requirements.

This approach accelerates the learning process of both individuals (new engineer learns predecessor technology, experienced engineer learns multifunction technology) and greatly reduces the likelihood of protection reliability problems.

In either case (in-house experts or outside experts), protection managers with fewer personnel having less experience have quickly learned that training is an integral part of the protection reliability equation. They have also learned that relay applications schools presented by the manufacturers are a cost-effective, efficient way of quickly increasing the engineering skills of their employees.

Technology Observations Associated with Personnel Experience/Training
A major component of protection reliability is the technical competence of personnel involved with detailed engineering, commissioning, operations, and maintenance. Based on that and the competitive pressures faced by all protection organizations to incorporate multifunction technology, the following observations can be made:

- The aggregate level of employee experience in a protection organization has a corresponding impact on protection reliability.

- The less an engineer understands about the application of a given product, the more likely there will be protection reliability problems.

- For most applications, the transition from predecessor technologies to numerical multifunction technology requires concentrated effort in the beginning to understand the technology and take full advantage of its capabilities. A mechanism must be in place to educate other groups that interface with the products, or protection reliability could suffer.

- With little maintenance required by numerical multifunction systems, the traditional method used to increase product knowledge and skills of operations and maintenance personnel is going away. As predecessor technologies are converted to multifunction, there will be less focus on maintenance and more focus on product commissioning.

Design Standards
Protection system design standards typically specify a number of considerations for each particular protection system application. In examining the characteristics of a design standard built around predecessor technologies versus numerical multifunction relays, we see that the requirements are the same. The actual content and considerations for design standards may differ.

- The design standard will typically specify what discrete relays are to be used for the application. This covers what protective functions and operating characteristics are required for the application. Distance, versus directional overcurrent, versus differential for example.

- The design standard will typically specify sensing and control schematics for inter connecting the various devices to form the protection system. This covers the logic required to make the protection system behave the way we want it to.

- The design standard will also often contain guidelines for the setting criteria so that settings and response characteristics are applied in a consistent manner throughout the system.

When developing design standards for particular protection applications, it is desirable to limit the variety of devices that are used throughout the system for different applications to limit the requirements for: keeping spares, developing relay test procedures, training on specific relay types, etc. Thus, we tend to apply specific relay types to many different applications. The only thing that differs from one design standard to the next is the schematic logic and/or the settings criteria.

Comprehensive design standards also cover all aspects of applying a particular standard to the power system. These include: ensuring that stocking is set up for spares; test procedures are developed for commissioning and periodic maintenance testing; appropriate test equipment and accessories are available; operating personnel know and understand what to expect when an operation occurs; etc. These extra considerations are important to ensuring that the entire organization is prepared to work with the new protection system covered by the design standard. This improves the comfort level and “buy in” of all persons that can affect the reliability of the protection system.

Technology Observations Associated with Design Standards

With predecessor technologies, a design standard specified the products to be used and the logic was specified by standard sensing and control schematics. With multifunction devices, many of these attributes are buried inside the box so a wiring schematic must be supplemented by an internal logic diagram and a specification of which protection functions are to be enabled.

With the comprehensive group of functions included within the multifunction relay, the same relay may be set up in many different configurations and its response may be completely different depending upon the applications in which it is used. For example, the user may decide to standardize on a particular multifunction overcurrent relay. This relay may be used in a number of design standards. One design standard might specify that it will be programmed for non-directional overcurrent, with reclosing and fuse saving for rural distribution feeders. Another might specify that it will be programmed with directional overcurrent with reclosing supervised by sync check for subtransmission lines. And still another might specify that it will be programmed with overcurrent and over-excitation for transformer applications.

The following additional observations can be made:

- With predecessor technologies, each standard relay represented a specific protective function and could be used in many different design standards. Multifunction relays may include many functions that are used in different combinations to make it applicable to many different applications.

- It is not sufficient for the design standard to simply specify that a multifunction relay is used in a particular application. The standard must specify the programming of what elements are to be enabled and how the logic is to be programmed.

- There should be a finite number of programming templates for a particular relay associated with each standard in which it is applied. The standard should specify internal and external logic schematics, elements included, and setting criteria for the elements that are to be used.

Ancillary Equipment
This section will discuss the effects of ancillary equipment (CT, PT, batteries, breakers, monitoring equipment, etc.) on overall protection reliability. Regardless of the technology type, performance of protective relay systems is inextricably joined to the performance of ancillary devices. We will begin with sensing devices such as Current Transformers and Voltage sources (Voltage Transformers or Capacitive Coupled Voltage Transformers and Bushing Potential Devices).

Predecessor technologies, being higher burden devices, require careful consideration as to the number of protection elements placed on a given sensing device. For current circuits, total burden is limited by CT performance capabilities as defined by ANSI C37.13. The specifics of a given application such as CT accuracy class, CT secondary impedance, lead length, and burden of each protection element are required to determine how many protection elements can be safely driven by a set of CTs. Voltage sources are subject to similar concern.

In the past, the only recourse for supplying burden in excess of the sensing devices limit was to replace it with a higher rated device or add another device (CT or VT). In most cases, neither was a cost-effective approach and, depending on the application, could result in borderline protection reliability. Alternatively, current circuit burden in a multifunction device is the same whether one protection element or all are selected. And, with burdens less than 10 milliohms, more than one multifunction system can be connected to a CT providing a lost-cost, low-burden alternative for independent backup protection. A multifunction system can also be added to a predecessor scheme to improve protection reliability with minimal impact on total current circuit burden.

Protection reliability during CT saturation has always been a concern. With predecessor technologies, CT saturation can result in an unwanted operation. Multifunction technology reduces the risk of misoperation by using “saturation detectors” to momentarily alter the operating characteristics of the protective device, creating more tolerance for poor CT performance, resulting in fewer misoperations. Thus, it prevents the costly replacement of sensing devices.

Another advantage of using numerical designs is that differential zones of protection can be improved in protection system upgrades because special CT connections are no longer required. When upgrading an existing facility, adding additional CT's is often not an attractive option. By being able to connect all CT's in wye with internal phase and zero sequence compensation, zones of protection can be improved by sharing CT's for differential and line applications.

Other critical ancillary components such as circuit breakers are also monitored by multifunction systems to mitigate their impact on protection reliability in the event of a problem. Trip circuit monitors are designed to alarm on loss of trip coil continuity, similar to the "red light" circuit in predecessor technologies except the alarm is immediately sent to a manned location. Circuit breaker interrupting contacts are also continuously monitored for wear and are set to alarm well in advance of failure. Also, trip and close speed of the breaker are recorded. These are all features that had to be supplied by separate devices or not at all in predecessor protection schemes.

Stand-alone sequence of events and oscillography equipment used to monitor system performance can be replaced or augmented with built-in SOE and oscillography features found in most numerical multifunction systems. This can lower overall project costs and provide monitoring features at levels where they could never be cost justified in the past. An effective operations analysis program is critical to continuous improvement of protection reliability.

Technology Observations Associated with Ancillary Equipment
Protection reliability of both technologies is affected by ancillary equipment problems; however, the degree of impact is quite different. This is an area where numerical multifunction protection systems seem to have a clear advantage over predecessor technologies. The following observations can be made:

- Numerical Multifunction technologies can communicate.

- Predecessor protection schemes are assemblies of many single function products, each having a cumulative impact on current and potential circuit burden. Conversely, multifunction products have a much lower, single burden while providing multiple protective functions. End result is improved zone coverage with the same sensing resources.

- Saturation detectors applied in multifunction products reduce misoperations caused by CT saturation.

- Monitoring circuits found in multifunction products provide early warning of ancillary equipment problems mitigating their impact on protection reliability.

- Built-in fault reporting features such as SER and oscillography reduce overall cost associated with operations analysis and allow reliability improvement at voltage levels that previously could not be cost justified.

Assembly Methods

Assembly methods refers to the process of assembling protection and control products into a protection scheme and what impact that can have on protection reliability. In most cases, predecessor technologies assembled for substation control house applications are mounted on pre-punched 90” high panels of varying widths. The panels are mounted on either side of the control house with panel fronts facing the middle of the room so that all protection, control, metering, and indications can be easily seen. There are many variations on this theme, but for purposes of comparing scheme assembly methods between predecessor and numerical multifunction technologies, this will be the example.

Regardless of the assembly method, predecessor technologies start with a group of single function protection products, control switches, auxiliary relays, meters, etc. that must be wired together point by point to complete the protection scheme envisioned by the engineer.

There are literally thousands of wire lugged terminations involved with the assembly that will require detailed wire checking and operational checking prior to placing the panel in service. When the panel is placed in service, power system readings will be taken as a final verification that the scheme (panel) has been properly integrated with its associated ancillary substation equipment. This is a labor-intensive process, but if the user is not diligent in following established test and checkout procedures, protection reliability will suffer. This is a time-tested method of providing high levels of protection reliability with predecessor technologies.

Multifunction products can be panel or rack mounted and require less panel and control house space. Because they are three-phase, numeric devices, all protection functions are in one box and are enabled or disabled through programming. There is no sensing or control interconnect wiring between phases and ground. All internal control wiring: input to protection element, protection element to timer, and on to the output relays, is accomplished through programming.

External wiring of the multifunction system consists of integrating the product with its associated ancillary substation equipment, a set of current and potential test switches, and perhaps several lights and control switches. Virtual switches included in most multifunction devices can replace the latter. This is similar to other technologies but requires less overall wiring. Also, a full complement of metering, SER, and oscillography eliminate the wiring associated with panel metering, transducers, and various types of external fault recording sensors. Test and checkout time is reduced as a result of less wiring. Most multifunction products provide continuous monitoring and real time metering that can be used to simplify and reduce commissioning time.

A major protection reliability factor discussed in a later section is the method used for commissioning. If traditional predecessor methods of commissioning are used on multifunction systems, problems can be missed. To take full advantage of the inherent protection reliability found in multifunction systems, computer driven dynamic or system testing techniques should be used.

Technology Observations Associated with Assembly Methods
As with ancillary equipment, there is a wide separation in degree of impact associated with assembly methods. With careful implementation, assembly methods can result in a dramatic improvement in overall protection reliability. The following observations concerning the assembly methods of predecessor and multifunction technologies can be made:

- Traditional testing and commissioning procedures used by most companies were designed for predecessor technologies.

- Traditional testing and commissioning procedures do not provide complete verification of multifunction "system functionality".

- Multifunction technology costs less, requires less space, requires less wiring, and meets multiple protection applications in one box.

- Traditional non-protection features such as metering, fault recording, SER, and control switches are included in the multifunction package, reducing opportunities for wiring error.

- It is difficult to modify or add protection functionality to predecessor product schemes. A protection element can be added to a multifunction protection system by turning it (the element) on.

- Multifunction control schemes are easily replicated by saving the program and using in other applications.

Installation and Commissioning Tests
The only thing standing between a perfectly engineered protection system and a perfectly performing protection system is the perfect installation and commissioning test. These tests are the last opportunity to find and eliminate potential reliability problems before the equipment is permanently placed in service.

Installation and commissioning of predecessor technologies follow long established procedures, tests, and guidelines for insuring proper protection system operation. These might include:
- wire checking the relay panel
- tightening terminations and inspecting single function relays
- inspecting the relay case to verify operation of current circuit shorts
- applying operational settings and verifying through calibration tests

- talking (ring out) and tagging wires external to the relay panel
- meggering all incoming wires
- loading current circuits
- ratioing and polarity checking CT's
- verifying voltage ratios and connections, checking rotation of voltage sources
- conducting thorough operational checks
- taking in service phase meter readings
- documenting results for future comparison

Most utilities also require or at least suggest these tests for large customers connecting to the utility grid. Installation and commissioning tests have evolved over the years and allow the user of predecessor technologies to get the maximum protection reliability allowed by the technology. Note, however, that there is no overall system test to verify aggregate operation of protection elements used in predecessor schemes. Also, most utilities have several "unexplained" operations a year that may be attributable to hidden system performance bugs not identified by static testing techniques.

The same tests used for predecessor technologies have been used with apparent success for installation and commissioning of multifunction systems, although many in the industry feel that:

- traditional calibration testing of each phase of each protection element is not required
- traditional static calibration and operational tests do not provide complete system performance verification of multifunction protection software

Verifying operational settings by inspection is gaining acceptance over traditional calibration methods because a single application of three-phase test quantities can verify A/D performance by comparing applied values to values displayed by the relay's internal metering. The same A/Ds are used for the protection elements, thereby eliminating the need for individual pickup tests. Also, traditional testing may require enabling and disabling protection elements to isolate the one under test, providing opportunity for inadvertently leaving an element off. Trip time test of at least one protection element may be required by the user; however, dynamic "system" tests provide better performance information and ensure that the proper protection elements are enabled.

One approach to dynamic system testing is state simulation where normal operating conditions from a computer controlled test set are applied to the relay and, at a predetermined point, automatically switched to a pre-set fault condition. Performance results are documented by the test computer and can be compared to the data recorded by the relay's internal sequential events and oscillography.

Analysis of data recorded for several different fault conditions provides a more complete representation of how the product will respond to real world conditions. Dynamic testing helps the user of multifunction products derive maximum protection reliability from the technology.

Documentation and record keeping is easier with numerical multifunction technology because the programmed logic and operational settings are saved in the same digital record. No separate, manual record keeping is required.

Technology Observations Associated with Installation and Commissioning Tests
Installation and commissioning testing is the last opportunity during a project to find and eliminate problems that could have a negative impact on protection reliability. The degree of protection reliability impact associated with these tests is about the same for both technologies. Therefore, the following technology observations can be made:

- Because dynamic “system” tests are less practical for predecessor technologies, occasional unexplained misoperations could result from hidden bugs, impacting long-term protection reliability.

- With either technology, poor installation and commissioning tests could have an immediate impact on protection reliability.

- Traditional minimum pickup and timing tests could have a negative impact on multi function reliability, resulting from failure to re-enable a protection element that was turned off during testing of another element.

- Dynamic “system” testing of multifunction products provides the best measure of performance by subjecting the relay to simulated conditions that are more representative of real world operating conditions. Therefore, it can have a positive effect on protection reliability.

- Documentation and record keeping is an integrated part of multifunction systems. Fault records, logic, and operational settings can be saved to a file and manipulated just like another digital record (print, email, etc.).

Electrical Environment
This section will discuss the electrical environment in which protection products have to perform, and its impact on protection reliability. Beginning with electromechanical devices, their design and construction were based on large coils, capacitors, resistors and good insulation. As a result, electromechanical devices were inherently immune to electrical environment conditions as described in IEEE standards C37.90, 90.1, 90.2, and 90.3. Predecessor protection schemes comprised of these products have operated for many decades in the hostile substation environment with little or no problem with surge withstand, fast transient, radio frequency interference (RFI) or electrostatic discharge.

The original solid state products produced in the late 60's and early 70's, however, had many problems associated with the electrical environment and were quite susceptible to misoperation and failure resulting from surges, fast transients, EMI, and RFI. The positive side of early problems was the tremendous research effort on the part of manufacturers and users that went into identifying and correcting the problems. The industry in general quickly learned new grounding, shielding, and isolation techniques including proximity of cable runs to transient producing primary equipment such as air break switches.

Most importantly, the resulting collaboration of manufacturers and users has enhanced (created) the IEEE C37.90 series of standards for utility grade protection. These efforts have allowed for several generations of solid state and numeric products that provide excellent protection reliability in a very hostile electrical environment. Present and future generations of computerized protection systems will also benefit from ongoing efforts to enhance existing standards and continue the improvement process by adding relevant standards such as the draft standard C37.90.3, Electrostatic Discharge Tests for Protective Relays.

Technology Observations Associated with Electrical Environment
Based on the stringent standards for which static component and numerical multifunction systems are designed, built, and tested, the degree of impact of the electrical environment is nearly equal between predecessor and multifunction technologies. The following observations can be made:

- Electromechanical products were inherently immune to electrical environment problems as defined.

- Utility grade analog solid state and microprocessor-based protection products built to conform to IEEE C37.90 series of standards provide excellent protection reliability.

- Utility grade numeric multifunction protection products built to conform to IEEE C37.90 series of standards provide excellent protection reliability.

- With equal environmental performance, multifunction products offer improved protection reliability (self-checking, SER, Oscillography, Communicating) over predecessor technologies.

Maintenance Programs
Predecessor technologies require regular maintenance to ensure protection reliability. Settings drift, contact corrosion, and thermal aging create the potential for incorrect operations, thereby reducing overall protection reliability. It is well known in the industry that there is a direct correlation between maintenance interval and the number and severity of problems. The tough part is finding an interval that balances cost and reliability. Referring to Figure 4, the ideal maintenance interval is the point on the curve just prior to turning up.

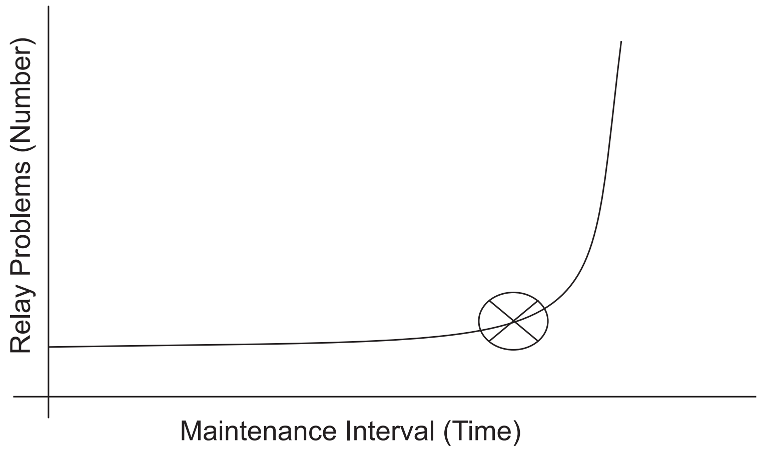

Figure 4: Maintenance Interval vs. Relay Problems

Intervals prior to that are a waste of money and beyond that get the maintenance supervisor fired.

In most utilities, the ideal point varies based on type of protection (OC, Distance, etc.) and manufacturer. The point will also vary from one utility to another for the same type of manufacturer's protection because of individual construction methods, type of enclosure, and geography.

In today's competitive environment, there is more pressure than ever to lengthen maintenance intervals and keep cost down. Maintenance managers must guard against going too far, or the costs associated with coming back will far outweigh any perceived savings.

Numerical multifunction products, on the other hand, require little or no maintenance. Self-checking, automatic removal from service, user defined major and minor alarms, and remote communications has eliminated many of the historical reasons for routine maintenance. Coupled with that is the knowledge that numeric systems do not deteriorate or drift as does an analog device. Computers were built to continuously run numeric calculations based on a specific program.

Most manufacturers recommend that an occasional trip test be performed if a fault operation has not exercised the system in a user-defined interval. If a user requires scheduled maintenance, a simple comparison of the operational settings found on the relay versus the commissioning records will verify that no settings have been changed. Analysis of fault and event data for normal operations provides the best feedback on product performance.

As the industry continues to gain experience with multifunction technologies, many have discovered that traditional routine maintenance actually lowers protection reliability. As discussed under Installation and Commissioning, protection element outputs are "internally wired" through programming to an output relay. Multiple protection functions will be connected to the same output relay, requiring that elements be defeated during individual element pickup and timing test, creating the opportunity for leaving an element turned off. If routine maintenance is required, it should be accomplished through dynamic testing as described under Installation and Commissioning.

Technology Observations Associated with Maintenance Programs
As is typical in most industries, maintenance is the first thing reduced or eliminated during periods of tight money. With the advent of deregulation in the utility industry, competitive pressures have created a sustained period of tight money, forcing utility managers to think more like their counterparts in other industries. Performance based maintenance incorporating continuous monitoring with automated analysis systems provides the most bang for the buck. "Maintenance Programs" is the only reliability factor where the degree of influence can actually go negative. The following observations can be made:

- Predecessor technologies require regular maintenance to keep protection reliability at acceptable levels.

- Effective predecessor maintenance programs require substantially more people and money than multifunction programs.

- Self-checking with automatic diagnostic routines eliminates most of the reasons for routine maintenance and removes the product from service before causing an incorrect operation.

- Remote communications allows for immediate notification of maintenance personnel when a protection product requires service.

- Regular review of remotely downloaded operations data (oscillography and SER) is much more cost effective than sending personnel to the substation to perform operational tests.

- Using traditional static testing techniques on multifunction products may lower protection reliability. If maintenance is required, use dynamic testing methods.

Record Keeping
Record keeping is an often forgotten area that can impact protection reliability just as much as other factors. During maintenance, or when troubleshooting a questionable operation, it is critical that the "as built" drawings and "as left" settings are documented exactly as commissioned. When starting a project to modify or add capacity to an existing station, the documents of record are the starting point. A weak record keeping

program results in many unnecessary hours of research and creates the potential for design errors that will impact protection reliability.

Predecessor technology record keeping can be automated to a point, including operational settings data files and elementary and wiring diagrams generated and stored with computer aided design and drafting systems. Other than visual inspection, however, the products themselves have no mechanism for telling the user what settings are on the relay. Operational settings have to be applied manually; "as found" and as "left settings" have to be manually entered into the database, again creating opportunities for error.

With numerical multifunction technology, a single file for operational settings and internal control logic is created off-line by the project engineer (not connected to relay). Data from fault study files can be electronically merged with the setting file, eliminating manual entries that might lead to errors. Control logic drawings are created using data from the same file. The settings file can then be delivered to the field via conventional methods such as email, on a floppy disk, on a CD, or on the hard drive of a portable computer. File production and record keeping using multifunction technologies is less labor intensive and requires less time to establish and maintain.

In the field, the file is uploaded to the relay, eliminating the manual steps involved with applying settings to predecessor technologies. If changes are required, they are made in the file and again uploaded to the relay. Setting changes can also be made on the relay and saved back to the settings file. In any event, the settings file becomes the document of record and should become a permanent part of the record keeping program.

Future jobs will depend on the "as left" records for a starting point. An effective record keeping program helps to ensure high levels of long-term protection reliability.

Technology Observations Associated with Record Keeping
The following observations between predecessor and numerical multifunction technologies can be made:

- There is no interaction between the settings on the relay and the setting record with predecessor technologies.

- Record keeping and documentation is more time consuming and labor intensive with predecessor technologies than with multifunction.

- There are more settings to deal with in numerical multifunction systems. For example, schematics of predecessor systems will be setting parameters in a numerical multifunction system. This mitigates the numerical multifunction advantage to some degree.

- Numerical multifunction products are computers, providing most of the file management benefits inherent to modern computer systems.

- With multifunction products, applying operational and logic settings to the relay consists of uploading a file, thereby saving time and eliminating errors.

Operations Analysis Programs

Effective operations analysis is the hub of a protection reliability, providing feedback required to adjust individual reliability factors such as philosophy, design standards, maintenance, etc. No matter what mistakes or oversimplifications may be made related to the rest of the reliability factors, analysis of actual operation of the protective systems in service can “close the loop” - allowing corrections to take place after or even before a misoperation occurs. With limited data on actual performance of protection systems, continuous improvement of protection reliability will be limited.

Predecessor technologies were limited in their capacity to collect and store operations data for future analysis. Only the most important transmission installations (usually lines from power stations or EHV lines) could justify the cost of installing fault recording equipment. At best, these products were somewhat temperamental and required more maintenance than the systems they were policing. However, the data they provided was excellent and gave users their first real look at how protection systems were performing under actual fault conditions and providing feedback for improving protection reliability.

Advancements in technology have lowered the cost of stand-alone fault and sequential events equipment to a point that most network transmission applications can justify the cost. However, some transmission and generation, and most distribution protection systems will never be able to justify the additional costs associated with stand-alone systems such as wiring individual circuit currents, voltages, controls, and sensors for sequential events input. The introduction of numerical multifunction protection technology was the first step in providing cost-effective recording capability for operations analysis of the entire power system.

Fault locating (distance to fault), oscillography, and sequential events along with fault summary reports are an integrated part of multifunction protection systems. Coupled with remote communications, these features provide a powerful, cost-effective tool for analyzing system performance. With human and distribution resources being stretched farther than ever before in most utilities, fast assessment and restoration after service interruptions is essential to maintaining high customer service levels, and perhaps in the near future, maintaining financial control of a “Distribution Company”.

Technology Observations Associated with Operations Analysis

Operations analysis provides the feedback required for fast assessment and restoration of service after a system disturbance. It also provides the feedback vital to continuous improvement of protection reliability. The following observations can be made concerning the differences between predecessor and multifunction technologies:

- With predecessor technologies, the cost of equipment associated with operations and analysis could only be justified for the most critical parts of the transmission system.

- Retrieval of data and equipment maintenance were time consuming, labor intensive efforts for recording equipment associated with predecessor technologies.

- With few exceptions, the resolution provided by multifunction fault and event recording elements is sufficient for effective analysis of most system disturbances.

- Fault and event recording capabilities are enhanced with each new generation of multifunction products.

- Integrated fault and event recording features found in multifunction products provide cost-effective analysis for all parts of the power system.

CONCLUSION

Competitive pressures brought on by deregulation have forced protection organizations to re-evaluate the way they do business. One major change in most companies has been the use of fully numerical multifunction protective systems. As stated in the introduction, the purpose of this paper has been to evaluate the reliability of numerical multifunction protection systems against predecessor technologies. Are multifunction systems of today providing long-term protection reliability at least equivalent to their counterparts?

Multifunction products have proven they can perform as well as their predecessors in a hostile electrical environment. As further evidence of product confidence and durability, unprecedented warranties are being offered by the manufacturers. Multifunction products are smaller, more flexible, offer increased functionality, and offer file management capabilities found in any computer, all at a fraction of predecessor costs.

After a thorough discussion of a select group of protection reliability factors, the authors have concluded the following:

- To realize the maximum protection reliability allowed by predecessor technologies, the user should have a detailed understanding of the products and must commit to a program of regular maintenance to keep reliability at that maximum.

- To realize the maximum protection reliability allowed by multifunction technologies, the user should have a detailed understanding of the products and be proficient in the use of personal computers.

- Assuming equal levels of product knowledge, the maximum protection reliability allowed by multifunction technology is higher than that of predecessor technologies as a result of self-testing, automatic diagnostics, fault recording, and remote communications.

By whatever process, most electric utilities have reached the same conclusion, and at least one has performed calculations to determine what effect the "rate of replacement" could have on long-term protection reliability. These calculations are shown in the following table:

Existing Predecessor T&D Relays	Existing Relays	No. of Relays Replaced with each Digital	Number of Digital Relays Required	Replacement Rate per Year	Years to Accomplish
Transmission Line Protection	6918	6	1153	20	58
Distribution plus Breaker Reclosing	8703	5	1741	20	87
Bus	3527	3	1176	10	118
Transformer	8962	3	2987	15	199
Capacitor	543	3	181	10	18
Reactor	34	3	11	10	1
Breaker Failure SBC	588	1	588	20	29
Breaker Failure Other	671	2	336	10	34
Breaker Reclosing Transmission	2306	2	1153	20	58
TOTAL	**32252**		**9325**	**135**	**69**

Referring to this table, the data indicates that even with an aggressive annual replacement rate (135/year), it will take **70 years** to replace all the predecessor relays with modern numeric systems. This is well beyond the life expectancy of predecessor systems and could have a significant impact on long-term protection reliability.

A final point for comparing the two technologies based on their respective levels of protection reliability:

If the history of our industry could be altered, making the degree of reliability provided by multifunction systems commonplace, would a predecessor system ever be considered for installation?

BIOGRAPHICAL INFORMATION

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Michael Thompson served nearly 15 years at Central Illinois Public Service Co. where he worked in distribution and substation field operations before taking over responsibility for system protection engineering. He received a BS, Magna Cum Laude from Bradley University in 1981 and an MBA from Eastern Illinois University in 1991. During his years at Bradley University, Mike was involved in the cooperative education program and worked in electrical engineering and maintenance at a large steel and wire products mill. Mike is Senior Product and Market Manager for the Protection and Control Product Line at Basler Electric. Mr. Thompson is a member of the IEEE.

REFERENCES:

[1] IEEE Standard C37.113-1999 Guide for Protective Relay Applications to Transmission Lines

[2] Protective Relaying Principles and Applications, J. Lewis Blackburn, Marcel Dekker, Inc., New York.

[3] IEEE Guides and Standards for Protective Relaying Systems 1995 Edition, Published by The Institute of Electrical and Electronics Engineers, Inc.

[4] Applied Protective Relaying, Copyright 1976, Westinghouse Electric Corporation, Relay-Instrument Division, Newark, N. J. 07101

[5] The Art and Science of Protective Relaying, Copyright 1964 The General Electric Co., Switchgear Department, Philadelphia, PA

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