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Downsizing is already a fact. New technologies must be provided to the remaining engineers.

OUR VIEWS ARE SHAPED BY OUR DIRECT EXPERIENCE in the field, which for some of us goes back almost as far as Dylan's lyrics! Electrocon started developing tools for computer-aided protection engineering in 1985, working with an advisory committee of working protection engineers from ten leading North American power utilities. The goal then was a combined network and protection system model to support automated relay setting and coordination checking. Underlying the model would be a true database management system to manage the massive data. Today, network models of 2,000 to 10,000 buses with protection system models of 5,000 to 50,000 relays are common. A master library of over 5,500 manufacturer-specific relay styles supports model development, and more relays are requested and developed all the time. (Figure 3)

The advisory committee's wisdom has become more apparent and their objectives even more relevant now, when we look at the challenges our protection community is facing twenty-five years later. We'll look at a few of the problems faced by our ever-changing electric power industry, and will propose solutions from our unique perspective as software

developers and consultants who have worked with protection groups around the world.

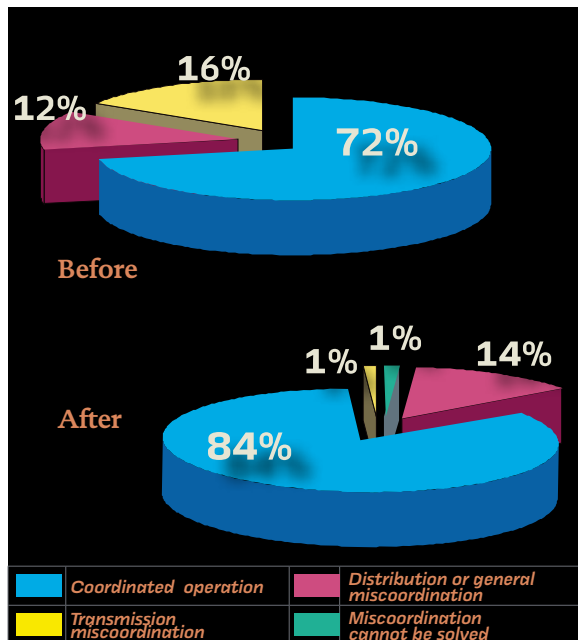
Key issues

Organizational isolation. This one might surprise you, in this age of communication, but organizational isolation is an increasingly important problem. Most utilities are interconnected with their neighbors and are interdependent with them by virtue of the energy they buy, sell, or transport, but evidence of isolation is everywhere you look. Planning, protection, and operations are separate departments within companies. Generation, transmission, and distribution functions are all served by different entities. Business people have business goals and ask questions like, "How can we make the company more profitable?" and "How can we do our work with a smaller, more efficient staff?" Engineers have engineering goals and ask questions like, "How can we provide energy more reliably?" and "How can we design our systems the right way?"

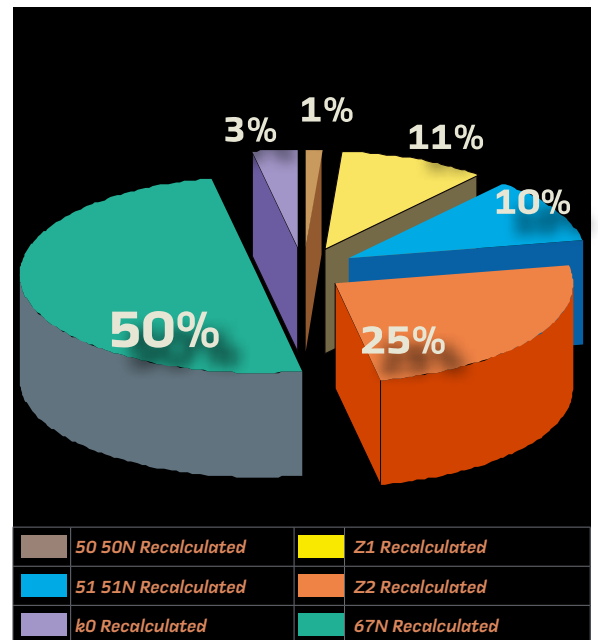
A very important effect of organizational isolation is the failure, reluctance, or inability to share data among the stakeholders who could do a better job if they had access to it. Within a given company, for example, planning, protection, and operations are separately modeling the same network. Historically, this came about because the different objectives of each group required different models of the same equipment. Whatever the reasons, the need now is for real cooperation among these groups. For example, few protection engineers have access to power flow data that would enable them to routinely account for load current extremes in their

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1 Proportion of miscoordinated conditions, before and after Wide-Area Review



2 Protection functions requiring recalculation





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Increasing complexity and additional governmental regulations are today's reality

fault calculations, which would give them better settings. Planners run electromechanical transient stability simulations without the benefit of a realistic model of the protection system, which would give more reliable warnings that the actions of protective devices may affect the scenarios being studied. Operations personnel would benefit from a timely warning if credible contingencies will overload lines to the extent of risking protective device operation. Likewise, why shouldn't SCADA systems warn the protection group about relay loading and CT rating infractions?

Companies experience parallel data sharing failures, as well. For many companies, the biggest shortcoming in the protection group's network model is the absence of an up-to-date model of their neighbors' systems. National security issues and competitive concerns play a role, but in many cases there are simply not enough people around to do the necessary communicating. Some utilities' security rules prevent vendors from examining and trouble-shooting their data, requiring the vendor instead to use guesswork and trial-and-error to find the cause of reported problems. And in a recent case, a company experienced measurable delays in restoring power after a blackout, because they were not allowed to know what generation was available to their system - this in the name of fair competition!

Experience Base. A second area of change and challenge for our profession is the diminishing experience base. We see several reasons for this. Utility reorganization (read downsizing) has been underway around the world since the early 1990's and has never led to increases in engineering

staffs. Retirements among engineers in the baby boomer generation in North America and Europe is another well-recognized cause. These losses combine with the diminished appeal to younger generations of careers in power engineering, particularly in countries with an affluent middle class and higher-paid alternatives.

Inadequate staffing contributes to another quality issue: in a surprising number of utilities the adequacy of the network model is marginal and the protection system model is absent or nearly so. We often see incorrect or incomplete transformer models, mutual couplings with reversed signs, and, on occasion, the absence of zero-sequence branch data.

Protection engineers are learning more by on-the-job-training and starting out with less depth of underlying theory and concepts. And that's even more of a problem because fewer protection groups today have resident experts or "gurus" to call on. Then, if engineers call the relay manufacturers, they find the vendors themselves have lost expertise in their old electromechanical relay products, many of which are still in service, although their builders are long gone.

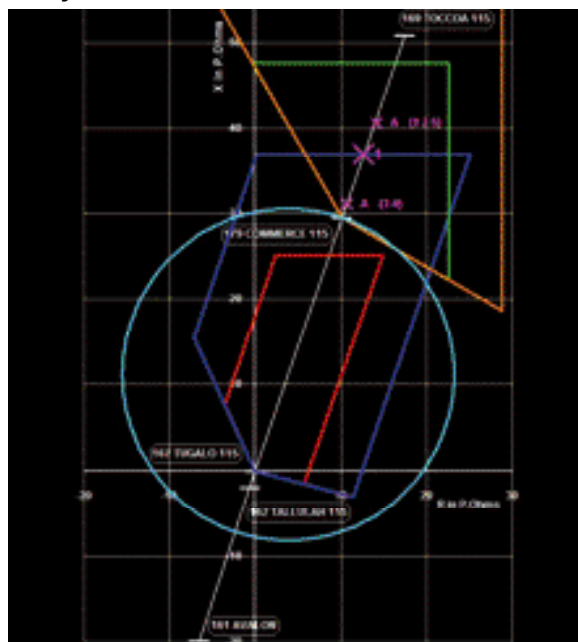
Apart from these phenomena, there is the thought-provoking observation made to us by the late Dr. Mark Enns, an IEEE Fellow and founder of Electrocon, at the end of his career: "You just don't see the towering intellects anymore who used to dominate our technical meetings." We would like to think that this is more a reflection of the stage of development of power system theory and solution methods than the numbers and mental prowess of the present generation of engineers.

Imposed Solutions. A third component of change and challenge is the effect of government-imposed requirements and solutions. The issue of energy demand vs. the environment is properly one for the public arena, but that arena can only be expected to yield more restrictive government regulations. The present light precipitation may well become a blizzard. Barring a long prayed-for breakthrough in fusion power, our civilization has two sources of new baseload energy: coal and nuclear. A heavy focus will remain on alternative energy sources and conservation, as the environmental debate heats up (pun intended). This situation can only mean great turmoil in the power industry, not to mention our society.

What has it meant so far for protection engineering? We can all appreciate that sustained blackouts lead to public outcry, which in turn leads to regulations and controls intended to avert the next one. The famous blackout in North America of August 14, 2003 led to NERC Recommendation 8a which now restricts zone 3 distance element reaches and other backup protection on operationally significant lines. Protection review deadlines were mandated on every utility.

Combinations of government regulation and the NIMBY ("not in my back yard") effect have long influenced the type and placement of large baseload plants. This has encouraged the proliferation of independent power producer plants, which are harder to accommodate and protect. Clearly this

3 R-X display of ABB, Siemens and SEL relays



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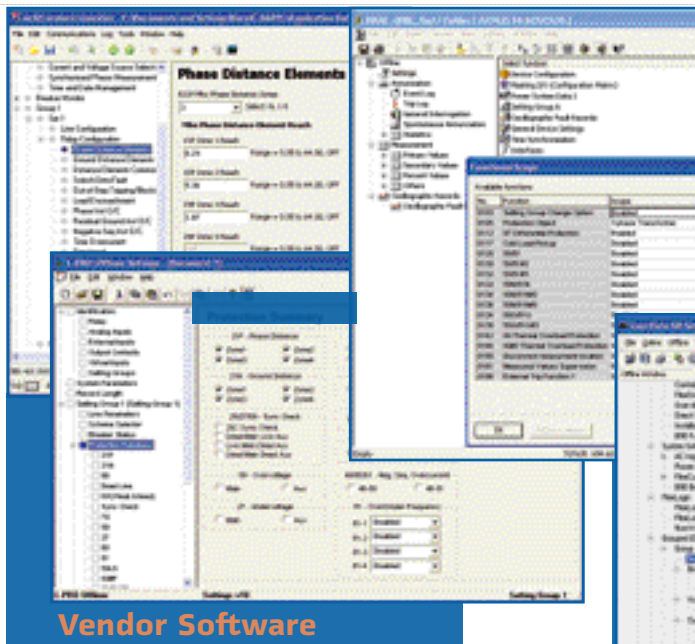
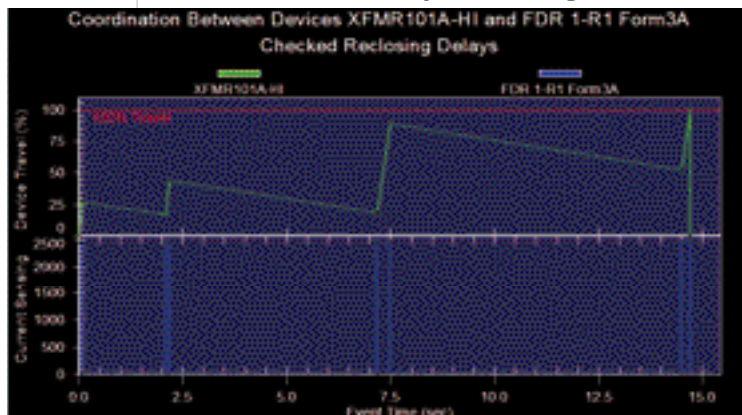
combination has yielded boom times for the wind generation industry. How to model and protect wind farms is a hot topic in our business. The power of public opinion is exemplified by a very recent news report from the state of Virginia in the USA. The state corporation commission overrode the local utility's \$14 million proposal for a five-mile overhead transmission line in favor of a \$82 million underground version. The protection engineers involved will now have the opportunity to develop their expertise in working with high-voltage cables.

Protection Complexity. We'd like to address one last force for change that certainly has brought challenge with it – the increasing technical requirements placed on power systems have led to a greater complexity of the power system in general and the protection system in particular. As population and demand grow, the electrical network becomes denser and is operated closer to design limits. As people around the world depend more on electrical energy, the societal cost of network failure motivates the design of more robust protection schemes and more of them.

How do we translate this to our experience? It's easy to answer this with another question. Back in the early days of Bob Dylan, who would have dreamed that the half dozen or so electromechanical relays in a scheme with perhaps three to four settings each would one day be replaced by one digital relay offering 100 functions and as many as 9,000 settings? Who could have imagined setting and testing one of them? Add to this the many relay manufacturers around the globe, the fact that each one offers its own software environment to manage the settings (Vendor software), and the fact that most of today's relays require special training to use. Keep in mind, too, that most utilities purchase relays from at least two manufacturers. Moreover, the protection schemes themselves have become more complex. Some form of teleprotection is often employed, and not just once but twice, as primary and backup. At this point, one may easily feel compassion for the dilemma faced by modern protection engineers. What can you do? Before suggesting solutions, we should mention some

Overcurrent
relay ratcheting
has caused
more than one
misoperation.

4 Overcurrent relay ratcheting



mitigating factors to the complexity issue. No utility uses all the available functions and most settings either don't apply to the protection functions directly, or at least do not change from installation to installation. Those that do are critical, of course, and must be computed by the protection engineer. Certainly the cost per function has dropped significantly. Also, the evolution of digital relay complexity was driven in part by a demand to solve many different protection issues associated with various governmental and engineering requirements. It seems that increasing technical feasibility and competitive one-upmanship played a role, too. With proper care, these forces can foster creativity and efficiency.

Possible Solutions

The challenges discussed above are complex. There is no single, simple solution. In fact, we expect a multitude of component solutions to become prevalent in the years to come, and these will affect multiple issues at once. The drain of experience and personnel continues and is not likely to be reversed any time soon. The solutions we are able to offer are aimed at making the best use of the engineers we have.

They may be classified into three broad categories:

- Apply new technologies to get the right answers
- Use the new technologies to counter the challenge of diminishing staff and experience
- Implement changes in data administration

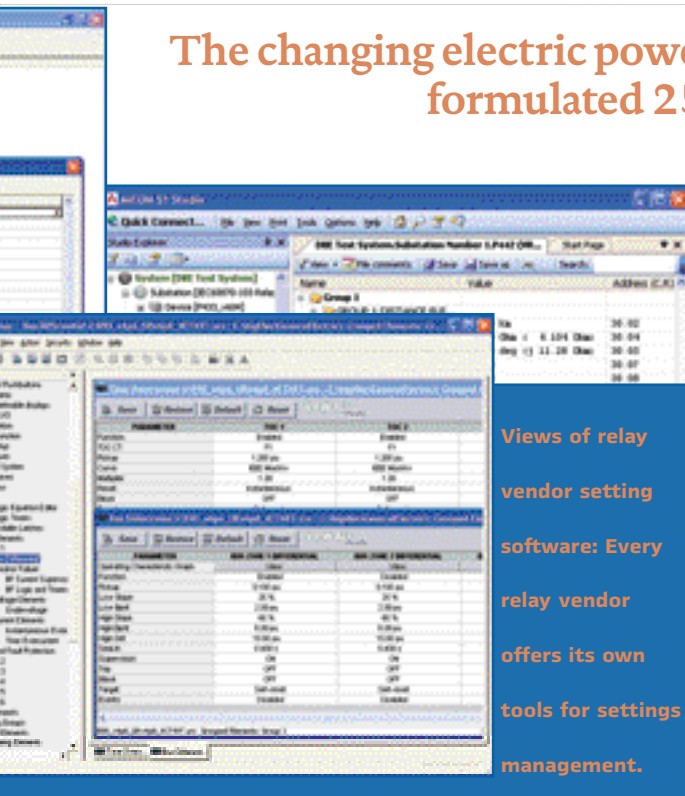
Apply new technologies to get the right answers

It is often said that protective relaying is both an art and a science – a science because the engineer can apply precise rules and techniques in developing relay settings; an art because, sometimes application of these precise rules does not quite work. The engineer has to use his or her experience, judgment, and knowledge of the power system to tweak or modify the relay settings to meet the desired objective.



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 "Tony" is the President and founder of ATG Consulting, which provides specialized protection engineering consulting services to the power industry. Prior to forming his company in 1995, Tony was Executive Vice President of GEC ALSTHOM T&D Inc. - Protection and Control Division. From 1967 to 1983, he was employed by General Electric and ASEA. He is a Fellow of IEEE and has authored over 50 technical papers. He is a frequent lecturer on all aspects of protective relaying, including electro-mechanical, solid state, and digital based equipment. Giuliani is a past Chairman of the IEEE Power System Relaying Committee 1993-1994, and past Chairman of the Relay Practices Subcommittee. He holds degrees of BSEE and MSEE from Drexel University.

The changing electric power industry has made these ideas formulated 25 years ago all the more relevant.



- Accurate modeling of the network of the neighboring utilities. This also relates to “Data Administration,” below.

- Accuracy of the protection system model: In our experience, to be able to develop relay settings for the power system, the engineer must have dependable software models of relays to work with. That is, the software model of the relay must be able to capture the behavior of the actual relay, within the framework of a phasor-based analysis.

This means that realistic comparator equations, polarization methods, internal supervision, phase selection, tripping and reclosing rules, and actual settings must be used to simulate the relay in the network model. When actual setting names are used, one has a way to share settings with the manufacturer’s setting software. Traditional analysis techniques might use a few generic methods for modeling protective devices. This works well enough for electromechanical and possibly some static relays, but the multifunction digital relays require more sophisticated modeling.

Protection engineers are increasingly recognizing the value of having such detailed relay models for analysis, and are pushing vendors of analysis tools like us to develop and supply them. Another advantage of detailed models is their usefulness in allowing evaluation of a protective device before actually purchasing it.

Automate relay setting calculations. Once the network and protection models have been verified as accurate, it is possible to perform fault studies and develop protective device settings for the power system network.

The process of developing relay settings can be automated to a large extent. The computer can be used to perform large-scale fault studies. The results of these fault studies can be used to set relays based on specific company-approved rules and parameters. Where settings of one relay depend on the settings of a neighboring relay, the algorithm can attempt to coordinate the two.

Automated setting algorithms should not be expected to replace the human protection engineer. Instead, they provide a convenient way of performing routine fault studies and “first-pass” settings calculations, or can serve as a second set of eyes reviewing settings calculated manually. However, a protection engineer may be required to review special cases.

Further, the initial settings computed by the setting algorithms will need to be tested by performing automated coordination studies. This could easily necessitate adjustments in the settings.

Interactive simulations to find miscoordinations. After verifying the network and protection models and developing initial relay settings, the engineer will normally perform interactive coordination studies to ensure that adequate coordination time interval margins are maintained between primary and backup devices.

Therefore, we propose that engineering management focus on tools and methods that give the relay engineer confidence that the protection system he or she has designed will perform as intended. Consider going outside your departmental staff resources when your workload cannot be accomplished by existing staff.

Correct your network and protective device models. The first step in designing a protection system is to ensure that the power system network is modeled correctly. Most utilities already have a phasor-based model of their network. It makes a lot of sense to use this data, verify its accuracy, improve it where necessary, and develop or evaluate protection schemes based on it.

Transient network models are very useful in performing special studies, but require specialized modeling knowledge. While this expertise is becoming increasingly available at utilities, familiarity with phasor-based models is widespread.

With phasor-based models, the following issues need to be addressed:

- Modeling of transformers and neutral circuits
- Audits on the accuracy of zero-sequence mutual coupling: Inaccurate modeling of zero-sequence mutual coupling can lead to incorrect relay settings for ground-fault protection. Many utilities have performed audits of their mutual coupling data and uncovered coordination problems due to missing couplings, reversed signs, and improper modeling of partial couplings.

Plot of dynamic expansion of digital mho element predicting operation for fault near balance point, where the actual self-polarized electromechanical relay operated too slowly.

Engineers must have tools to cope with their increasingly complex environment.

Interactive simulations may be performed to identify problem areas using the following methods:

- Graphically plotting overcurrent and/or distance relay characteristics and studying their response to applied faults. (Figure 6)

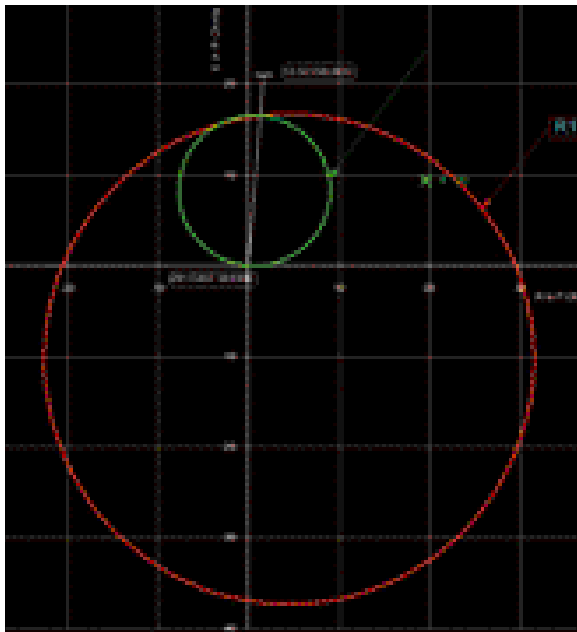
- Looking at device operating times on a one-line diagram of the network.

It is important to consider faults that test the coordination intervals between protective devices:

- Faults at overcurrent and distance element reach points
- Faults at mutual coupling separation points
- Faults that must be cleared by sequential breaker operations
- Faults in the presence of contingencies like minimum infeed conditions, outaged and grounded mutually coupled lines, etc.

An interactive study with faults applied by hand will give engineers a very good idea of the coordination problems that they might face. But the number of conditions to be tested can quickly become quite large and impractical to study manually. Such simulations may not be adequate and should be repeated over a wide-area of the network, if not the entire network.

5 Dynamic expansion of digital Mho element



Conduct wide-area coordination reviews. Protective system reliability can be measurably improved by combining the unified network and protection system model, detailed protective device models, and the power of modern computer technology to evaluate protection system performance to uncover conditions of miscoordination and, on occasion, relay design problems. Where such reviews were formerly considered a worthy but impractical goal, they are now possible and of demonstrable benefit. In one documented case, a wide-area coordination study revealed that 16% of the applied faults resulted in a miscoordinated condition. (Figures 1 and 2) The miscoordinations were mostly due to incorrect settings in the neutral directional overcurrent (67N) and zone 2 distance elements. By identifying these conditions, the utility was able to adjust the relay settings and reduce the miscoordination percentage to around 2%.

One of the interesting results of this study was the uncovering of a design problem in a distance relay, later verified by an actual misoperation in the field of the same relay. The cause was unexpected behavior of the polarizing quantity used by a ground distance element, which only a detailed relay model could uncover. This led the utility to temporarily disable the offending element in all the relays of that type until a fix was obtained from the manufacturer.

Use computer tools to respond more efficiently to government regulations. In the USA and Canada, the aftermath of the August 14, 2003 Northeast blackout brought new regulations that utilities had to comply with. One was directed at protection engineers – namely, NERC Recommendation 8a for zone 3 (backup protection) relays. Utilities with existing network and protection system models could easily automate a system-wide review to comply with the recommendation.

Use computer tools to conduct post mortem analyses. An accurate, combined network/protection system model can be a valuable tool for studying questionable relay operations. In one case we studied, an existing zone 1 relay (an electromechanical design, with a mho-supervised reactance characteristic) was slow to operate for a resistive fault. The fault was at the reach limit of the mho supervisor, which was not designed to use the prefault memory voltage for polarization. This was verified by subsequent simulation. Simulations also showed that using a digital relay with memory polarization would result in fast operation for the same fault (Figure 5). So proper representation of the equations behind the relay's operating characteristics is necessary.

Use new technologies to address the challenge of diminishing staff and experience

The methods and tools described above are also valuable as training tools.

1. Detailed models of protective relays in a master library can help counter the burden of learning relay details the hard way, particularly when the model is documented. This serves as a knowledge base when consulting an expert is not an option.

