The Useful Life of Microprocessor-Based Relays: A Data-Driven Approach

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***Abstract*—Confidence in microprocessor-based protective relays has steadily increased over the four decades since their invention. As the service life of these devices exceeds multiple decades, questions regarding when and how to strategically replace these relays are increasing. This paper defines terms associated with the reliability of protective relays, provides field-observed life cycle reliability data, and suggests replacement strategies.**

I. Introduction

As microprocessor-based relay technology approaches four decades, and companies have devices in service that are several decades old, the following questions start to arise:

- What is the useful life of a microprocessor-based protective relay?
- What replacement strategy should be adopted?

This paper answers the questions by analyzing the field return data of a population of relays that were in service for 19 to 25 years. It also assesses the effects of aging on a sample of those relays.

We conclude that adherence to high-quality design and manufacturing processes, the use of high-quality components, and robust repair and communication policies ensure that relays reliably operate beyond their stated service life.

A. Definitions

To promote a common understanding, we offer the following definitions.

Reliability: the probability that a product or system will perform its specified function over a specified period in a defined environment.

Latent defect: a defect that could not have been discovered by reasonably thorough tests or inspection before a product was sold or placed in service.

Failure rate: the average number of failures over a specified period, expressed in failures per year.

Useful life or service life: the intended operational lifetime of a device.

End of useful life: the period following the service life when the device has an insupportable failure rate or experiences an unrepairable failure.

B. Reliability Life Cycle

Latent defects from various sources are sometimes introduced into equipment. As the defects become failures, the affected population must be repaired or replaced. End users must also resolve other sources of failures, such as product handling and installation errors. The combination of these efforts results in an exponentially decreasing failure rate.

Fig. 1 depicts the field-observed reliability life cycle of 12,761 microprocessor-based transmission relays manufactured between 1992 and 1999.

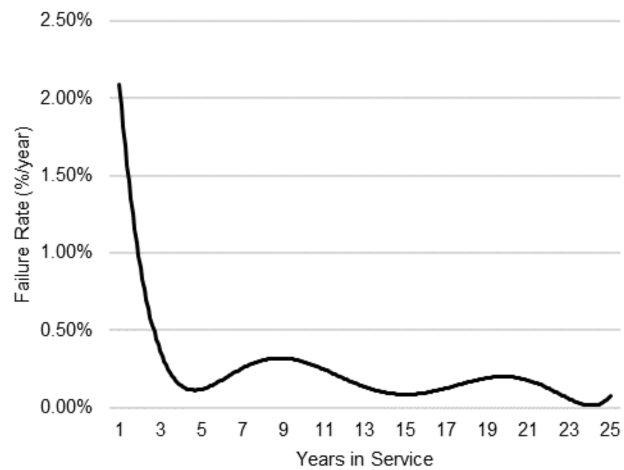

Fig. 1. Field-observed reliability life cycle of a 1992-vintage transmission relay manufactured between 1992 and 1999.

Latent defects can result in a higher failure rate anytime during the service life of a product. For instance, some of the relays in Fig. 1 experienced a common mode of failure after reliably serving for five years. Open communication between end users and the manufacturer along with robust maintenance policies were vital to restoring and improving product reliability.

The relay associated with Fig. 1 was designed for a service life of 20 years. After 25 years of service, field return data indicate that the relay has not yet reached the end of its useful life, and the manufacturer can still repair the relays. However, the manufacturer lacks a means to identify when relays are retired from service, which might skew the reliability data.

II. Background and Considerations for Relay Replacement

This paper focuses on the useful life for a protective relay. However, there are a variety of other reasons for replacing relays, including many listed in [1]. It is useful to acknowledge the importance of other issues and considerations that affect why and when end users decide to replace a protective relay.

Table I provides a summary of the motivations and considerations for deciding when to replace or upgrade protective relays.

TABLE I
MOTIVATIONS AND CONSIDERATIONS FOR RELAY REPLACEMENT

Motivation	Explanation
New technology	Faster protection reduces equipment damage and improves stability. New and faster communication improves protection, control, and automation. Higher-resolution sequential events recorder (SER) data, event reporting, and monitoring capabilities improve system performance and analysis.
Safety	Faster protection reduces incident energy (arc-flash hazard) in switchgear [2] [3], and downed conductor detection improves safety for distribution systems [4] [5].
Compliance	Regulations and standards may require relay replacements [6] [7]. Distribution owners may require adherence to interconnect standards [8] [9].
Obsolescence and form factor	Secure supply chains and the consistent availability of materials is crucial for a manufacturer to produce, support, and repair a relay. Manufacturers may replace old models with similar new models for substantial time and cost savings.
New primary equipment	When primary power system equipment (generators, transformers, etc.) is upgraded or expanded, protection is typically upgraded to match and improve to state of the art.
Budgeting for replacement	Utilities operating in a cost-of-service model favor capital upgrades over operations and maintenance spending [10]. This may make proactive, large-scale projects (complete panel or control building replacement) more attractive financially than running relays to failure and replacing them with maintenance funds.
Training and process	Rigorous training on old and new technologies is required to maintain the competence and expertise of personnel. Trained personnel executing a well-defined replacement process will optimize results.

III. MANUFACTURER'S PERSPECTIVE

There are many aspects to ensuring, maintaining, and improving reliability. Ensuring reliable operation over the useful life of a relay begins with meticulous design principles, selection of high-quality materials from excellent suppliers, and high-quality manufacturing processes. Maintaining and improving in-service device reliability requires formal communication of reliability trends between the manufacturer and end users and warranty and repair policies that promote product returns.

A. *Accurate Product Return Data*

Accurate product return data are essential for quantifying reliability and developing a strategy for maintaining and replacing relays.

Retaining records of product shipments by model number and serial number and recording all service actions enables manufacturers and end users to calculate and analyze observed reliability metrics. It makes sense for manufacturers to offer user-friendly return and repair policies to encourage end users to return every failed relay, regardless of whether the failure is covered by a stated warranty. This collaboration provides manufacturers a chance to update reliability metrics, identify the root cause of failures, and improve the design, process, or materials of present and future products.

Relay return data from 2018 were analyzed to gather a relay manufacturer's perspective. Relay failure rates were calculated based on year of manufacture and the number of relays sold that year. The annualized failure rate is plotted by relay age in Fig. 2. Using only these data, one might conclude that the increasing annualized failure rates of relays in service for more than 16 years indicate the end of useful life. However, latent defects caused many of the failures and were disclosed through service bulletins and resolved by replacing defective components.

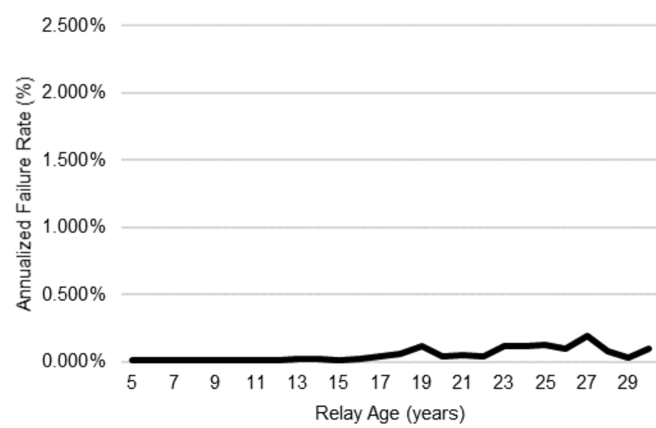

Fig. 2. Annualized failure rate by relay age for relays returned to the manufacturer in 2018.

While this information is useful, it might present an incomplete picture because end users could take relays out of service without notifying the device manufacturer.

Increasingly, in part due to regulatory requirements, end users are keeping more detailed data, including when a device is put in service, tested, and removed from service and the cause of removal. Information sharing between the end users and manufacturer could complete the picture and help the industry better understand the longevity of microprocessor-based relays.

B. *Communication Between Manufacturers and End Users*

Proactive manufacturer communication of issues that could affect device reliability along with proactive end user maintenance programs can improve long-term reliability, dependability, and security and extend the useful life of microprocessor-based relays.

Additionally, manufacturers and end users benefit from the exchange of information from periodic updates of reliability data.

Fig. 3 shows the number of relay failures recorded by a specific end user (Utility A), normalized to the relay population for the year of manufacture.

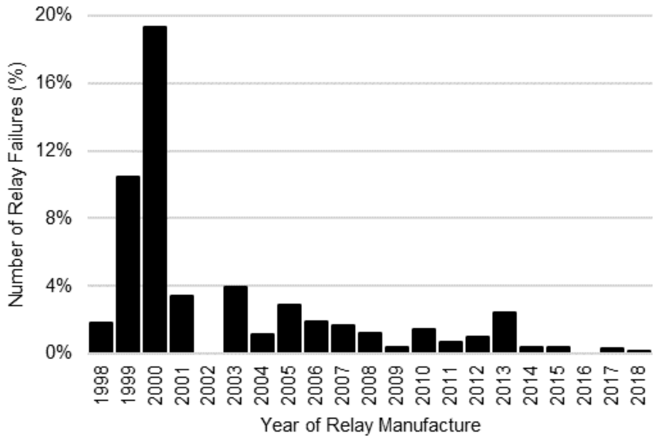

Fig. 3. The number of relay failures recorded by Utility A versus year of manufacture.

Using only this data set, one might conclude that relays from 1999 and 2000 have reached the end of their useful life, but combining the data with information available from the manufacturer provides a complete account.

Fig. 4 shows the cumulative relay failures experienced by Utility A versus year of relay failure as recorded by the manufacturer. A service bulletin was issued in 2006 by the manufacturer, which addressed an issue affecting relays manufactured in 1999 and 2000.

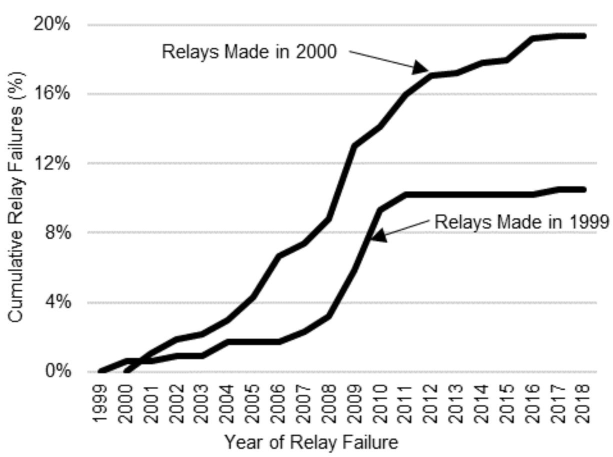

Fig. 4. Cumulative relay failures experienced by utility a versus year of relay failure as recorded by the manufacturer for relays manufactured in 1999 and 2000.

Utility A proactively replaced most of the relays manufactured in 1999 between 2007 and 2010. Since Utility A had backup protection in place, they conscientiously balanced risk, reliability, and economics and replaced the remaining relays as they failed.

C. Analysis of the Effects of Aging on Electronics

Measuring the effects of aging on critical electronics is required to confirm the useful life of microprocessor-based relays. Eleven relays from eleven utilities across the United States were examined and tested. The service lives ranged from 19 to 25 years. These relays were designed for a minimum service life of 20 years by using high-quality components and by considering the effects of aging on components that are critical to the protection functions and safety of the relay.

The relays were previously installed in different utility substations from various regions of the United States. The following relay functions were tested and verified to conform to published specifications:

- Electromechanical outputs
- Digital inputs
- Analog voltage and current inputs
- Liquid crystal display
- Light emitting diodes
- Pushbuttons
- Power supply
- Relay diagnostics

The performance of the following components, critical to relay protection functions, were measured and verified to conform to published specifications:

- Precision resistors
- Precision analog references
- Crystals and oscillators

The reliability of the safety insulation systems was verified by subjecting relays to high-voltage impulse and hi-pot testing per IEC 60255-27: 2013 product safety requirements for measuring relays and protection equipment.

Solder joint integrity of the contact output circuitry was confirmed by analyzing cross sections using a metallurgical microscope.

The results from the evaluation of the 11 relays, combined with the field-observed reliability life curve confirm that when relays are manufactured from high-quality materials and high-quality processes and the effects of aging are considered during product design, that microprocessor-based relays can reliably perform within specification during, and beyond, their intended service life.

IV. Utility-Reported Data

Three different utilities reported data on how many relays they installed, how many relays they replaced, and how many relays were still in service.

Table II summarizes the data from these three utilities, Utilities X, Y, and Z, showing the number of relays manufactured prior to 1999 that are still in service.

TABLE II
CASE STUDY OF DIFFERENT UTILITIES' RELAY INSTALLATION DATA

Utility	In-Service Relays More Than 20 Years Old
X	1,844
Y	194
Z	294

This case study shows that all three utilities have confidence in relays beyond 20 years. Utility X's larger population of aged relays can be attributed to them purchasing more relays more than 20 years ago compared with the other utilities and their earlier adaptation to asset management. Based on Utility X and Y data, about 75 percent of relays older than 20 years are still in active service.

Elective upgrades comprise a large portion of relay removals. Utility Y estimated greater than 85 percent of the removals were not due to failure but, rather, due to the need for new technology. For example, Utility Y has replaced all extra-high-voltage transmission line relays and is replacing all high-voltage transmission line relays because of the obsolescence of an older communications infrastructure and greater fiber availability. Utility Y replaced both transmission and distribution relays for increased communications and reporting requirements, in part mandated by new industry regulations.

Utility Z estimated 80 to 90 percent of removals are due to elective upgrades. One reason cited is transmission line protection is being upgraded to use line current differential protection due to greater fiber availability.

V. Utilities' Perspectives

There are many approaches from a utility's perspective on how to address the useful life of equipment. We summarize these approaches into three general categories.

A. Replace Only After Relay Failure

This approach is the simplest in concept. Utilities simply do not replace protective relays until they fail. Utilities still monitor and periodically test relays per manufacturer and utility guidelines, consistent with applicable standards and compliance requirements.

Utilities that adopt this philosophy still replace relays for other reasons (see Section II), but there is no specific timetable for relay replacements.

B. Based on Specific Time or Relay Age

With this approach, utilities replace relays based on their service life or age in an attempt to replace relays before they fail.

One utility reported that they attempted to quantify the useful life of several relay technologies and fit a failure curve based on observed data with protective relays divided into three categories: electromechanical, solid-state, and microprocessor-based [11].

One benefit of a time-based approach is that utilities can match the replacement time with North American Electric Reliability Corporation (NERC) requirements on periodic testing of protective relays. For example, Utility B, per the guidelines in [12], has adopted a maintenance testing interval of 12 years. Their replacement plan corresponds with their testing interval and is summarized in Table III.

TABLE III
UTILITY B'S APPROACH: MATCH MAINTENANCE TESTING SCHEDULES WITH PLANNED REPLACEMENT

Time Line	Planned Action
Initial install (0 years)	Perform commission testing and put into service
12 years	Perform periodic maintenance per [12]
24 years	Replace/upgrade protection or perform periodic maintenance per [12] and put the relay on a list to replace before next maintenance interval

By matching the relay replacement time with required maintenance intervals, the utility avoids maintenance on a relay near the end of its design life. This has benefits for operating and maintenance budgets.

C. More Sophisticated Approaches

Several more sophisticated data-driven approaches have been shared [11] [13]. For these general approaches, utilities use a variety of factors, including the age of the relay, to generate a performance factor to quantify the relative need of whether or not to replace a specific relay. For example, one approach is to combine and weight an estimated "criticality score" with a numerical estimate of the overall health of a relay called the "health score" to provide a quantitative assessment of risk for a particular relay [11].

VI. Conclusions

Based on data, microprocessor-based relays manufactured from high-quality materials, using high-quality processes, can reliably perform within specification during, and beyond, their intended service life of 20 years.

Measuring the effects of aging on critical electronics confirmed that relays in service for greater than 20 years showed no signs of wearing out.

Utilities are keeping relays in service beyond manufacturer warranty and beyond service life expectations.

Manufacturers should collect and maintain data on relays, including the date of manufacture and return and repair activities, and effectively communicate with end users, including sharing service activities and providing reliability data.

End users should maintain relay data, including the date of installation, maintenance activities, date of removal, and the reason for removal.

Manufacturers should have a proactive and robust process for communicating product service bulletins to end users. End users should have a robust process for evaluating and acting on service bulletins.

Manufacturers and end users should partner to make the best data-driven decision on the useful life of microprocessor-based relays.

VII. References

[1] IEEE PSRC Working Group I22, "End-of-Useful Life Assessment of P&C Devices," PES-TR46, May 2015. Available: pes-psrc.org/kb/published/reports/I22-UsefulLife-Final-May2015a.pdf.

[2] B. Hughes, V. Skendzic, D. Das, and J. Carver, "High-Current Qualification Testing of an Arc-Flash Detection System," proceedings of the 9th Annual Clemson University Power Systems Conference, Clemson, SC, March 2010.

[3] J. Buff and K. Zimmerman, "Application of Existing Technologies to Reduce Arc-Flash Hazards," proceedings of the 33rd Annual Western Protective Relay Conference, Spokane, WA, October 2006.

[4] D. Hou, "High-Impedance Fault Detection—Field Tests and Dependability Analysis," proceedings of the 36th Annual Western Protective Relay Conference, Spokane, WA, October 2009.

[5] W. O'Brien, E. Udren, K. Garg, D. Haes, and B. Sridharan, "Catching Falling Conductors in Midair – Detecting and Tripping Broken Distribution Circuit Conductors at Protection Speeds," proceedings of the 69th Annual Conference for Protective Relay Engineers, College Station, TX, April 2016.

[6] NERC Standard PRC-023 – Transmission Relay Loadability. Available: nerc.com.

[7] NERC Standard CIP-007 – Cyber Security – Systems Security Management. Available: nerc.com.

[8] IEEE 1547, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources With Associated Electric Power System Interfaces.

[9] K. Zimmerman, "SEL Recommendations on Periodic Maintenance Testing of Protective Relays," December 2010. Available: selinc.com.

[10] Advanced Energy Economy, "Optimizing Capital and Service Expenditures," a 21st Century Electricity System Issue Brief, June 2018. Available: info.aee.net/hubfs/PDF/Opex-Capex.pdf.

[11] A. Feathers, A. Mubaraki, A. Nungo, and N. Paz, "Relay Performance Index for a Sustainable Relay Replacement Program," proceedings of the 41st Annual Western Protective Relay Conference, Spokane, WA, October 2014.

[12] NERC Standard PRC-005-2 – Protection System Maintenance. Available: nerc.com.

[13] Q. Aziz and G. Sonde, "Protection & Controls Analytics for a Reliable Grid," proceedings of the 69th Annual Conference for Protective Relay Engineers, College Station, TX, April 2016.

VIII. Biographies

Derrick Haas graduated from Texas A&M University with a B.S.E.E. He worked as a distribution engineer for CenterPoint Energy in Houston, Texas, until 2006 when he joined Schweitzer Engineering Laboratories, Inc. Derrick has held several titles including field application engineer, senior application engineer, team lead, and his current role of regional technical manager. He is a senior member of the IEEE and involved in the IEEE Power System Relaying Committee (PSRC).

Matt Leoni received a B.S. degree in marine engineering systems from the United States Merchant Marine Academy in Kings Point, New York, in 1994 and an M.S. degree in electrical engineering from the University of Colorado in Boulder, Colorado, in 1996. From 1996 through 2002, he worked as a consulting engineer with a focus on utility and industrial power system protection. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2002 and has contributed to field application engineering, team leadership, and Engineering Services branch management. In 2014, Mr. Leoni was promoted to regional sales and service director. He has conducted numerous seminars, workshops, and SEL University courses on system protection and integration. He is a member of the IEEE Industry Applications Society and a registered professional engineer in Colorado and Texas.

Karl Zimmerman is a principal engineer at Schweitzer Engineering Laboratories, Inc. in Fairview Heights, Illinois. His work includes providing application and product support and technical training for protective relay users. He is a senior member of IEEE, a member of the IEEE Power System Relaying Committee, and vice-chairman of the line protection subcommittee. Karl received his B.S.E.E. degree at the University of Illinois at Urbana-Champaign and has over 25 years of experience in the area of system protection.

Adrian Genz is a senior engineering manager in the Quality division at Schweitzer Engineering Laboratories, Inc. (SEL). He joined SEL in 2007 as a hardware engineer and has held engineering design and management positions. He received his B.S. in electrical engineering from Utah State in 2004 and M.S. in electrical engineering from Brigham Young University in 2006.

Travis Mooney is the director of the Quality division at Schweitzer Engineering Laboratories (SEL). He joined SEL in 1995 as a hardware engineer and has held multiple engineering design and management positions. He received his B.S. in electrical engineering from Gonzaga University in 1995 and has been with SEL ever since. He holds two patents, with one patent pending, in data acquisition and measurement techniques.

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