

## Upgrading Relay Protection?—Be Prepared

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**Abstract** – There are many advantages to upgrading old electromechanical, solid-state, and first-generation numeric relays with modern numeric relays. Reliability increases because there is less direct wiring and interconnection wiring. Reliability and security of multifunction logic and settings are improved with next-generation user interface software. Remote I/O modules, remote analog/digital inputs, and thermal measurement capabilities have expanded protection, control, and monitoring. New protection and monitoring features improve power system equipment life and increase personnel safety. Maintenance costs are reduced, while internal watchdogs alert the user if the relay has a problem. Settings groups can be changed instantaneously to adapt to varying power system requirements. Modern, second-generation numeric relays offer a variety of secure communications capabilities for interfacing with Smart Grid controls, SCADA systems, and business networks. Event memory is larger for more on-board, standardized oscillographs and event reporting. Relay security is in accord with the latest NERC standards.

Initially, every relay upgrade seems simple and straight forward; then come the details. Operating personnel have expectations for reading targets, resetting trips, ease of interface for settings and events, motor restarting, synch closing, etc. Regulator requirements (NERC-CIP, for example) must be implemented while maintaining smooth operations. Relay engineers must assure that operational ease is maintained with the new upgrade relay. Accurate one-line drawings and connection drawings, as well as good wiring documentation, are essential. Escutcheon plates might be necessary, or perhaps switchgear will need modification (panel cutting, new doors, relocation, etc). Also, this is an opportunity to reevaluate arc-flash hazards and possibly reduce the risks. These and other considerations are taken from actual relay replacement projects.

This paper provides guidance for your next replacement or upgrade project, resulting in reducing cost, saving time, and minimizing unexpected or unplanned complications.

*Index terms* – Protective relays, upgrades, cost analysis

### I. Introduction

Protective relaying in industrial and utility power systems has changed greatly since the beginning of system protection over a hundred years ago. At first, finely made, “Swiss-watch” precision electromechanical relays were developed and installed by the hundreds of thousands.

In the 1980s solid-state (or static) relays became available and replaced the electromechanical relays with little change in scheme protection or relay function. These relays had the advantage of lower cost, smaller size, lesser burden, less calibration drift, simpler maintenance, and little programming. Typically, solid-state relays have no communication or event recording functions. Some plug-n-play solid-state relays remain

very popular because there is very little installation labor, low outage time for replacement, and the scheme design remains minimal. Some prefer to keep their systems in this configuration because no extensive computer software training is required to operate an effective power-system protective scheme.

Wide-spread growth of computer technology in the 1990s resulted in the introduction of microprocessor-based numeric (or digital) relays. This first generation of numeric relays brought innovations in developing new algorithms, and the beginning of placing many protection functions in one multifunction relay package. Desktop and laptop computers set the first-generation numeric relays via DE-9 or DB-25 serial ports (with all the complications of configuring these connections). Initially, first-generation numeric relays operated on ASCII protocol or proprietary serial commands; relay manufacturers later developed graphic user interface (GUI) software to generate the background serial commands to program the relay elements.

Now these first-generation numeric relays are reaching an end-of-service-life state. This situation is caused by through-hole component mounting design and poor solder joints; heating and cooling of circuit boards leads to problems such as bad vias (electrical connections from one layer of the circuit board to another), and electrolytic capacitor failure (particularly in the power supplies). Because first-generation numeric relays have built-in test routines (a “watchdog”) that signals an alarm output, operators know when the numeric relay has failed (this was not so with electromechanical designs). Electromechanical designs and most solid-state designs did not have a watchdog alarm output.

The new-technology, second-generation numeric relays are equipped with powerful microprocessors, have more-reliable, surface-mount construction, and have more and improved algorithms and elements. These developments have provided relay protection engineers with new protection schemes and have advanced the quest for reliable and dependable operation. However, some manufacturers have provided so much programming capability in these second-generation products that extensive training is required to set and operate these relays. In some cases, the customer contracts with the manufacturer to develop settings files. In other cases, the manufacturer has simplified the settings process by using computing power to make setting a relay more straightforward and by providing setting intelligence in relay setting software.

Operations personnel now have input into second-generation numeric relay settings because the newer relay front panels have operating indicators and pushbuttons directly related to system operation.

The total costs of upgrading relays must be considered. There are engineering, labor, testing, and commissioning costs. Also, you must consider the future values of longer-lasting relays, and newer settings checking features that help relay engineers make better settings to avoid expensive outages (and the related paperwork and possible fines).

## II. Replacing/Upgrading Relays

Knowing when to upgrade your relay protection should be a proactive function; you should not operate protective relays to failure. Operating to failure might seem to be a cost-saving method, but this philosophy reduces the reliability and dependability of the power system. Relevant standards for determining relay life are found in ANSI C37.90 [1] for the USA, and in IEC 60255 [2].

### A. Replacement/upgrade timing

You must monitor the rise in relay failures so that you can schedule the replacement/upgrade before an existing relay fails [3]. Monitoring is necessary especially for older electromechanical relays, solid-state relays, and first-generation numeric relays. Figure 1 presents study results on relay longevity.

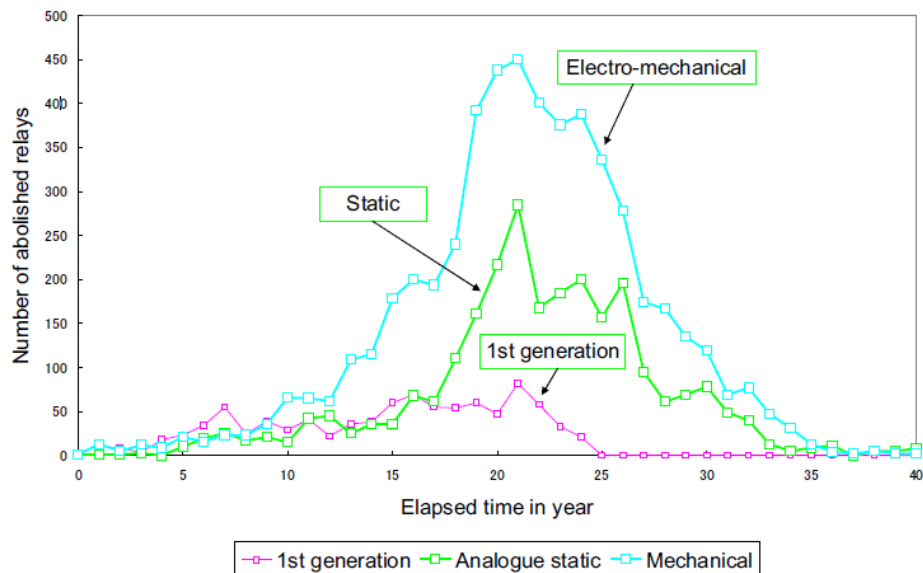


Fig. 1 Study of Relay Longevity

The longer a relay is in service the more likely it is to fail; which is why primary/backup relaying is recommended. Generally, the lifetime of a numeric relay is 15 to 20 years. This is based on the life of capacitors (loss of capacitance because of electrolyte drying and leakage), and by semiconductors (mainly ICs) that degrade because of thermal vibration and humidity. Most of the first-generation numeric relays have already reached or passed normal lifetime (writing in 2012). It is recommended that you schedule a replacement or upgrade to second-generation relays, or replace existing solid-state relays if you want to keep the solid-state relay scheme.

## B. Protective relay stressors

Relays operated in severe conditions will need more maintenance and more record keeping to document performance. Severe conditions include extremely hot and cold environments, outdoor locations, and humid operation areas.

## C. Costs of upgrading relays

The costs associated with relay upgrades and replacements have many variables. Depending upon the importance you and your organization place on reliability and dependability, optimizing relay upgrades and replacements might seem like an unanswerable problem because of the many variables of relay operation. However, there are some interesting methods of quantifying upgrades and replacements with statistics and probability mathematics. These mathematical models use terms such as MTBF (mean time between failure), MTTF (mean time to failure), MTTR (mean time to repair), reliability, and dependability.

Reliability is MTBF or MTTF parameters. Assuming that modern, second-generation numeric relays have surface-mounted components that cannot be repaired to the component level, the model for MTTF is more accurate because MTBF does not make sense in this case; relay users generally do not repair modern relays because the relay price is low and replacing a failed unit brings more peace of mind.

One study on relay replacement is by Wang, Xue, Bi, and Huang (2011), based on the least unit life-cycle cost with minimum maintenance model [4]. Minimum maintenance is repairing a relay board subsystem only or replacing the relay, with no hardware refurbishment. These researchers found that relay longevity follows a lognormal distribution, with the following parameters for cost over the life cycle of the relay  $[C(t)]$ :

$$C(t) = \frac{C_L(t)}{t} \quad (1)$$

Where  $C_L(t)$  is the unit life cycle cost,

$$C_L(t) = C_d + C_x \int_0^t \rho(t)dt + C_t \frac{MTTR}{MTTF} \int_0^t \rho(t)dt \quad (2)$$

Where  $C_d$  is the price of a protection device (including installation),  $C_x$  is the average cost of maintenance,  $C_t$  is the cost effect when the power system is out of service because of a protective relay failure.

This equation shows the effects of outages, maintenance and initial relay installation. The cost of downtime (the third term with  $C_t$ ) can be greater than the cost of maintenance (the second term with  $C_x$ ) if the mean time to repair (MTTR) is large and the mean time to failure (MTTF) is relatively small.  $C_t$  is the loss of power from the power system being out of service because of a protective relay failure.  $C_t$  divided by MTBF represents the probability that another device is also out of service. Note that the initial cost of the relay and installation (the first term with  $C_d$ ) is not significant for a single relay when that relay is in service for a long period (large  $t$ ). However,

replacement/upgrade projects seldom have only one relay; by batching many relay replacements at one time this term becomes significant. Shopping for a low relay price with small setup time (to reduce labor cost) is advised.

The lognormal probability distribution,  $r(t)$ , indicates that once the relay has one failure, subsequent failures will occur with lesser and lesser time intervals. It is a good idea to replace/upgrade a relay right away after the first failure. High-reliability situations require that you make the decision to replace and/or to upgrade before relay failure. Wang, Xue, Bi and Huang found the optimal replacement at 18.4 years. In fact, power industry standards [5] specify that relay protection device life is generally not less than 12 years and, for devices operating in harsh conditions, the useful life should be shortened.

Another analysis of relay life is by Montignies, Basu, and Gruffaz shows similar results [6]. These authors describe reliability as the summation of the probability of relay failure over time  $t$ , (the failure rate). They use the familiar “bathtub curve” to confirm the large infant mortality of brand-new relays, the useful life of in-service relays, and finally, the end-of-life obsolescence period where relay failures accumulate rapidly. See Figure 2. The IEC describes the useful life as “the time interval beginning at a given moment in time, and ending when the failure intensity becomes unacceptable or when the time is considered to be unrepairable as a result of a fault (IEV 191-19-06) [7].”

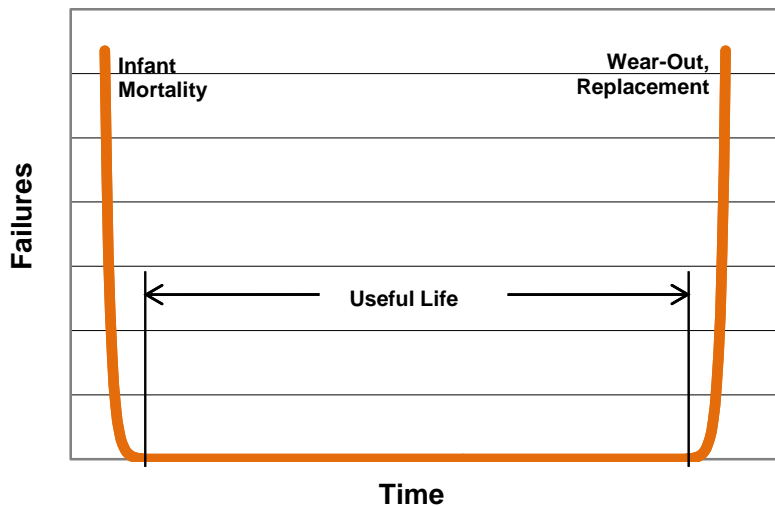


Fig. 2 – Relay Failures Over Time

During the middle, constant-aging period the failure rate,  $\lambda(t)$ , remains constant during this useful life period. The average operating time is the following:

$$MTTF = \int_0^{\infty} R(t)dt = \int_0^{\infty} e^{-\lambda t} dt = \frac{1}{\lambda} \quad (3)$$

Where  $R(t)$  is the reliability at time 't.' The natural exponential function of the probability of failure  $l(t)$  also describes reliability  $R(t)$ .

Thus the relationship of MTTF and the failure rate is inverse. When the failure rate goes up, the mean time to failure goes down, and vice versa. An MTTF of 300 years means that one relay out of 300 relays will fail during an operational year.

Availability is the probability that a system operates properly at a given time. During the useful life and over a long period of use, availability ( $A$ ) is the following:

$$A = \frac{MTTF}{MTTF+MTTR} \quad (MTTF > MTTR) \quad (4)$$

To increase availability the MTTR must be as fast as possible. Having on-the-shelf spares speeds repair and increases availability. Also, be sure to apply power to spare relays for thirty minutes every year. Doing so keeps the internal electrolytic capacitors fresh, improving the usable life of shelf spares.

#### ***D. Primary/Backup Relay Systems***

Protective relays should have a primary/backup arrangement from different vendors, especially when applied to critical protection areas and in the severe conditions mentioned above. In this manner, you avoid mutual failure modes from hardware and from software algorithms with the same manufacturer. Primary/backup relaying is also recommended for the climate controlled environment as a method to prevent double failures. Relay manufacturers use different algorithms, have different accuracy and precision, and different hardware. These differences make the primary/backup different-vendor solution more robust. Using two separate relays can save valuable equipment if one relay does not detect a fault but the other relay does detect a fault. The added cost of training on another relay is offset by the savings realized in avoiding a fault.

### **III. Upgrading to Second-Generation Numeric Relays**

Upgrading to the latest, or "second generation" of numeric protective relays gives a distinct advantage. There have been advances in hardware, software, element mix, and communication.

#### ***A. Hardware advances***

Second-generation protective relays have the following advantages over previous offerings:

##### ***1. Faster and better processors***

Faster analog-to-digital conversion benefits protection because more samples of the power system voltages and currents are available to the relay internal microprocessor. Thus, the relay has a more accurate representation of the actual conditions in the power

system. The newer A/D converters also offer wider range, so small signals and large fault signals can be more accurately measured (if cts and vts are of good quality).

The processing power of the new microprocessors in protective relays mirrors the computing power improvements in ordinary office computing platforms. While first-generations could be compared to an old Intel® 286 or 386, the latest protective relays have PowerPC (Performance Optimization with Enhanced RISC – Performance Computing) or i5 core-type processing chips. These new microprocessors are faster, smaller, and less expensive; and have had an effect on the relay-design trend toward improved algorithms and simplicity.

## ***2. Surface-mount reliability***

Older relays employed “wire-lead” components that experienced vibration and heating issues, making the protective-relay circuit board unreliable over time. Power supplies were of the brute-force design, requiring large electrolytic capacitors, which are known to dry or leak, and fail. This drying effect is true especially with shelf spares that are not powered on a yearly basis.

Surface-mount technology has made protective-relay circuit boards more robust because the surface-mount components lay on the circuit board. The components are less subject to vibration, and heating issues are less because the components have better thermal conduction to the circuit board.

Power-supply design reliability has improved by using switching designs, where dc and low-frequency ac are converted to a higher frequency, then smoothed to internal working power using smaller electrolytic capacitors with greater life. Also, manufacturers have learned to optimize component selection for more reliable working life.

### ***3. Plug-out design more reliable than drawout***

There is a move to eliminate drawout protective relays in second-generation products. Many drawout designs damage the internal relay plug/jack interfaces with repeated use.

One popular fix to this problem is to use a “plug-out” design where, if the protective relay needs to be replaced, technicians detach the already wired terminal blocks from the back of the relay. After the entire relay is removed from the panel, the technician replaces the already wired terminal blocks (plugs) onto the back of the relay. This method has lower force distributed over a number of connections, providing a more gentle connection scenario. Current-input circuits have shorting mechanisms for protecting personnel from open-ct arcing. Reliability is increased with comparable downtimes to a drawout-case relay.

### ***4. Ethernet-based connections***

Second-generation hardware supports Ethernet-based communication. Usually copper 100BASE-T and fiber-optic 100BASE-FX are provided. Properly managed for security (see, for example, NERC Critical Infrastructure Protection [CIP] requirements [8]), these connections make possible a substation LAN, remote connection, and newer protocols like IEC 61850.

## ***B. Firmware and software advances***

Second-generation numeric relay firmware offers improvements in the available number and type of protective elements, allows new protection schemes, increases relay recording and reporting, provides improved relay internal diagnoses, and complies with the latest NERC security requirements. External settings software is GUI-based and includes settings analysis and checking, along with template import and export, to improve and simplify the settings and tests processes.

### ***1. Number and type of elements***

More processing power has allowed protective relay manufacturers to increase the number of traditional elements in a relay (for example, providing six or more 50 and six or more 51 overcurrent elements with any phase, sequence, or specialty input(s) for a feeder relay). In addition, newer elements are packaged in the relay for use in newer protection schemes; an example is a 21 distance element(s) and 78 vector-jump element(s) in a generator relay. Hybrid-grounding generator schemes and fast-synchronization, main-tie-main schemes are examples of newer protection schemes supported by the many elements in second-generation protective relays.

### ***2. Increased relay recording and reporting***

Second-generation numeric relays have more non-volatile memory, allowing these relays the ability to record longer and more event records and oscillography. Especially when synchronized by satellite IRIG or Ethernet time, a fault is much easier to analyze

because more data are present and time is aligned across multiple relays. Ethernet connections make downloading these high-data-volume reports fast.

Second-generation relays provide more elements that can be used for early warning of impending failure; and for through-fault, remaining-life estimates. Thus, you can realize long-term costs savings because of the ability to extend equipment maintenance intervals

### ***3. Improved relay internal diagnoses***

Electromechanical relays had no diagnostic features. You could test the EM relay, then put it back into service only to fail immediately. You would not discover this failure until the next testing interval expired and it was time to test again. Solid-state relays have power-supply alarms, but not much else in diagnostic testing. The first-generation of numeric relays have a microprocessor watchdog with a “deadman” alarm that would close alarm contacts upon suspension of algorithm execution and of power loss.

Second-generation protective relays employ more intricate self tests that analyze not only when the microprocessor(s) is operating; these relays check memory status, measure accuracy of the A/D (analog to digital) converter, and monitor power supply tolerances. If the relay exceeds any of these parameters it sends an alarm via contacts or communications protocols to operators to check the relay. Again, long-term costs are lower and power-system protection is improved.

### ***C. Enhanced relay security***

Worldwide, data security has become an important part of the protective relay arena. As shown in the Aurora Effect [9], utilities and commercial/industrial power users must ensure that their processes are secure from ill-intentioned hackers. For example, in North America the NERC Security Requirements, CIP-002 [8], require that protection relays connected to the bulk power system must log all entry attempts. First-generation protective relays were designed before these requirements and do not provide adequate data security protection (without layering external security). Second-generation relays have extensive security provisions, including logging who accesses the relay and for what purpose.

### ***D. Smart software increases programming simplicity and provides checking***

Recent studies [10] have shown that a large amount of relay misoperations are caused by poor relay programming. Although it is good to have nearly endless, computer-like programming in protective relays, it can be a pitfall to the unknowing or inadequately trained protection engineer. The latest setting and monitoring software checks programmed logic, and has templates for many protection schemes. These templates can be used “as is,” or modified as a special settings or monitoring template for protection department use. The new smart software for second-generation relays features step-by-step guided settings, and summary pages when complete to check that

all elements are programmed and set. Simplicity is improved and misoperations are minimized.

In addition, the latest relay software provides for monitoring capabilities for the power system such as basic current and voltage measurements, sequence components, phasors, power quality, and harmonics. For motors and generators there are start reports, calculated and actual temperature measurements. Trends are reported for crucial operating parameters such as starting, transformer through-fault monitoring, and predicted end of life.

Automated testing has become essential and the newer relays coordinate with several available products to make testing and commissioning far easier than first-generation numeric and previous relays.

#### IV. Installation Data And Example

Experience from numerous relay installations over the years lends evidence to the need for relay upgrades and replacements. Historic data and an installation example make the benefits of upgrading apparent.

##### A. Historic installation data

Modern relays with active components (not electromechanical construction) do not have the service life of electromechanical relays. The chart of Figure 3 shows the expected, maximum and minimum service life of the four main relay types. However, numeric relays and solid state relays offer more reliability, better testing correction retention, and more repeatable protection than do older electromechanical relays.

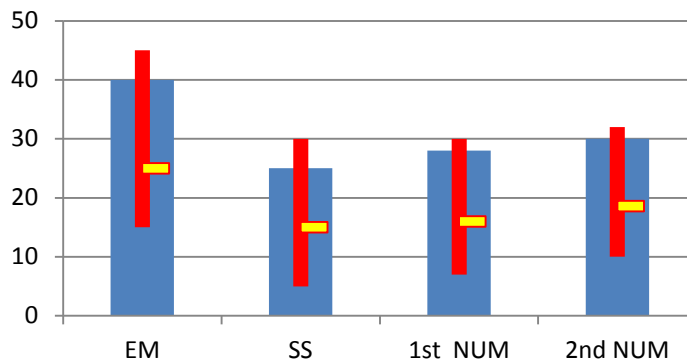


Fig. 3 Relay Longevity by Type (Years)

Note that advances in component technology and circuit-board reliability have made a useful contribution to relay life. Components such as electrolytic capacitors continue to be a limiting factor. Improvements in component technology and proper manufacturer selection has made second-generation numeric relays last longer.

##### B. Electromechanical transformer differential scheme

Some practical examples of relay replacement show efficiency gains in having multiple functions in one relay, in communications ease, and in space savings. Figure 4 presents the “before” picture for a transformer differential scheme; electromechanical (EM) relays were installed in the switchgear[11]. Not shown are the single-function overcurrent relays that backed up this differential scheme. The old installation had minimal protection without a modern, dual-slope algorithm. There was no transformer life monitoring and no circuit-breaker or station-battery monitoring. In addition, the old scheme offered no communication so operators and engineers could not monitor the transformer working in the power system. Also, the many EM differential relays consumed much valuable switchgear front-panel space.



*Fig. 4 Old EM Transformer-Differential Relays*

Upgrading the electromechanical relays to numeric relays resulted in better protection, better relay communication, and a less-cluttered use of panel space (along with built-in metering, the company enjoyed increased ease of operation and less downtime). Figure 5 shows that this installation features new panels with a multifunction numeric relay replacement, as well as test switches not available in the original installation. Backup protection could be added in the remaining panel blank at a later date.



*Fig. 5 Smaller Space, Better Protection with Numeric Relay Upgrade/Replacement*

## **V. Cost of Upgrading**

Performing the actual relay upgrade and replacement begins with analyzing the cost. A value must be placed on the operation of the power system with no changes and compared to the value of power system operation with protection upgrades.

### **A. Making no change**

Continuing operation with older relays can make economic sense if the costs are acceptable for downtime and equipment repairs caused by non-working protection. As was seen in Section I of this paper, all of the electromechanical, solid-state, and first-generation numeric relays are coming to the end of usable life. The loss of one power transformer for which the utility or commercial customer has no backup, or must reduce service/production to provide remediation, can be prohibitive. Management and the protection division must work together to identify the high-risk protection areas and get these relays upgraded as a high priority.

### **B. Upgrading costs to consider**

Upgrading relay protection can save money in the long run. The future values of a relay upgrade far outweighs the initial cost of implementation (see Section I). Costs to consider are the following:

- Drawing changes
- Physical mounting considerations (including building subpanels and rewiring to reach the new relays, if needed)
- Upgrading communication infrastructure
- Resizing battery requirements
- Labor, including engineering, settings and commissioning
- System downtime and damaged equipment--
- End-of-life maintenance

## **VI. Implementing a Relay Upgrade**

When you have made the decision to upgrade protective relaying these are the steps to follow:

- Obtain management approval and team acceptance
- Update drawings for the new relays or panels
- Order all required materials, tools, and labor
- Develop an outage plan
- Do the installation
- Complete drawings with as-is data
- Responsibly dispose of old equipment

- Report outcome to management

Performing these steps helps keep your project on time and within budget.

### ***A. Obtain management approval and team acceptance***

Organization management should be aware of your plans and should grant approval for the upgrade project. The Costs of Upgrading section in this paper help justify replacement so you can obtain permission and develop a reasonable budget. Communicate the plans to the upgrade team of workers. Do not forget to account for the unexpected (incorrect relay or panel fit, door swing problems with long-depth relays). A good value for unexpected costs is 10 percent (thorough planning) to 25 percent.

### ***B. Update drawings for the new relays or panels***

Planning begins with examining the existing drawings for the switchgear, substation, or line section. Be aware that the condition of existing system prints might not be up to date. Send a crew to examine the site, comparing the latest drawings to the present configuration; make any changes required.

Next, make demolition drawings. These drawings provide detail on the relays or panels to be removed.

Installation drawings follow, with detailed notes on relay or panel placement. These documents help to focus on the materials (metal stock, escutcheon plates, terminal blocks, panels, and relays, ct and vt replacements/connections, etc.), tools, and labor that will be required for a successful transition.

Consult the relay manufacturers' web sites and contact the manufacturers' applications engineers for your area for a final overview of your plans. This action helps to make apparent any assumptions about relay operation that you might have missed. In addition, you can find tools for settings, application notes, and white papers that pertain to your upgrade work. Developing a relationship with the manufacturer and manufacturers' field organizations now can save you money in the future.

Prepare a detailed list of step-by-step procedures for the work. This planning reduces cost, increases efficiency, reduces upgrade overall time, and makes the probability of excessive commissioning troubleshooting time much less.

### ***C. Develop an outage plan***

An important safety measure is performing the work when the associated areas of the power system are de-energized; you avoid possible hazards to both your technical crew and to power-system equipment by upgrading an out-of-service portion of the system. Doing "hot" upgrades and replacements is not recommended. Effective outage planning achieves the following goals:

- Avoids outage cost increases and project delays
- Avoids unforeseen circumstances during the outage because you have “walked through” the upcoming work
- Simplifies coordinating your technical staff during inspections and commissioning; increases personnel productivity

Review work order historical data for the area of the power system getting the upgrade to determine whether there were existing problems and emerging trends. If you are using database software to schedule work orders, investigate whether it has an outage-planning module (many of these programs and options exist). Consult with electricians, the machine shop, and other trades on the nuances of the existing system. Document, order, and store these data so that all concerned parties have access (perhaps through a web/internet interface). Produce a draft of the work flow, estimate required hours, and identify resources. Add or subtract items in the plan addressed during the outage (time of year, provision for continuing customer or plant loads, backup protection during the outage, etc.).

#### ***D. Order all required materials, tools, and labor***

Early ordering of all the required materials, tools, and arranging predicted labor needs make the upgrade go more smoothly. Generally, protective relays have a three to four week lead time because of the many ordering options; manufacturers do not stock relays but build these to an exact option (or style) number. Although manufacturers can produce the relays faster, you might incur increased cost.

Some upgrade solutions match the old terminal numbers to the new relay. In this manner there are significantly fewer drawing changes and technicians simply wire from the old relay to the upgrade relay using the same terminal number. This method has been known not only to reduce cost; it also reduces mistakes during the upgrade. Laser-cut, plastic overlays on the back of the new relay, or pre-wired, terminal blocks marked with the old relay terminal numbers are a few examples. End-to-end wire testing would be reduced, as well. If replacing an entire relay panel, be sure that some method of support is available for these heavy panels.

Getting key labor supervisors involved is important at this point in the work. These men and women can make the job go well because of their special insights about the system hardware on which they and their subordinates work. Listen and learn. A protection engineer not only has to determine the protection settings, now it is important to apply the right amount of effort on the user interface, screens, labels, and so on [12]. If you do not get labor buy-in, consulting labor later could bring rework and an unsuitable working relationship that makes for late, over-budget upgrades.

#### ***E. Do the work***

Refer to the installation drawings and procedures prepared earlier. Make sure that everyone on the installation team knows the order and scope of the work.

Labor can be your best help or a painful experience. As noted above, the earlier that the labor pool is onboard, the better will be the project implementation. These days technicians are not as familiar with older relays, especially EM types. If installing these type of relays make sure that staff knows where to get the test-fixture extenders, where to attach the serial port, whether the port is “straight-through” or “crossed,” the data rate, and all pertinent passwords. Many newer technicians are comfortable with USB ports, IP addresses and Ethernet ports in the modern, second-generation numeric relays, and are not so comfortable with older, serial connections.

Put a dedicated land-line telephone connection at the site. Not only is this telephone line a safety improvement, it is easier to use for contacting manufacturers’ application engineers because there is no signal fading from nearby power-system noise as is found with wireless or cellular telephones. Also consider using a headset because noise levels at the site can make it difficult to hear someone on the telephone line.

Computer-aided testing is becoming standard throughout the industry in an effort to help existing technicians save time, providing more work at less cost (obviating the need to hire more personnel who are not there). Make sure that staff is trained for the relays in the upgrade [13].

Commissioning testing is essential to verify that all wiring is connected properly to all relay inputs and outputs (hardwired and virtual), and that the upgraded relays communicate as expected. Computer-aided testing can help save time at this point; make sure to analyze expected results against the scheme design to ensure trouble-free operation. When changes come (and changes are a certainty), be ready with a revision-tracking method; these days there are many software library management programs that can assist in enforcing one copy of the changes as the working set.

#### ***F. Complete drawings with as-is data***

Documentation is essential for saving time and money. From good planning to smooth installation and final testing, complete, accurate documentation furthers efficiency. Updating project drawings should be an ongoing effort. Make final notes on protection design. File logic and software reports in a place where you can find these in the future. Capturing the as-is data now keeps those who follow you from guessing and wasting time on understanding the work.

Besides updating drawings, now is a good time to write a project summary and update project design documents. Those who come after you will bless you.

#### ***G. Dispose of old equipment responsibly***

Be responsible about disposing of older electronic equipment. Consult and follow RoHS guidelines for guidance [14]. There is much lead, cadmium, mercury, and other dangerous chemicals in refuse landfills. The European Union spearheaded efforts in these areas, reducing contamination and making ground water safe.

Think about donating older equipment to a local vocational or four-year college. It is important that the new crop of protection engineers and technicians are familiar with older products because these students can learn valuable lessons about algorithms and test procedures. Mark the replaced, old relays with painted or labeled warnings about re-use in the power system. Besides the enhanced goodwill that donations give, perhaps your organization can get a government tax reduction as well.

#### ***H. Report outcome to management***

At the end of the relay upgrade take the project summary report and ask to make a formal presentation to company management. Not only does this let management know what was accomplished, this effort pays back in increased favorable management buy-in when proposing the next project.

Reporting the project outcome also helps to complete upgrade documentation, and gives an opportunity to point out helpful colleagues and staff, and give you one last look at what was done. It is good to write a “lesson learned” document to pass along to the next project leader on the next upgrade.

### **VII. Conclusions**

Upgrading power-system protection relays gives the opportunity to see long-term cost reduction and increased operational efficiency. In these days of cost cutting and striving for doing more with less, relay upgrades, though initially requiring some cost and effort, make better use of organization funds. Whether it is a PUD, an industry application, or a large utility, upgrading can alleviate many system problems and expensive relay failures.

Second-generation numeric relays (new multifunction microprocessor relays with Ethernet communication) are often less expensive per function than earlier relays. The new relays are rugged, with surface-mount technology that endures harsh operating environments better than older construction. The unreliable connections from older draw-out designs are not a factor in newer relays, enhancing the already increased reliability.

More functions in one relay means lower cost and less likelihood of replacement to improve protection schemes; the relay elements are already in the newer, second-generation numeric relays. If these elements are not in use now, these elements are available for later use that might be required because of management, government, and protection mandates. Less panel wiring, longer maintenance intervals (from stable calibration and active watchdog reporting), and automated testing interfaces lower overall costs. An unplanned outage can be more expensive than the cost of a relay replacement project, not to mention the possible monetary fines (especially when connected to the bulk power system), loss of capital, loss of production, and loss of reputation.

Software for modern relays actually assists the protection engineer to make more consistent, better settings. In addition, second-generation numeric relay software provides summaries and internal logic checking to make certain that the protection elements are on, connected, and working.

Plan the upgrade project well. Keep management and labor informed on progress. Consult relay manufacturers for assistance. Make a final project summary and report to management and all stake holders (available to all who worked on the project, especially). In this manner more upgrade projects will come in the future, with improved power system performance and increased reputation for the relay protection engineer.

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