Life Cycle Considerations for Microprocessor Relays

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Abstract

With proper maintenance, users of older technology electromechanical (EM) relays have considered 50+ years as the normal life cycle for these devices. When applying microprocessor relays new considerations must be taken into account for lifecycle expectations. This paper proposes to examine microprocessor relay life cycle and the sometimes unexpected costs associated with their use.

During the course of microprocessor relay life there are inherent costs associated with the maintenance of these devices which are generally not considered but are critical to the performance of the device and the intended application.

To be examined is non-planned mission critical updates and product notifications. Microprocessor relay challenges from a manufacturer and user perspective will also be examined.

Consideration of the costs associated with extending the service duty of these devices past their intended designed life will be discussed as well as a case study.

Introduction

The very first electromechanical induction disk protective relay was introduced by Westinghouse Company in 1902 and was designed to replace the simple yet effective solenoid and core type protective devices. Upon invention of the transistor we once again saw an evolutionary step in protective relay design to include multifunction relays. These were referred to as static (no moving parts) or solid state relays. A smaller step in technology further enhanced static relays with the introduction of analog operational amplifiers (op-amps) and discrete digital gates. Complementary Metal Oxide Semiconductor (CMOS) technologies allowed for lower power consumption over the stable yet power hungry 74LS digital logic. When combined, these later technologies provided relay manufacturers the means to design multifunction relays capable of sub cycle secure tripping.

The first microprocessor was introduced in 1971 and managed to squeeze 2300 transistors onto a single chip. At this point in relay design history, static and electromechanical relays were still the only technologies being utilized by relay manufacturers. As microprocessors evolved into 4 and 8 bit word structures, relay manufactures began to realize the potential of these technologies and began to develop multifunction relays based on the Intel 80xx and Motorola 6300 8 bit microprocessors. Figure 1 shows one of these devices developed on an 8 bit microprocessor platform.

Figure 1 – 8 Bit Microprocessor Relay Circa 1986

With the use of microprocessor technology, relays were now capable of not only providing protection but also monitoring, control and fault location functions. Communications in the American Standard Code for Information Interchange (ASCII) provided the means to remotely monitor, control and interrogate these devices. The use of microprocessors in relay design was truly a major evolutionary step in relay protection and control but these devices also faced many challenges and still do today. The purpose of this paper is to examine some of these challenges from a manufacturer as well as a user's point of view.

Manufacturer Design Considerations

As with electromechanical and static type relays, design considerations are given to microprocessor relays to enhance product life. Many of the principles applied to the electromechanical and static relay designs have carried over to microprocessor relays with some unique additions and subtractions. One of the design considerations for electromechanical relays was in the movement of the internal parts (disk, plunger, hinged armature) associated with accurate and reliable tripping. An induction disk relay uses a disk that rotates on a pin and jewel set. Over time, these pieces collected dust, oil and other contaminants from the surrounding environment. It was understood by the users that these devices required periodic maintenance to assure proper operation. Improper or lack of maintenance on these devices would cause the device timing to be compromised. In a power system where coordination was

required, the improper maintenance could cause a failure to coordinate. Manufacturers specified periodic maintenance procedures and schedules for these devices to assure their proper operation. Periodic maintenance on electromechanical relays was the norm and the “nature of the beast”. Typically the design of these devices was such that the electromagnetic components were manufactured “in-house” where control on materials and quality was the sole responsibility of the manufacturer. This becomes a consideration when designing static and microprocessor relays as we will further examine in the text below.

Engineering Design Considerations and Selection of Components

Static and microprocessor relays suffer from the same fate when it comes to component selection. From a design standpoint, engineers are tasked with designing for manufacturability and longevity. This means that considerations are given to all components selected to assure availability after the release to manufacturing. Longevity not only means that the design is expected to last for X period of years but that the original components selected are available for manufacture for many years after the release. It is rarely the case that a microprocessor relay design will stay the course without any need for design changes because of component availability but this is always part of the design criteria placed on the development engineering team.

With the constant frequent changes in the semiconductor industries technology, manufacturers are constantly faced with component life cycle issues. In the grand scheme of things, relay manufacturers purchase very low volumes of components as compared to personal computer and consumer electronics companies. One of the largest driving forces in semiconductor technological advancement is the cell phone industry continuous drive for smaller, faster, more powerful and more efficient devices. This leaves the relay manufacturer little to no influence on a component manufacturer when the decision is made to discontinue a component. The only choice in this case is to purchase components on a last time buy basis or consider changing the design of the product to introduce a new component. The issue with the later choice is that many times when this done, the relay must undergo retesting to industry standards to assure that there is no change to product reliability. This can be a costly process to a manufacturer. Generally speaking this has not been an issue with microprocessors themselves since the industrial market substantially lags the consumer electronics market and there is sufficient volume for semiconductor manufactures to justify continued production of microprocessors long after being abandoned by consumer electronics companies.

One such problem that has risen in the past several years is the introduction of “counterfeit components” to the semiconductor marketplace. These components have the same look and markings as their OEM counterparts but may come from substandard manufacturing processes that render them prone to failure inside the relay design criteria. It is critical for a manufacturer to perform component quality inspections and periodic type testing especially on older relay design where this could become more of an issue.

Design Life

Every relay ever designed has an expected life span. No one technology will last indefinitely. Given the history of the protective relay, the microprocessor design is a relative new-comer. Users have become accustomed to the electromechanical relays ability to last 50 plus years and this has strained the expectations of microprocessor based relays. When microprocessor relays began to be applied in the mid 1980’s, little to no consideration was given to end-of-life. Today we now find ourselves in the 30 year mark for the first generation microprocessor relays. While many are still operational, we are seeing that the lifecycle of the microprocessor relay has reached its mark. At end-of-life, the microprocessor relay can become a challenge to maintain.

We have already discussed some of the component challenges over the relay life but what are other factors that affect life? In general engineering terms, the simpler the device the longer it will last. How many of you still have electromechanical relays on your system that are 60 to 70 plus years old and still functioning as designed? These were simple single purpose devices whose life cycle depended solely on

environment and proper maintenance. Aging effects of conductor insulation are the main reasons to replace these devices.

Microprocessor relays face many challenges that their electromechanical counterparts did not. Some of these can include:

Thermal: Microprocessor relays utilize DC to DC converter power supplies that generate heat. Other solid state components such as RAM, ROM and the microprocessor itself will generate some heat. Heat is the number one enemy of components used in any digital device and it is a challenge for the design engineer when considering components and circuit board layout. Severe cold temperatures also have an adverse effect on relay life. Electrolytic capacitors are known to degrade much faster at temperature extremes than they would at ambient temperatures of 23 degrees C. Designers of switch mode power supplies have made great strides in design by using parallel low equivalent series resistance (ESR) and Tantalum type capacitors. At ambient temperatures of 23 degrees C, the case study below will show that a life span of 17+ years can be expected when using older technologies. 20+ years can be expected from newer generation switching converters.

Vibration: In an industrial environment or power generation plant vibration is a consideration to relay life. The constant mechanical harmonics produced by rotating machinery can cause solder joints and crimp connections to fail sooner than they would in a substation.

Battery Backed-up RAM: Generally not in use today, early microprocessor relays used a small "nickel cell" battery to hold data in RAM when power was lost. These batteries, just like in consumer electronics had an expected life span. Maintenance was required to periodically replace them.

NVRAM cycles: While generally not a concern for microprocessor lifecycle, it is worth mentioning here. Nonvolatile RAM (NVRAM) sometimes referred to as "Flash Memory" has a finite number of write cycles before it degrades or fails. NVRAM is used where data needs to be stored and held even in the case of power failure. Usually relay targets, event data and oscillographic data are stored here. In the case of newer logic based relays the state of the relay logic may also be held in NVRAM. Some consumer electronics NVRAM can only withstand 100,000 write cycles before the memory begins to deteriorate.

Contact Cycles: Make, break and carry are terms used by discrete relay designers to specify the current capability of the contacts internal to the relay. During the engineering process, designers give consideration to the required make, break and carry currents of the microprocessor relay. These contacts have a certain life span and number of operations before they will need to be replaced. In a medium voltage relay such as a recloser control, the contact operations will need to be considered much more than a high voltage relay due to the fact that the recloser control will operate many more times than its HV equivalent relay. While generally not seen as an issue, this topic is addressed for consideration by the user.

Lightning Strikes: Although manufacturers take great precautions during the design phase to minimize the effects of surge damage due to lightning strikes, a severe strike may degrade relay power supply surge protection circuitry to the point of premature failure. Figure 2 shows a Metal Oxide Varistor (MOV) that has successfully protected a circuit during a severe lightning strike. The MOV was the sacrificial short circuit to the surge. Although the power supply continued to function, the MOV has degraded such that any subsequent severe strike would most likely render the relay power supply inoperable. In the case of a grounded substation this is not usually an issue. Direct pole strikes on reclosers are more of a concern.

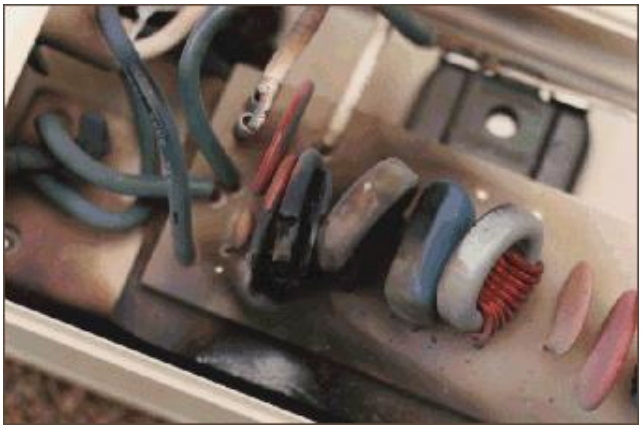

Figure 2 – Example of MOV Failure[i]

Considerations during the design process should also be given to engineering computing power and memory such that there is significant bandwidth available for future enhancements that may be required by users or regulatory agencies. Failure to consider this will ultimately shorten the expected product life cycle and require unplanned monetary commitments to replace relays prematurely. From a manufacturer's standpoint, this is a difficult process. How much computing power is enough? How many samples per cycle and memory is enough? Will we move from simple 16 samples per cycle for protection or will we be required to perform complex waveform analysis and power quality analysis requiring 128+ samples per cycle? In many cases, these relays already exist. Designing a product to perform these tasks is not a difficult one but comes at a price. Economics versus computing power and engineering resources is always a challenge.

Firmware

Up to this point the focus has been on microprocessor relay hardware. The selection of components is critical to maximize a problem free life, but what about relay firmware? Firmware is the relay programming or instructions as coded by the engineers to perform the tasks to which the relay was designed. These instructions are not accessible to the user. Software is that which the user has control. Settings, relay logic and configuration are done with software. The complexity of this coding is ever increasing due to the number of functions now available in microprocessor relays. The challenge for the relay designer is the ability to implement these functions in such a way that not only do they function as designed but also that they operate correctly for scenarios outside of the intended use. It is virtually impossible to account for every-and-all scenarios when testing relay functionality and firmware. With multifunction relays touting hundreds of settings and thousands of possible setting combinations the designer could take several years to adopt a test plan to cover all of the possibilities and even then the "what if" list is most likely not complete. When an issue arises in service that was not intended when the firmware was coded, the manufacturer must address the issue in two separate ways. In either case the user may not have accounted for the costs associated with these updates and frequency of these updates when purchasing the relay. We will examine those costs in a later section.

1. Non-critical firmware updates: This is the case where a feature or function may be added or a security update is done to accommodate changes in NERC CIP requirement. For example; a webserver update. These firmware updates are not critical to the protection and control scheme. These remain fully functional and secure. It is up to the user to choose whether or not to perform the update.

2. Critical firmware updates: In a case where the relay will fail to function as intended and expected, the manufacturer will issue a service advisory letter to the user recommending the update be performed. This may be a false trip, fail to trip, hardware issue or other function that is mission critical. It is then the user's responsibility to perform the update and test for the scenario

presented as the issue. The frequency of these updates can be very costly and resource draining to a user depending on the application and number of relays installed. This is why it is so critical for a manufacturer to perform many months of type testing to reduce the possibility of any critical firmware updates. It is the user's responsibility when selecting a supplier to evaluate the number of mission critical updates that have been required since release to market and to determine if these are acceptable.

Looking at the impact of either critical or non-critical firmware updates from the perspective of a user, the impact is similar when it comes to cost of implementing the changes. The main differences are that with a non-critical firmware update users can typically choose whether or not apply the changes to the relay. This can be done on a case-by-case basis as the functionality may or may not be needed. Users can also implement the changes when they can comfortably be fit into scheduled work. Critical firmware updates will have a much higher sense of urgency as the changes are needed to avoid a potential problem with the relay that could result in a mis-operation if a certain set of conditions is met.

In some cases it may be possible to skip implementing a critical firmware update if it is certain that the problematic conditions will not occur in a specific application. This not considered a best practice. For instance, if the update only affects the 67 directional overcurrent function, but all of the distribution feeder relay schemes only use non-directional overcurrent protection, the user could opt not to apply the update. Applying the critical firmware update on a relaxed schedule in between other higher priority work projects, perhaps over a 5 year cycle, would be more prudent than to skip it completely though. Choosing not to perform the critical update is a poor choice because you do not know if your protection scheme may ever need to change. Failing to perform the update now, could be setting a trap for someone else to find later. Choosing to apply the updates on select relays only will ultimately leave to question later which devises were updated.

To understand the possible cost a user could face if a firmware update is needed to a group of relays, consider an example where a company has 100 of one type of microprocessor relay and the manufacturer releases a critical firmware update to correct a problem that could delay the trip output by 30 cycles in some cases. This issue would have a high probability of causing over-trips to the transformer protection, which would adversely affect the company's reliability metrics, reduce the customer satisfaction rating, and result in lost revenue. If it costs approximately $2000 to roll a truck and have a relay technician perform the upgrade, then that would be a costly hit against the companies operating budget and tie up valuable relay technician time. Assuming the user was able to realize some savings by performing two upgrades per truck roll out, the cost would still be a $100,000 impact against the operating budget. This would also result in a lot of other deferred work while the relay technicians are busy with the critical firmware updates. This is a very simple example, but it illustrates that the costs associated with critical and non-critical firmware updates can add up quickly. Even if your company is lucky enough to have invested in protection schemes with backup relaying that could allow you to avoid having to switch load off of circuits, thus allowing you to perform four relay updates in a day, the cost would still be $50,000 dollars and 25 lost days of relay technician work.

Microprocessor Relay Maintenance Requirements

The North American Electric Reliability Corporation (NERC) Standard PRC-005-2 states that the maximum maintenance interval for protective relays on elements of the Bulk Electric System (BES) is six years if the relay is unmonitored and 12 years if it is monitored.[ii] . One of the high value benefits of microprocessor relays over the older electromechanical relays is the ability to cut the required maintenance in half, provided the requirements for monitoring are met, which includes alarming for failure of the relay self-check function. The maintenance itself is less for microprocessor relays, as there are no user serviceable components like with an electromechanical relay. If a microprocessor relay fails during the testing to verify correct operation of its inputs and outputs, then it is simply replaced and sent back to the manufacturer for repair or replacement. This simplified preventive maintenance applies to non-BES relays as well. Typically non-BES relays are performed on a 12 year cycle similar to that of the monitored BES relays, but the interval could vary depending on local or company governing guidelines.

Think about this 12 year maintenance cycle for a typical non-BES distribution system protection relay. Microprocessor relays are installed, checked once in twelve years for correct operation, and then will reach their end-of-life before reaching their next required maintenance interval. That adds up to some substantial cost savings. Looking at this cycle from a cost perspective, if a user waits too long to replace aging relays that are beyond their advertised end-of-life, they will incur the costs of an added maintenance cycle in addition to the possibility of negatively impacting reliability metrics.

Service Life versus Supported Life

This paper will define two terms. Service Life and Supported Life. Definitions:

Service Life: The Service Life is the time that the device can be reasonably expected to function before failure. This will also be covered below in the Mean Time Before Failure (MTBF) discussion. The in-service life of a relay is what we are calling "life cycle". It is not a definition of the exact life of a product but more, does the product perform its designed task for a period of time as defined by the manufacturer.

Supported Life: Supported life is the industry driven period of time that the technology can be expected to be supported by the manufacturer. Supported life means that the manufacturer can continue to provide new replacement units, repair failed units and will continue to offer product updates as required. Factors discussed in a previous section will drive the end of supported life not necessarily having to do with the manufactures desire to discontinue said product. A user may determine that when supported life ends, the service life should also be considered. Once supported life ends, the natural result will be an increased user cost to maintain the product and the need for replacement. In the case study below, we will look at what occurs when relays are pushed past both their supported life as well as their service life.

Manufacturer End-of-Life

Manufacturers determine end-of-life in the following ways:

1. If a product is specified and its revenue stream is healthy, a manufacturer will accommodate engineered changes to the product within a certain reasonable time period. This period can be in the 15-20 year range. By that time, new product releases and customer demands for higher functioning devices will naturally drive a legacy product to end of production. In the consumer electronics industry, this trend is only 1-2 years. What we have seen is interesting in that the older electromechanical relays have held their own from a market share perspective. These devices have their place in 1E (nuclear) applications and are still used in heavy industrial and back up relay applications where simplicity and reliability are considered.

2. Serviceability and ability to manufacture. As discussed earlier, component availability can become an issue as semiconductor manufacturers cease production on components originally specified in the relay design. Component availability is defined as the ability of a manufacturer to procure a part or parts within a reasonable amount of time. If this is not the case then this warrants redesign which may be deemed acceptable if the product has a healthy revenue stream. Remember that natural product life will be driven by a requirement for increased functionality. Figure 3 shows a graphical representation of returns data collected from a utility with a large install base for years 1986 to 2007. We clearly see the component availability in percent versus the number of units returned for each year. This does not mean that components are no longer available but that lead times have become unacceptable or that multiple sources may have decreased to only a single source. The data represented by the blue legend is the number of units returned for repair. We see a peak at the 17 year mark and then as older relays get replaced with newer technology, the returned units taper off. We also see that the number of units sold tapers off after a 10 year period due to the introduction of newer technology relays.

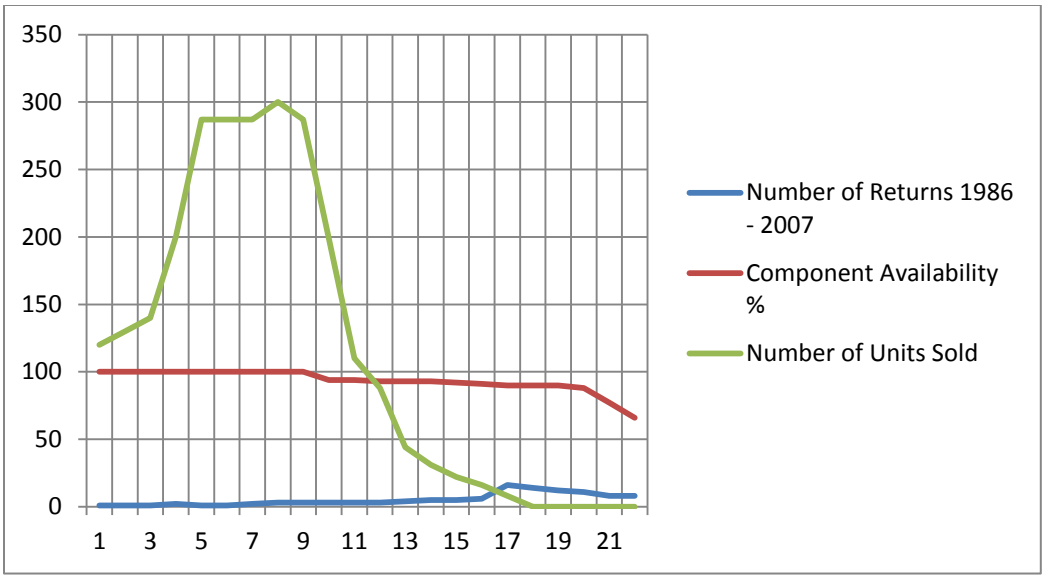

Figure 3 - Number of Returns and Availability of Components from 1986 to 2007

User Considerations on End-of-Life

The end-of-life of a microprocessor relay could be driven by a proactive replacement philosophy, but more often it is driven by an increasing failure rate being experienced in a certain type or vintage of relay. Ideally, a user should recognize the need to stay ahead of this failure rate to avoid suffering a significant reduction in reliability metrics and the financial costs that accompany additional unplanned customer outages. This plan will then shorten the effective end-of-life for that type of relay to some optimum value that gets the most return out of the initial investment. This proactive approach replaces the relay without running it to failure. For the relay type shown in Figure 3 above, the 15 year mark is a good place to set the effective relay end-of-life. At that point, the advertised microprocessor relay life has been exceeded and component availability and associated lead time is dropping. In practice, users would probably not know the manufacturer is having increasing difficulty in sourcing components, but the manufacturer would probably discontinue the relay as the revenue stream decreases and as newer technology products are available. By starting a relay replacement initiative at the 15 year mark, a user would run a better chance of staying ahead of the relay failure rate increase at year 17, and since each working relay that is replaced becomes an additional spare, a user could maintain sufficient spares to complete the relay replacement as scheduled work and utilize the pool of spares for rapid replacement of any failed relays until they can also be replaced per the scheduled work.

End-of-Life Options

1. Last Time Buy. When a product is deemed by a manufacturer to be no longer viable for reasons shown in 2 above, a last time buy is announced. Manufacturers need to consider warranty terms for last time buy products since the reasons behind this may be component availability. Components on a limited supply need to be sourced such that a supply is available for repair support for the warranty period and beyond. Users should consider replacing any last time buy product with newer technologies so that there is assurance of supported life (discussed earlier) beyond any warranty period.

2. Engineered Solutions. A user may opt to re-engineer a relay or switchgear panel to replace older microprocessor relays. This may include the replacement of the entire bay including the breaker or replacement of the relay only. A replacement relay should be selected with considerations for future protection needs or compliance concerns in mind. For example, a simple 50/51 feeder relay is replaced. Consideration should be given to the possibility of future load shedding

requirements. The small cost of adding the voltage inputs and functions in the new relay will greatly outweigh the cost of re-engineering at a later time. “Future proofing” is the term used to assure that a new relay installed is a viable solution for its entire service life. Communications and automation are also considerations when re-engineering panels for future needs.

3. Form Fit / Wire-Alike Solution. There may be some reluctance from a user perspective to change technologies since this requires a reengineering of panels or racks with all associated electrical and mechanical drawings in addition to labor and extended outages to perform the work. Reengineering can be costly and time consuming. Manufacturers may provide “form fit” and/or “wire alike” solutions to replace older technologies with newer technology. Form fit means that the newer product will fit into the same panel cutout or rack with no cutting or mechanical reconfiguration. Although it is form fit the solution may require modification to the wire harness in the panel. Wire-alike means that the wiring from the older product can be directly transferred to the newer product without the need to reconfigure of the wiring or control scheme. The existing wire harness is transferred directly to the same “mimic” terminal blocks on the new relay. Form fit and wire-alike forms combine the two solutions to provide a means to easily and directly replace older units with newer technology. These can be done at a relatively low cost since minimal or no drawing changes are required and minimal engineering is required. Figure 5 in the Case Study section outlines an example form fit / wire-alike solution. Manufacturers ensure that the newer technologies perform at the level of the older units with the added functionality and security that is gained with the new technology. In cases where there are security concerns a manufacturer may opt to discontinue certain functions or protocols (i.e. ASCII protocol). Figure 4 shows several examples of form fit, wire-alike replacement solutions. These solutions are also sometimes referred to as “adaptor panels”. If end-of-life is extended beyond supported life (product is no longer supported or repaired), there may be some urgency to get units replaced if the failure rate becomes costly and unacceptable. This solution can be effective in this case. More detail is examined in the Case Study below.

Figure 4 – Form-Fit, Wire-Alike Replacement Examples

When available, the last time buy option can serve to afford the user some additional time to develop and execute a replacement strategy for the affected relay type. It is a short term fix, however, not a long term solution. If you get the chance to execute a last time buy, consider it carefully. Acquiring a few additional relays might buy just enough breathing room to complete replacements without falling behind the failure rate. Also, if the user has an established business relationship with a company that deals in refurbishing and supplying obsolete equipment, they may be able to recover some of the cost by reselling the remaining working inventory of relays that were replaced before they failed.

MTBF

Mean Time Between Failure (MTBF) has been used as a metric for measuring product hardware reliability. This paper proposes other considerations to measure product reliability specifically tied to microprocessor based relays. MTBF is a measure of how reliable a hardware product or component is.

For most components, the measure is typically in thousands or even tens of thousands of hours between failures. For example, a hard disk drive may have a **mean time between failure** of 300,000 hours. MTBF is estimated or calculated by taking the number of units in service over a period of time and dividing the number of product failures. So keeping it simple, if there are 1000 relays sold in a 2 year period and there are 5 hardware failures out of 1000 relays in the same 2 year period, it can be calculated that the product has a 0.5% failure rate over that period (5 returns divided by 1000 units in service). This assumes that these 1000 relays have the exact same amount of service hours from beginning of service life. We all know that this is not possible but for sake of theoretical calculation we will assume this to be the case.

Since 2 Years = 17,520 hours and with 1000 relays in service we multiply 17,500 hours x 1000 relays and we get 17,520,000 product hours. Divide that number by the number of product failures (5) in that same 2 year period and we get 3,504,000 mean time before failure hours or approximately 400 years.

As stated above, this is all theoretical and does not mean much since in order to get to this, we would need to assume that all 1000 relays were placed into service at the same time and were in service the entire 2 year period.

There are many other metrics used to determine MTBF but this paper will not discuss those as it is not the intended purpose.

The key to this metric is only that there was a hard failure of a product or a failure that rendered the product dead or inoperable. But what if we took that same metric and factored in a mis-operation of a product and what the effect of that mis-operation has on the product MTBF? In the eyes of a user, it really doesn't matter what the mode of failure was. It matters that the product did not perform as expected. If a relay failed to trip because a power supply failed or if the same relay failed to trip because of a firmware malfunction, what is the difference to the user?

Let's take a look at the MTBF metric a little differently. Now let's say that the same 1000 relays have been in service for that same 2 year period and that the same 5 returns were seen. Now, let's say that over that same time period, half of those in service relays experienced a need for a critical firmware update due to a mis-operation condition that requires correction. Each of those 500 relays could be considered as failed since the user is now required to take the relay out of service for firmware correction. So now instead of a 0.5% failure rate we have a 50.5% failure rate. The MTBF metric now drops to 34,693 hours or approximately 4 years. If a user is required to visit the same 500 relays each year, the MTBF number drops in half again.

Can a user assign a cost associated with MTBF? Yes. There are always costs associated with product down time whether that down time is associated with a hard failure or a firmware failure. The cost is not much different. The initial price or cost of a relay is negligible when routine updates are required to maintain the products integrity. This was discussed earlier.

An Illustrative Case Study for an End-of-Life Scenario

Consider the following example scenario, with a moderately sized distribution provider utility, serving 250,000 customers uniformly spread across the service area. The utility operates 100 substations with 400 radial distribution feeders. The breakdown of feeder protection relays is as follows: 80 electromechanical relays, 40 solid state relays, 120 first generation (1stGen) microprocessor relays from manufacturer X, and 160 later generation relays from manufacturer Y. The 1stGen relays are beyond their advertised 15 year end-of-life, having been in service approximately 20 years. The later generation relays are typically at 10 years of service or less.

As a protection engineer for the utility, you are tasked with replacement of all of the 1stGen relays. Given that you are already are starting 5 years beyond the advertised end-of-life of the relays, you consider the option of employing the manufacturer's retrofit option to streamline the relay replacement process. The retrofit option provides the latest generation microprocessor relay in an adaptor chassis that fits in the same size cutout as the 1stGen microprocessor relays. Also, it will allow you to add voltage inputs and under frequency tripping capability even if VT's are not present at the time of replacement. Users then

have the option to implement under-frequency load shedding and protection should protection guidelines change as dictated by regulatory agencies.

Cost Analysis Per Installation

	Retrofit Solution		Engineered Solution	
Relay Cost	$	6,000	$	2,000
Installation Days		2		4
Relay Tech Cost	$	4,000	$	8,000
Engineering Days		0.5		10
Engineering Cost	$	500	$	10,000
Total Cost Per Install	$	10,500	$	20,000

Figure 5 – Simple Cost Analysis

The simple cost analysis looks favorable, but users will still want to confirm the right decision so a list can be generated for the benefits and drawbacks to selecting the retrofit solution. Below is a table with some of the items that could be considered. Is the retrofit solution worth the $9,500 in savings per installation that is hoped to be achieved?

Retrofit Benefits vs Drawbacks

Benefits	Drawbacks
* Reduces Engineering costs	* Possible depth issues
* Simplifies Installation	* New relay to learn
* Reduces Tech time costs	
* Adds UF trip capability	

Figure 6 – Simple Benefits vs Drawbacks Analysis

The benefits seem to outweigh the drawbacks. The cost savings can be realized due to the reduction in engineering and cutting the relay Technician's job time in half. The addition of the UF tripping capabilities is also a nice bonus and allows for "future proofing". With all the focus on building in some reserves to UFLS program recently, it is an added bonus to get that additional functionality on circuits where it did not previously exist. Even at stations with a dedicated UF relay, this functionality adds a layer of redundancy in case you have a failure.

The drawbacks are not show-stoppers. In a real case, the retrofit chassis requires two inches additional clearance. This will not present a problem for panel mounted relays in switchgear. There might be an issue depending on how things are configured in a walk through duplex rack, but that can be solved by using an offset mount. Manufacturer X offers an offset bezel for that situation or one can be fabricated using C-channel. The bigger drawback is the need to learn a new relay with different methods of configuring the logic and settings. Training will also be required for relay technicians and engineers for programming the relays and retrieving event records. Since you are highly motivated, you take on the challenge! The solution is sound because it streamlines the work for the majority.

Given the simple analysis, you move forward with the replacement project, planning to complete all replacements within a 5 year cycle. The total savings you are reporting in your business case are substantial. See the Simple Total Cost Analysis in Figure 7 below.

Total Cost Analysis

	Retrofit Solution	Engineered Solution
Total Cost per install	$ 10,500	$ 20,000
Number of relays	120	120
Total Project Cost	$ 1,260,000	$ 2,400,000
Savings Realized	$ 1,140,000	
Tech Days per install	2	4
Number of relays	120	120
Total Project Days	240	480
Day Savings Realized	240	

Figure 7 – Simple Total Cost Analysis

This case study presents some of the key concepts the user will need to consider in their own application. There are many factors that could simplify the project or add layers of complexity to it. When you are faced with the need to upgrade and replace your own obsolete devices, consider these concepts carefully along with those that are specific to your existing protection configuration. Your approach will be driven to a large extent by what protection equipment you already have in place, your company's standards, your company's best practices, and what equipment offerings are available to you at the time.

Sometimes it can be difficult to quantify these cost-benefits when you are making your business case. Just do your best to capture them so you have some basis for comparison. For instance, it can be hard to fully quantify your reliability benefit from choosing one solution over another. In the project that was the basis for the case study above, it was easy to illustrate that the reliability improvement could be realized

much faster with one solution than the other due to the installation time taking half as long. Further reliability benefits were realized by prioritizing worst performing circuits and replacing them earlier in the project cycle.

One other aspect of these retrofit replacement devices that is often overlooked is the communications capability. As discussed earlier older microprocessor relays typically used ASCII communications. This communication protocol is generally considered today to be unsecure unless isolated by a communications firewall. In some cases, ASCII communications to in-service older devices has been removed because of security concerns. Newer microprocessor relays utilize much more secure communications and can directly connect to the user's communications infrastructure although not recommended for BES applications. Also available is the ability for automation if desired. True IEC 61850 relays now have the capability to perform peer-to-peer high speed communications and can be utilized in such applications as auto-transfer and dedicated bus protection schemes just to name a couple of applications. Users considering retrofit replacement may want to evaluate what the possible future needs would be in this area. For example, is there bus protection in my substation? What if I could get it at no additional cost? Would I benefit from an auto-transfer scheme? What if I could get that at no additional cost?

Conclusions

When looking at the data and case study shown in this paper it is clear that microprocessor relays have a certain life span. If pushed passed their original intended design life, the maintenance and cost to the user can become higher than originally considered. It is also important to consider the life cycle cost associated with these devices. Generally not considered during the initial specification stage and purchase is the history of a device. How long has it been on the market versus typical supportable life span? What is its history and frequency of service advisories? Is the total cost of ownership considered?

When faced with the end-of-life of a microprocessor relay, the most important advice that an owner of older microprocessor relays can take away from this paper is; do not wait. Make a business case, establish a replacement plan, and start the replacement cycle. The longer the process is delayed the higher the probability that your failure rates will increase beyond what can be reasonably handled. If failures cannot be dealt with on a timely basis, the cost to operating budgets and reliability metrics will be high.

When users consider updating to newer technologies it is important to evaluate critical and non-critical firmware update histories when specifying a relay. Will a small cost savings initially be consumed by a much higher cost later because of a poor history of critical firmware updates or reliability issues? As shown above, these costs can be substantial. Also, what is the total installed cost and are the relays "future proof"? Are there added no-cost benefits to the upgrade as discussed above? Is there a cost effective retrofit solution available? These are just a few questions to ask when determining the best strategy for older microprocessor replacement.

It is imperative that engineering, operations and management work to help those who set long term business plans so they understand that microprocessor relays cannot be treated the same as the electromechanical relays our industry has long relied upon. The microprocessor relays have a shorter life cycle and many more considerations to be evaluated when upgrading. They have forever changed our industry and brought many added benefits. The expectation is that this will continue long into the future.

Biographies

Michael (Mike) Kleman has been involved in protection and control for over 30 years. He began as a relay technician at General Electric in Malvern, PA and moved to a product engineering role after four years as a technician. He began a career as an application engineer with ABB in 1995 where he was able to shape the direction of distribution products from relays to automated substation systems. Mike is currently a Regional Technical Manager with ABB and is a member of the IEEE Power and Energy Society. Mike holds a BSEE from Washington International University.

Todd Moyer, PE earned his BSEE from the US Coast Guard Academy in 1996 and his MSEE from the University of Rhode Island in 2004. He is a registered Professional Engineer in the State of Connecticut. He is currently a Distribution Protection Engineer at Metropolitan Edison, an operating company owned by FirstEnergy Corporation. Prior to his current position, he worked as a Circuit Reliability Coordinator in Asset Strategy and as a Distribution System Operator in their Regional Dispatch Organization.

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Douglass Barefoot – Relay Supervisor – Metropolitan Edison Company

[i] Photo courtesy of ZeroSurge

[ii] North American Electric Reliability Corporation Standard PRC-005-2