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The Myth of Complexity – Configuration Mechanisms of Modern Microprocessor-Based Relays

THE MYTH OF COMPLEXITY – CONFIGURATION MECHANISMS OF MODERN MICROPROCESSOR-BASED PROTECTIVE RELAYS

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1. Introduction

Modern microprocessor-based relays provide far-reaching flexibility. Configuration mechanisms include: programmable logic, programmable time curves, selectable operating quantities and modes of operation, user-definable display messages, configurable LEDs, programmable input and output contacts, programmable oscillography and event records, and programmable pushbuttons, all in addition to traditional protection “settings” such as pickup or reach.

As a result some users are overwhelmed with the flexibility and resulting complexity of modern microprocessor-based relays. Instruction manuals became thick, programming a relay from a keypad is difficult or impossible (programmable logic, for example), and some settings are complicated and not self-explanatory.

In fairness to modern relays, this paper analyses ways of achieving similar functionality using single-function and multi-function microprocessor-based relays. The paper touches on the areas of designing, setting, troubleshooting, documenting and maintaining a protection system comparing time and resources required by “old” and “new” technologies. The myth of disproportionably increased complexity is disputed.

Major points of the paper are:

- Numerous settings exist on digital relays that were not available in older technologies (type of a TOC curve, for example). Instead, vendors offered a number of variants of basically the same single-function relay. The setting process used to be divided into two phases; 1) selection of a specific model from a catalog followed (usually a long time later) by 2) selection of settings. Often the first, catalog-based, stage is not considered as a part of a setting process although it involves important decision-making.
- A microprocessor-based relay applies programmable logic to establish connections between its functions and selected control actions. This replaces entire set d.c. interconnections of a potentially large number of single-function relays. The amount of time and resources needed for designing, documenting, wiring and troubleshooting a design based on single-function relays have been replaced by “programming” a single microprocessor-based relay. The latter process is not only simpler and less time-consuming, but far more flexible and cost-efficient (future reprogramming, for example).
- A typical multifunctional device replaces a number of single-function relays. The number of settings for those single-function relays, number of decisions or selections to be made during a setting process, and the total number of pages of their instruction manuals combined are about the same as for an equivalent multi-function digital relay.
- New functions such as oscillography, communications, self-monitoring, etc. have been introduced. These functions require to be configured in order to suit the needs of various users under various relay philosophies. This increase in number of settings is a fair price to pay for the previously non-existing features.
- Additional benefits are available through digital technology such as setting files that can be copied and pasted between the relays, sent electronically, archived, printed, imported into general purpose software packages, etc. Resources previously needed for maintaining setting records and other documents such as drawings must be taken into account when making any comparisons.

2. Review of Configuration Tools

2.1. Numerical Settings

This is a basic configuration level available in any generation of protective relays. Typical examples include overcurrent pickup level, distance reach, zero-sequence compensation factor, time delay, maximum torque angle, etc.

Microprocessor-based relays, however, tend to increase the number of numerical settings in this category by providing the user with an option to modify parameters that used to be fixed by design in electromechanical and static technologies. Hysteresis of an Instantaneous Overcurrent (IOC) function, effective "filtering" of a Time Overcurrent (TOC) function, comparator limit angle of a directional function, fundamental frequency to which a given single-function element shall respond (50Hz/60Hz), are good examples.

In numerical technology practically all parameters of a protection function are easily adjustable and are not limited by design. This creates the temptation of providing the user with more flexibility by allowing to "tune" the settings more precisely for a given application. Such tuning, however, requires extra work and/or knowledge, is often unnecessary, and may lead to misapplication of the relay.

From a vendor perspective, widening the range of settings and moving various parameters from the category of "factory constants" to "user settings" is an easy way of reducing the number of relay models and satisfying needs of a world market by meeting various protection practices and philosophies.

On the other hand microprocessor-based relays are much more user-friendly when it comes to "entering" numerical set-points. Instead of requiring re-calculation between amperes, volts, ohms, seconds, etc. into a combination of knob, tap or dial positions, a microprocessor-based relay accepts plain amperes, volts, ohms, seconds, degrees, per unit values, etc. This simplifies not only the setting process, but also speeds-up troubleshooting as the relay becomes its own setting record that keeps settings in their natural user-friendly form.

2.2. User Programmable Curves

Numerous protection functions such as time overcurrent, under- and over-voltage, and volts-per-hertz may use inverse time characteristics. Typically several standard curves are provided for user selection.

The curve selection on a microprocessor-based relay is clearly seen as a part of the setting process (decision required), but it is not necessarily seen as such when considering the older technologies. However, if the curve type is important for a given application, certain amount of engineering work is required to select the curve. This is no different in electromechanical, static or digital technologies. Instead of typing "12IAC54B801A" in the order code box when ordering an electromechanical TOC relay, the user clicks on "IEEE Very Inverse" on a drop-down menu of a PC configuration program. Both operations must be preceded by a decision-making process, which is the critical element as compared with the mechanics of setting the relay (filling-in an order form, turning a knob or a dial, clicking a mouse). When an error is made in the former case, a new relay must be ordered. In the latter case, correction is quite easy.

Another benefit of digital technology in this area is better standardization of curves and their implementation. Instead of a large selection of vendor-specific, often design-driven curves, the user selects from a list of standard families of curves such as IEEE or IEC. This simplifies applications and coordination between relays from various vendors.

Quite often user-programmable curves are available on modern microprocessor-based relays. The user curves help solve difficult coordination cases, meeting various user standards and practices, and coordinating and/or reproducing curves of electromechanical or static relays when the former are to be coordinated with. Typically, a user curve is entered on a point-by-point basis with some 50-80 points. While intensive this is not complex!

2.3 Multiple Operating Modes

Often several modes of operation of a given protection or control element are available to the user. For example, an out-of-step tripping element may generate trip in an “Early mode”, i.e. instantaneously, or in a “Delayed mode” - in order to avoid stressing the circuit breaker. A neutral directional overcurrent element may be polarized from the zero sequence voltage, ground current, or both. A time overcurrent element may respond to the true RMS value (appropriate for thermal protection) or to phasor magnitude (appropriate for fault protection), etc.

This level of flexibility demonstrates itself as a multi-choice selection and was rarely available in previous technologies. It is probably the best example of the effect of “packing” the entire catalog of single-function relays into a single chassis of a microprocessor-based device. Selecting a model (option) of an electromechanical or static relay from a catalog has been replaced by selecting a mode of operation when setting protection or control function of a microprocessor-based relay.

2.4. Configurable Analog Inputs

There are relaying solutions where any given protection or control element available on a relay may respond to any of the existing a.c. input signals. This creates a completely new level of flexibility when configuring the relay. The mechanisms available on some relays refer to “Analog Points” or “Sources” [1]. Some important applications include for example, a transmission line relay for a breaker-and-a-half configuration that measures both currents and provides for two breaker fail functions, but allows the basic protection functions such as distance to respond to the sum of the two physical currents.

One particular solution (“Sources”) is based on modular hardware. The relay may be ordered with different combinations of CT and VT inputs. These inputs are configured individually (ratios, rated secondary values, connection, etc.). “Sources” are next configured as any combinations of available phase and auxiliary voltages, and phase and ground currents as per user needs. Protection and control elements are subsequently configured to respond to selected “sources”.

This mechanism is equivalent to “virtual a.c. wiring” and becomes a very powerful configuration tool. It may be, however, perceived as added setting complexity, while in old technologies based on single-function relays, the a.c. wiring of a cubicle was definitely not consider a setting.

Protection schemes based on single-function relays have the flexibility of connecting the relays practically without any restrictions. A typical microprocessor-based relay has its functions pre-configured in terms of the “a.c. wiring”. The concept of “sources” available on modern solutions completes the loop and returns flexibility to the user.

2.5. Programmable Logic

In the past, protection schemes were implemented with single function relays and the scheme logic was hard-wired according to the requirements of the specific application. When first-generation multifunction relays were introduced their capabilities were limited. Consequently, the relay manufacturers resorted to the development of embedded, hard-coded scheme logic. Manufacturers attempted to make these schemes general enough to be applied to a wide range of applications. Situations still arose where these hard-coded schemes were incompatible with existing protection philosophies. The advent of multifunction relays with fully programmable logic has completed the circle. The designer once again has the ability to tailor the protection scheme for the specific application. However this flexibility is in some cases now looked upon as unnecessary complexity.

Programmable logic has become a standard feature for microprocessor-based relays. It allows the user to perform some basic control functions and to build an application from elements available in a relay by combining the outputs from the protection elements into auxiliary signals to be used within the relay and to be interfaced with output contacts or sent to other equipment over communications channels.

A typical set of functions consists of gates, latches, timers, edge detectors, and counters.

Advancements in relay communications, using both proprietary and open standards (such as the UCA protocol and GOOSE messaging) allows exchanging digital state information on a peer-to-peer basis between several relays. This opens a whole new field of distributed logic across very long distances.

From the configuration point of view, programmable logic causes some concerns. Traditionally, there is an expectation that a microprocessor-based relay could be fully programmed from a local keypad or via communications protocol. If this principle is to be applied to programmable logic, the choice of a programming language becomes very limited and the final solution is not going to be a user-friendly one. On the other hand, there is an expectation of a graphical drag-and-drop type programming language. The two requirements are quite contradictory. In the long run, the graphical interface will likely prevail. Today's microprocessor-based relays offer some kind of low-level programming language that can be used from a local keypad such as Reverse Polish Notation. This is a well-known language supported in the early days of microprocessor industry. In addition it allows the programmer to control precisely sequence of execution and loops (feedback lines). Graphical editors may use different ways of resolving feedback lines and therefore may create unexpected or undesired effects.

Regardless of the programming language, programmable logic is a very useful configuration tool in a modern microprocessor-based relay. It replaces d.c. circuitry as well as a number of other devices that may be otherwise needed (bi-stable relays replaced by latches, for example).

Designing and documenting d.c. circuitry for single-function relays is not considered as a part of a setting process. On a microprocessor-based relay, the same activity is clearly seen as a setting effort. Strictly, programmable logic is equivalent to tens of hundreds lines of code in some low-level language or to a soft-drawing that, upon completion, gets compiled and downloaded into the relay. On the surface this may be perceived as a complex part of the relay, but in reality it is an old well-known function accomplished with a new tool.

Undisputed advantages of programmable logic versus d.c. circuitry that counterbalance the required learning effort include:

- Ease of modification
- Self-documenting
- Flexibility of using latches, one-shot edge detectors, timers, etc.
- Cost saving
- Ability to interface with other devices via communications.

2.6. Configurable Input and Output Contacts

Input contacts on modern microprocessor-based relays become user-programmable. This includes factors such activation voltage, de-bounce time, text label (ID) and event recording. This brings new flexibility when developing an application on a multi-function relay. Inputs may be set to different activation voltages enabling interfacing with various battery systems. Each contact may have different de-bounce times (to cater for high speed interface requirements with communication equipment, avoid false operation due to capacitive discharge caused by grounding of leads, and to cater for contact bounce), thus balancing speed and reliability of information exchanged between relays via contacts.

In the past a large array of auxiliary relays were necessary to interface field devices with protections schemes. Close attention to voltage ratings, coil burdens, operating times and contact configuration was generally required during the selection process. The designer now must select the proper setting for activation voltage and debounce time for the specific application. This arguably requires less time than was required for auxiliary relay selection. Furthermore a problem may be corrected via a setting change versus replacement of a relay.

Moreover, settings associated with digital inputs are good examples of confusion between plurality and complexity. It does not cost any extra work or knowledge to label an input contact for clarity and self-documentation (“52b_A”, “52b_B”, “52b_C” for example). It does not take any involved math to select an activation voltage of 33V for a 48V battery. Deciding whether or not an event shall be logged if the input changes, while it may be a setting decision, requires engineering judgment on what information will be useful for future diagnosis. This initial effort with new microprocessor technology has to be compared with the time spent on analyzing the operation of older relays with limited available information.

Output contacts also have user-programmable settings . These include an activating flag (i.e. a digital state within the relay, either a direct output from a given function or a point within programmable logic that is to drive the contact), text label (ID), sealing-in flag, event recording, and integrated d.c. current and/or voltage monitoring. These are powerful tools enabling complex applications such as d.c. seal-in to prevent contact damage or trip coil circuit monitoring.

“Virtual outputs” constitute another category of “outputs”. The mechanism may allow labeling of any point within programmable logic and the creating of event logs for those points. Again, settings are very straightforward.

2.7. Configurable Display Messages, Target LEDs and SEO Records

Modern relays allow the user to specify, for each protection and control element, whether pickup, dropout or operation of the element should produce a target LED, and/or display message, and/or an entry in an event log. This allows customizing the relay to avoid overflow of Sequence of Event (SOE) records or faceplate indication with non-critical information.

In addition user-programmable LEDs and display messages have become an option. This capability is used to customize and enhance the relay by making diagnostic information available immediately.

Settings associated with the above features are not involved and are means of achieving well-known and straightforward functionalities. For example, in order to enhance targeting while using single-function devices one would have to order targeting relays and wire them accordingly. That is much more involved and costly than setting a user-programmable LED to respond to say "loss of communication channel" event.

2.8. Programmable Oscillography

Modern relays allow programming the oscillography records with the following options:

- Sampling rate (actually data recording rate),
- File content (user selectable analog traces such as magnitudes, angles, power, power factor, etc.; as well as user-selectable digital traces such as Z1 pickup, Z2 pickup, Z2 operate, etc.),
- Triggering signal,
- Position of a trigger (split between the pre-trigger and post-trigger data),
- Number of records versus record length,
- Ways to treat old records (overwrite or not),
- Etc.

Oscillography in modern microprocessor-based relays, that sample at 64 or 128 samples per cycle with the functionalities described above, are getting close to the recording quality of full-featured Digital Fault Recorders (DFRs). They are still simpler, provide less recording time, and do not include any really sophisticated analysis software, but they are powerful enough to justify comparison with DFRs. Consequently when evaluating complexity and number of settings, one should rather compare a modern digital relay with a full-featured digital DFR than with single-function relays monitored by an analog DFR.

Similar observations apply to data logging and demand recording functions that are sometimes provided on modern relays.

2.9. Multiple Setting Groups

Multiple (switchable) setting "groups" (or "banks") have become a standard. A modern relay allows the user to store several variants of the same setting, typically organizing the entries into groups, and provides for a programmable mechanism to switch the groups based on a number of conditions such as state of protection and control elements, input contacts, keypad commands, communications ports, self-monitoring alarms, etc. It is expected that the use of multiple setting groups to perform adaptive protection functions will increase in the future.

Two aspects of multiple setting groups are worth mentioning.

First, multiple setting groups appear in the user interface, implying a much higher number of settings and increased complexity.

Second, because the purpose of multiple setting groups is to switch the settings dynamically, a new feature controlling the active settings is needed. As with any feature, it requires its own settings. The learning curve and the mechanics of setting up multiple setting groups are irrelevant when compared with the actual engineering required for adaptive relaying (deciding if, when and how to switch settings in order to achieve desired adaptive action).

2.10. System Settings

Typically, a modern relay contains a number of miscellaneous settings on a "relay" or "system" level. Examples are:

- System frequency (50 or 60Hz) and phase rotation (ABC vs. ACB)
- Relay name (ID) and/or substation name
- Frequency tracking (on/off)
- Real-time clock and IRIG-B settings
- LCD Display properties (intensity, time-out)
- Etc.

This category may also include maintenance or testing actions. For example one may take the relay out of service, force contact inputs, upgrade relay firmware, force oscillography trigger, reset the relay, etc.

On modern relays this category may become significant. However, a majority of these settings are very straightforward. They not only facilitate new features, but they also may save time and resources. Consider for example, the system phase rotation. This setting allows uniform wiring standard across the utility network that uses two sequences.

2.11. Communications / Protocol Settings

This category contributes significantly to the myth of complexity of modern relays. There are numerous settings required for communications and effective usage of protocols. Terms and principles are not necessarily well known to protection engineers, hence the difficulty.

On the first level one needs to establish communications with the relay. This is almost always required, as the majority of users would use a PC program rather than a keypad. Before establishing communications for the PC program, quite often the basic port settings may require modification via keypad.

Serial and Ethernet ports are typically supported on modern relays. They require some basic settings such as baud rate, parity, IP address and masks, etc. Good PC programs tend to have a connection or communication wizard to help the user connect the PC to the relay.

Communication protocols require certain settings as well. These include two categories. First, some basic settings are needed such as access port, etc. Second, memory mapping settings are required for user-configurable memory tables.

2.12. Settings for Advanced Algorithms

Microprocessor-based technology has led to enhancements in protection techniques. The algorithms and principles become more sophisticated in pursuit of better performance. Sometimes the vendors manage to design a protection technique that fits all applications with the minimum number of user settings. However, certain settings cannot be avoided.

Positive-sequence restraint for neutral and negative-sequence overcurrent functions [2] is a good example. The principle subtracts a small portion of the positive-sequence current magnitude from the neutral or negative-sequence current in order to dynamically compensate for system unbalance and CT errors and allows for more sensitive settings. Either a one-size-fits-all approach is selected for the amount of the positive-sequence correction, or a brand new user setting needs to be introduced.

Offset impedance for ground directional overcurrent functions for series-compensated line applications [3] is another good example. An offset impedance acts as a multiplier for the operating current before the created "voltage drop" is used to augment the polarizing voltage. As this impedance needs to be carefully selected for each application, the setting is unavoidable and quite involved.

Providing the user the flexibility to make these settings is justified by better performance for a particular application.

3. Myth 1: Overweight Instruction Manuals

A 500-page Instruction Manual for a utility-grade relay is not exceptional. Recently one-thousand-page Manuals became reality.

Several factors must be considered with respect to Instruction Manuals:

- The documents typically contain a very well organized reference material. The volume does not matter as long as the required information may be found quickly.
- The Manuals are available as searchable pdf files with bookmarks and other features that allow quick and precise search and access to required information.
- Typically Instruction Manuals contain extra chapters that are not directly related to a product or its settings. Examples are: sample applications, application notes, theory of operation, commissioning, etc.
- Instruction Manuals of modern relays may contain memory maps of all the metered values and settings, for all the supported protocols. This may account for tens of pages of a pure reference material.
- Given the number of functions and their user-programmable flexibility, a typical Manual of a microprocessor-based relay is not thicker than a collection of 20-page "Manuals" for each time overcurrent, instantaneous overcurrent, overvoltage, undervoltage, autoreclose, breaker fail, etc. function incorporated.

4. Myth 2: Plurality not Complexity

Plurality of settings must not be mistaken for complexity. Microprocessor-based relays typically contain hundreds of settings. But this is just plurality.

Probably some 80% of the settings can be set without any real engineering work just by answering "yes" or "no" to a number of straightforward questions (the questions are straightforward only after the real engineering work is done, however).

Examples are:

- Function setting for protection and control elements (enable or disable per requirements)
- SEO setting for protection and control functions (enable if an event is to be logged)
- Blocking input (indicate a flag that is meant to block an element, if any)

- Pre-/post-fault split in the oscillography record – set as needed
- User-programmable LED No. 25 – set as needed, print and attach a label
- User programmable pushbutton No.12 – set as needed, print and attach a label.

The above settings are not involved and do not increase complexity.

5. Myth 3: Increased Productivity not Complexity

Today's modern microprocessor-based relays are perceived as being complex by today's protection engineers partly because of the extremely increased amount of work assigned to them. The amount of work that used to be spread in time between a number of workers in different design, drafting and engineering groups tends to be squeezed in time and concentrated within a smaller group of engineers.

Consider scheme development. One big task is to design and verify the interconnecting logic. This logic was performed in the electromechanical technology via d.c. circuitry, and is now performed via programmable logic.

When developing the d.c. circuitry a protection engineer used to design the scheme. A drafting person would then assume responsibility for developing drawings according to utility standards. A technician would assemble and test the first panel. Many older schemes were developed over decades of trial and error with cooperation between manufacturers and users and input from engineering design and operations personnel.

With new technology a protection engineer is a designer, draft person (some PC programs provide self-documenting functions either in a graphical or textual form), an assembler (building the logic using some kind of editor) and tester (some relays allow a fair amount of testing).

Solid preliminary engineering effort before even ordering a relay would ease the setting process significantly. However up-front design has become more and more a luxury item. Because of time and resource constraints, even relatively simple issues appear to be quite complex ("perception is reality", though).

6. Myth 4: Unjustified Complexity

Perhaps "Is the complexity justified?" is a better question than "Are modern relays complex?". Complexity is not necessarily a sin – unjustified complexity is.

- Protective relaying is not a simple task! It is one of the "mission critical" areas for power systems. Protection schemes and certain settings require an in-dept analysis, short-circuit calculations, validation and testing. As long as a given setting required by a modern relay is easy to understand and the vendor provides a crisp recommendation or calculation procedure, this setting does not necessarily bring in any new complexity.
- Certain settings are required for better performance. As long as the performance is really better, extra settings or extra complexity is justified.
- Completely new features have been brought into protective relaying by modern relays. This includes digital communications, programmable logic, user-programmable keys, LEDs, messages, curves, etc. Each feature requires some settings calls for increased knowledge. If these

features are not required, their presence alone may create an impression of complexity. If these features are required and used, the associated benefits overshadow the complexity.

- New types of relays have been brought into the market such as digital line current differential or digital low-impedance busbar protection. Where new principles take advantage of the advances in technology, increased complexity are justified by better performance. Digital line current differential is a good example of increased complexity due to the novelty of the operating principle. In addition to basic protection knowledge, application of the scheme requires some knowledge for communications channels and GPS timing (interface standards, channel asymmetry, bit error rate, multiplexer, fall back strategy on GPS loss due to bad weather, etc. are new terms to be learned and dealt with). This particular application creates challenges for testing and validating as well.
- Modern relays are getting more complex partially because requirements for associated devices are getting relaxed. For example, if digital communications channels for line current differential protection were not creating any channel asymmetry, no GPS-based compensation would be required. If CTs were appropriately rated and demagnetized after faults, no sophisticated differential algorithms would be needed. If new lines were constructed instead of putting series compensation on the existing ones, no sophisticated settings for series-compensation would be required. Etc.

7. Conclusions

Modern protective relays appear complex. Multi-functionality is the primary reason for this. Modern relays are not “relays” but “Intelligent Electronic Devices”. The latter includes – in various proportions – the following: protection, control, communications, programmable logic, recording, oscillography, monitoring and metering, and some form of power quality monitoring. The IED therefore can replace control switches and indicators, panel meters, auxiliary relays, panel annunciators, fault recorders, SOE recorders, and RTUs. All of these devices have associated “learning curves”. While the "combined instruction manuals may be daunting and settings may seem overwhelming, comparisons with single-function electromechanical relays are not justified.

New fields, mostly communications, have been brought into the protective relaying world. There is a learning curve associated with these new areas. Subjectively the need to learn creates extra complexity.

There are several myths, however, regarding the complexity of modern relays: Instruction Manuals are not overweight when measured on a “per function” basis; there are many settings but the majority of them are quite straightforward; engineers tend to do “more with less” with a small allowance for learning and up-front work, thus creating subjective complexity.

Undoubtedly one will find a fair amount of complexity that is unjustified from the perspective of a given user at a given time with respect to a given application. Vendors, trying to satisfy a world market with a single or small number of products commit a “make-it-generic” sin. In most cases, however, increased complexity is justified by better performance, new functions, easier standardization and cost savings for the user.

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