

Evaluating the Arc-Flash Protection Benefits of IEC 61850 Communication

by Anssi Jäntti, Olavi Vähämäki, and Juha Rintala of Schneider Electric and Lauri Kumpulainen and Kimmo Kauhaniemi of the University of Vaasa, Finland

Executive summary

The goal of arc-flash protection is to minimize the damaging effects of released energy, which requires very fast and reliable communication among protection system components. In addition to discussing communication requirements and options for sensors, current transformers, relays, circuit breakers, and upper level control systems, this paper introduces and evaluates the benefits and drawbacks of new IEC 61850-based communication options.

Introduction

Arcing faults in switchgear are rare events but their consequences can be severe. Characterized as electrical explosions, the radiation, heat, pressure waves, and flying particles associated with an arc flash can injure or kill personnel. These impacts can also destroy systems components, ruin switchgear, and trigger process outages that result in unanticipated expense.

Due to the explosive nature of arcing faults, traditional overcurrent protection is often ineffective. A number of published articles in scientific publications discuss advanced methods for addressing these issues.^{1 2}

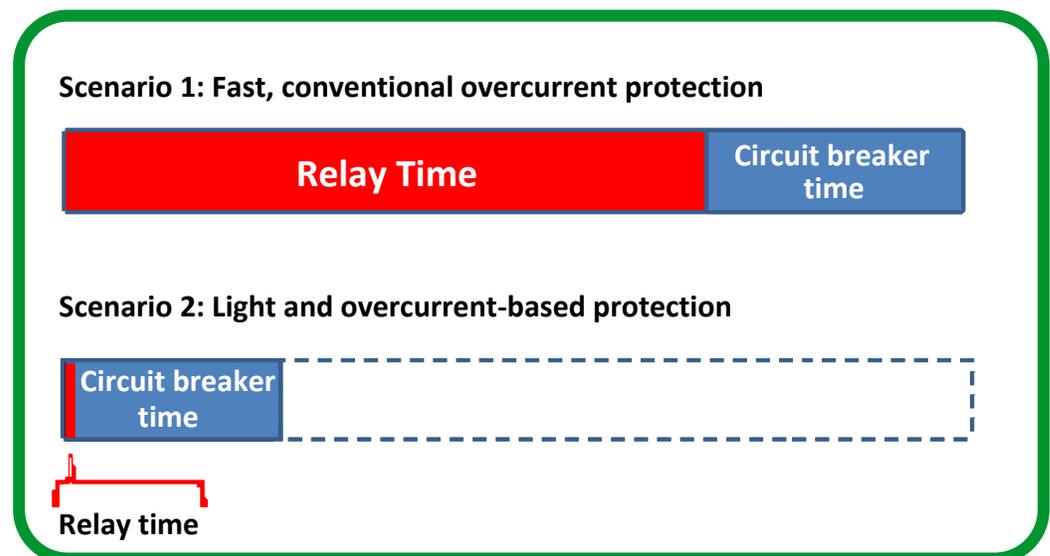
The IEEE, for instance discusses the concept of incident energy (IE), which they define as the amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event.³ Incident energy calculations were developed for defining arc-flash protection boundaries and for the development of protection strategies.

These calculations can also be applied when comparing different protection approaches. IE levels can be calculated using parameters of voltage level, working distance, bolted fault short-circuit current, and arcing time. The key parameter to influence is that of arcing time, i.e., the time required for protection to operate.

In traditional, relay-based protection, arcing time consists of arc detection time, the protection relay's operation time, the operation time of the device that extinguishes the arc, and the communication delay between components. Either a circuit breaker (CB), fuse, or a short-circuit device extinguishes the arc (see **Figure 1**, scenario 1). Protection based on the simultaneous detection of overcurrent and light provides extremely fast operation (see **Figure 1**, scenario 2). When applying this protection approach, the dominant component of the arcing time is the operation time of the circuit breaker (with that being some tens of milliseconds). On the other hand, as can be seen in **Figure 1**, relay time is dominant in traditional overcurrent protection.

Figure 1

The composition of arcing time in light- and overcurrent-based protection compared to traditional overcurrent protection



¹ J.A. Kay, J. Arvola, L. Kumpulainen, Protecting at the Speed of Light. IEEE Industry Applications Magazine, May/June 2011. pp. 12-18

² D. Shipp, D. Wood, "Mitigating Arc-Flash Exposure", IEEE Industry Applications Magazine, July/August 2011, pp. 28-37

³ IEEE Std 1584™-2002, IEEE Guide for Performing Arc-Flash Hazard Calculations, IEEE, 2002.

Arcing time of only a few milliseconds can be achieved by using a short-circuit device. When detecting an arcing fault via simultaneous light and overcurrent detection, the arc protection system sends a trip command to both the very fast short-circuit device and the appropriate circuit breaker. The short-circuit device then creates an intentional short circuit and extinguishes the arc within a few milliseconds by eliminating the voltage. Meanwhile, the circuit-breaker begins to operate and breaks the current after some tens of milliseconds. Short-circuit devices are not applied on a regular basis today, but are receiving increased interest.

Pre-emptive protection is another approach that is under development. This approach employs on-line monitoring to sense early signs of slowly developing faults. In medium voltage systems, partial discharge (PD) detection can efficiently discover early signs of isolation deterioration. However, one cannot apply the PD approach in low voltage systems, though thermal sensors have proven to be an effective means of detecting potential arc fault causes such as loose contacts.⁴

Communication between various protection system components is an essential element of all the aforementioned arc-flash protection approaches. Communication to an upper-level control system is also required. This paper reviews communication options and compares a traditional system to a new, IEC 61850-based approach.

Simultaneous light and overcurrent detection

Fast light detection

Fault arc detection times can be as short as 0.5-2ms. Testing reveals a strong correlation between arc power and the intensity of observed light.⁵ As a result, an arc can be detected almost immediately via a light-sensitive sensor such as photodiode (a point type of sensor) or optical fiber (a loop type of sensor). No precise, universal threshold value yet exists that can always differentiate between light emanating from arcing faults and light derived from other sources. However, practical experience concludes that a sensitivity of approximately 10,000 lux gives excellent results. Sensors with this level of sensitivity are likely to detect the light in all relevant arc fault situations involving metal-enclosed switchgear. At the same time, they maintain a low risk of false activation. This is especially true in cases where arc detection accompanies overcurrent detection.

Fast overcurrent detection

To eliminate possible nuisance tripping caused by external light, a current condition (i.e., detection of overcurrent) is often required in parallel with light detection. Normal current transformers can measure the current. In arc-flash protection applications, however, operation times must be minimized. Special methods can rapidly detect overcurrent. At the International Conference on Electricity Distribution (CIRED conference)⁶ an algorithm was described that employs instantaneous sampled current values, and 1 ms detection times in three-phase faults were demonstrated. An IEEE publication has described an approach that takes advantage of current waveform discontinuity (change in di/dt) to achieve very fast overcurrent detection.⁷ Applying an analog comparator can also enable fast overcurrent detection.

⁴ H. B. Land, III, C.L. Eddins, L. R. Gauthier, Jr., J. M. Klimek, Design of a Sensor to Predict Arcing Faults in Nuclear Switchgear. IEEE Transactions on Nuclear Science, Vol. 50, Issue 4, 2003, pp. 1161-1165

⁵ B. Melouki, M. Lieutier, A. Lefort, The correlation between luminous and electric arc characteristics. Journal of Physics D: Applied Physics, Vol. 29, Number 11, 1996, pp. 2907-2914

⁶ M. Öhrström, L. Söder, H. Breder, Fast fault detection for peak current limitation based on few samples. Proceedings of CIRED 2003, Barcelona, 12-15 May, 2003

⁷ R. Garzon, The Arc Terminator, IEEE Industry Applications Magazine, Vol. 9, Issue 3, 2003, pp. 51-55

Because many arcing faults start as single-phase faults, phase-to-earth fault detection is also justified. If an arc is detected and eliminated before it escalates into a high-power, three-phase fault, the damage is less.

How to avoid nuisance tripping caused by switching arcs

In almost all cases, in both medium (MV) and low voltage (LV) systems, the trip condition of simultaneous light and overcurrent detection is a proven success. However, some low voltage circuit breakers (air-magnetic types) emit light while operating. Use of a special type of light sensor (which is less sensitive or designed for a limited wavelength range) or applying pressure sensors can mitigate this problem.

Dedicated arc-flash protection system communication approach

Existing system architecture

This section describes the operating principles of a state-of-the-art arc-flash protection system. Other systems operate under similar principles. Although its basic functionality is fairly simple, the complete arc-flash protection system consists of several components. Providing selective protection by dividing installations into individual protection zones is a key approach. **Figure 2** illustrates a rather complicated design with different parts of the installation marked as different protection zones. The arc-flash protection system mainly comprises the following four types of components:

- Sensors (light or current)
- I/O units
- Central units
- Communication cables

The system requires additional components (e.g., a battery-backed auxiliary power supply system) but these are omitted for the sake of simplicity.

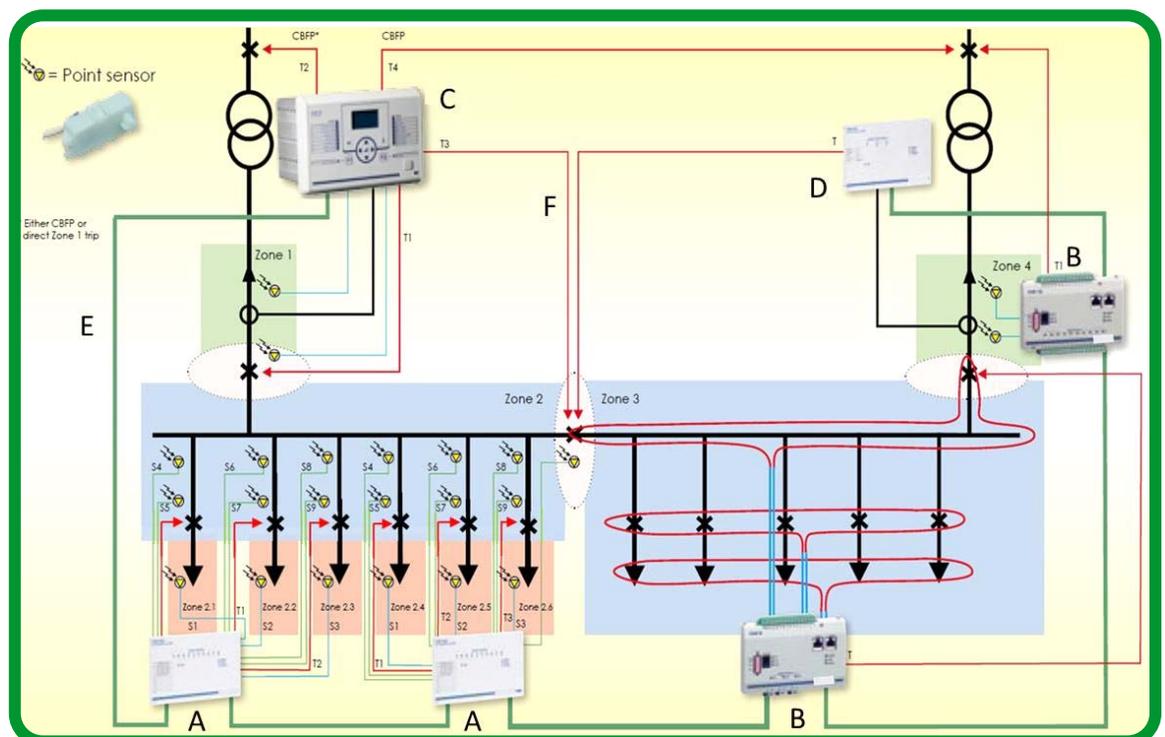


Figure 2
An example of a dedicated arc-flash protection system for an MV substation

On the left side of **Figure 2**, point sensors detect light. On the right side, the installation is equipped with fiber optic sensors. I/O units read the sensors and send sensor information to the common communication pathway. The point sensors connect to I/O units in Zone 2 (A) and fibers connect to an I/O unit in Zone 3 (B). I/O units can perform a local trip based on information from the sensors connected to the I/O device itself, or based on a signal from any other I/O unit in the same zone. All light sensors connected to one I/O unit can only belong to one particular zone. Five zones are available, one of which is always reserved for transferring overcurrent information.

Current can be measured by current transformers connected either directly to the arc-flash protection central unit (C) or to a current I/O unit (D). All units are linked to the central unit by the communication cables (E). Circuit breakers receive trip commands from the central unit or from the I/O units via circuit breaker wiring (F).

The system architecture is centralized and the central unit is always required. The central unit monitors the system (self-supervision) and maintains communication. It can also perform trips based on the light sensors connected to the central unit itself or based on the information received from the I/O units. In addition, the central unit can communicate with SCADA systems by using various standard protocols.

Dedicated arc-flash protection system communication

I/O units are linked to the central unit with modular cables. Each I/O unit and the central unit have two modular cable connectors. Therefore, if one wants to connect more than two I/O units to the system, they must be daisy-chained. That means that only line topology is supported. To be precise, the devices do not actually act as repeaters by reading the information received from the communication pathway and then passing it on to the next device. The topology actually is not a line, but a bus. **Figure 3** illustrates these two different network topologies among other common ones.

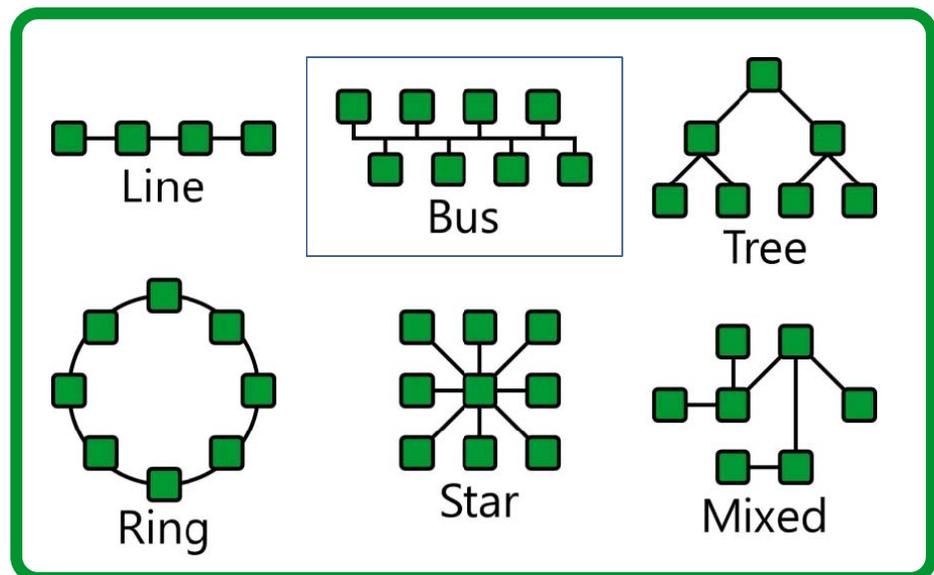


Figure 3
Commonly used network
topologies

A major advantage of using a bus topology is that the devices do not have to act as repeaters. This approach supports very fast communication, as adding new devices to the network does not slow communication.

Two somewhat independent communication pathways are utilized when communicating between I/O units and the central units. Both reside inside the same modular cable but utilize different wires. The first of these communication pathways is a simple, fast, infinitely repeating frame, only a few bits long, containing zone-based activation information. Each of the devices in the network can use this to report activation (i.e., detected light or current) in any of the available zones. The second communication pathway is slower communication used during, for example, installation, querying sensor status, or releasing latches. Both of these communication types are proprietary and nonstandard. Also, both of these communication types are controlled by a central unit. There is no communication through the modular cable between the I/O units without the central unit being present and operational. These proprietary communication pathways are also designed for relatively short-range communication.

Power supply to I/O units

In addition to communication, the modular cable is used to supply power to the I/O units from the central unit. An external power supply is required after a certain amount of cabling or number of I/O units. When connected to an external power supply, an I/O unit can further distribute power to the surrounding I/O units through the modular cable.

Proprietary communication system limitations

Experiences with the communication system described previously have been positive. Regarding speed and reliability, performance is excellent. However, this system has some limitations. The system is nonstandard and designed for relatively short-range communication; the maximum length of total cabling is about 100m. The topology of the network must always be a bus, and this poses further limitations. The maximum number of zones is five, and the proprietary communication protocol does not provide a convenient way of increasing this. Furthermore, in certain installations, it would be advantageous to configure the sensors in a single device to reside in more than one zone.

Communication system performance

A series of tests were conducted in order to determine the performance of the communication system described above. Several configurations were constructed using key components; light sensors, I/O units, and a central unit. Several I/O units were always present in each of the different configurations in order to simulate actual installations.

Ten sensors were connected to each of the I/O units in the case of point type sensors and one sensor in the case of fiber type sensors. Regarding the point sensors, a total of 10 sensors were always activated simultaneously, simulating the worst case in an actual installation. A piece of sheet metal was used to fasten the sensors as close to each other as possible in order to ensure that they would activate at the same time. A professional-grade camera flash was used to activate the sensors.

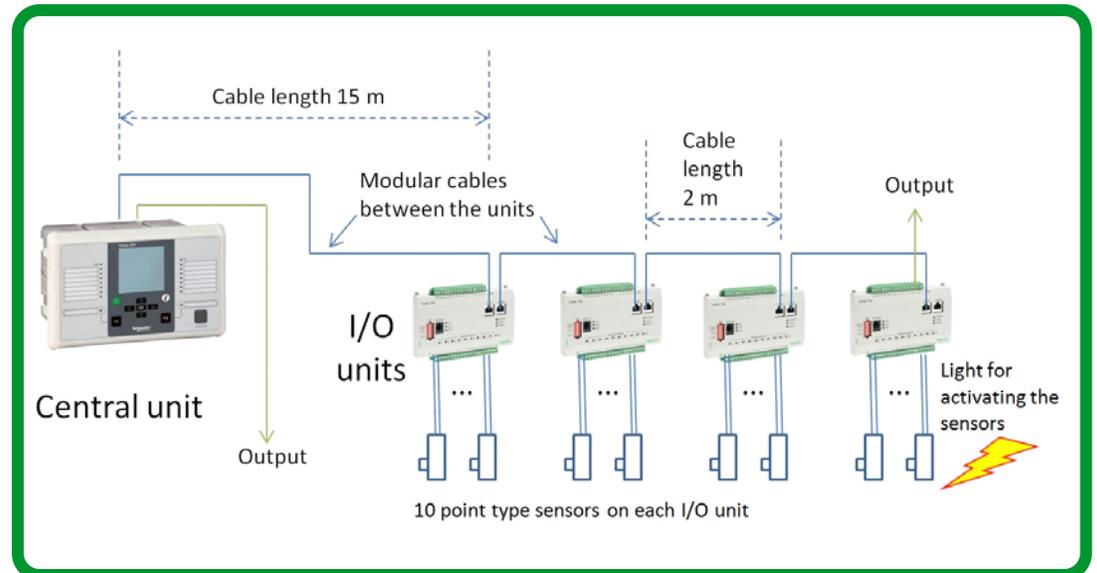
As mentioned, the units had to be daisy-chained with the modular cable. Different types and lengths of cables were used during the testing. In these tests, only modular cable was used to link the I/O units to each other and to the central unit. The central unit was always positioned at one end of the bus and the I/O unit with the activated sensor at the opposite end. No additional power wiring or power supplies were used. **Figure 4** illustrates one of the test installations.

In order to evaluate performance, system reaction time (time from light detection to trip) was measured. This was achieved by using an oscilloscope to measure the trip times of both the central unit and the I/O unit on which the sensors were activated. Trip times were measured from the point of the sensors activating on the last I/O unit to the output relay contacts closing

on both the central unit and on the I/O unit itself. The relays in the devices were configured to latch on light detection.

Figure 4

Configuration of test case #2, shown as an example

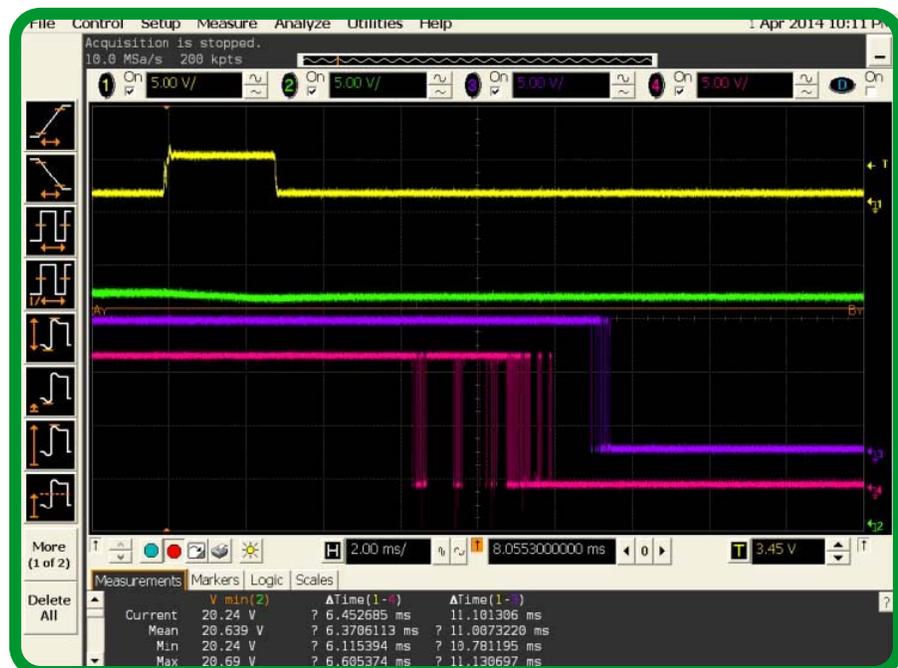


A four-channel oscilloscope was used to perform the measurements. The first channel of the oscilloscope was connected to one of the activated light sensors. The second channel was used to measure the operating voltage of the last I/O unit in the chain during trip/light detection. The third channel was connected to the output relay of the last I/O unit, and the fourth channel was connected to the output relay on the central unit.

The oscilloscope Delta Time feature was used to measure trip delays. Channel 1 rising edge and channel 3 and 4 falling edges were used as the signal sources. Trip delay measurements were performed 10 times for each test case. An example is illustrated in **Figure 5**.

Figure 5

Oscilloscope with the voltage and Delta Time measurements



The following cable lengths were used during testing: 2 meters, 15 meters, and 30 meters. In situations where different cables lengths were used in one test, the longest cable was always connected between the master and the first I/O unit because this is the worst case. The following combinations were tested:

1. Five point type sensor units, five 2m cables
2. Four point type sensor units, one 15m cable, three 2m cables
3. Three point type sensor units, one 30m cable, two 2m cables
4. Five fiber type sensor units, five 2m cables
5. Four fiber type sensor units, one 15m cable, three 2m cables
6. Three fiber type sensor units, one 30m cable, two 2m cables
7. Four point type sensor units, one current sensor unit, five 2m cables
8. Three point type sensor units, one current sensor unit, one 15m cable, three 2m cables
9. Two point type sensor units, one current sensor unit, one 30m cable, two 2m cables

Ten measurements were performed for each of the nine test cases. **Table 1** lists the mean, minimum, and maximum trip times of these tests. The measurements were taken from the mechanical output relays, so the delay caused by the relays is included in the measurements. Use of high-speed semiconductor/hybrid outputs would have produced better results.

Test case #	Central unit trip time (ms)			I/O unit trip time (ms)		
	Mean	Min	Max	Mean	Min	Max
1	6.32	6.2	6.41	10.73	10.23	11.05
2	6.28	6.08	6.46	10.37	9.81	10.75
3	6.28	6.15	6.42	11.16	10.85	11.37
4	4.7	4.62	4.79	7.68	7.53	7.96
5	4.75	4.64	4.88	7.82	7.6	8.28
6	4.81	4.47	4.88	7.86	7.74	8.39
7	6.19	6.07	6.38	10.34	9.82	10.56
8	6.27	6.03	6.45	10.05	9.58	10.58
9	6.37	6.12	6.61	11.01	10.78	11.13

Table 1

Mean, minimum, and maximum trip times in the tests

The results show that fiber type sensors are slightly faster than point type sensors. The tests also show that a slight variation of the I/O units' trip times exists depending on the configuration. Based on the results, it can be determined that with point type sensors, the average trip time for the central unit is about 6.29ms. The average trip time for the I/O unit is about 10.61ms. With fiber sensors, the respective trip times are 4.75ms and 7.79ms.

IEC 61850 communication in arc-flash protection systems

Ethernet-based communications in general and IEC 61850-based technology in particular are rarely applied in arc-flash protection systems. However, zone-selective interlocking (ZSI) is a common application closely related to arc-flash protection. In ZSI, IEC 61850 and Generic Object Oriented Substation Events (GOOSE) have successfully been utilized,⁸ but ZSI is slower than light/overcurrent-based arc-flash protection.⁹

GOOSE messages are limited to relay-to-relay communications in light/overcurrent-based arc-flash protection systems.¹⁰ GOOSE messaging can also be applied for communication between other components of arc-flash protection systems: sensors, input/output units, relays, and circuit breakers. The essential question is whether GOOSE can provide the required speed and reliability.

In order to avoid delays caused by network traffic, virtual local area networks (VLAN) are used to separate priority and non-priority traffic on the network.^{11 12} Another means to enable very fast communication is to utilize high-speed fiber media for networking the devices.^{13 14} Previous studies have shown that the speed of GOOSE-based communication is as good as direct serial communication.¹²

Principles of an IEC 61850/GOOSE arc-flash protection system approach

An IEC 61850/GOOSE-based arc-flash protection system shares the same four basic components as the proprietary system previously described: sensors, I/O units, central units, and cables. In this scenario, however, the central unit is an optional component. The system architecture is distributed instead of centralized, and the system can operate perfectly without the central unit. This makes the system more robust. The central unit can, however, still serve as a centralized information collection and communication device that can be used as a gateway for relaying information to SCADA systems, for example.

The proprietary system differentiates between the arc-flash protection network and the upper-level communication network (e.g., connection to SCADA) in two ways. First, the protocol in the arc-flash protection communication is proprietary. It also has separate physical connectors for the different networks. This is an important factor for improving an installation's cybersecurity. The same kind of security can also be achieved when using an IEC 61850-based approach by having two separate processors, two independent network stacks, and two physically different Ethernet connectors for the different networks.

The concept of zones still exists in the new system. However, the zone settings in this system do not need to be configured at the I/O unit level. They can also be set at the sensor level.

⁸ J. Holbach, Mitigation of Arc Flash hazard by using Protection solution, 60th Annual Conference for Protective Relay Engineers, IEEE, 2007. pp. 239-250

⁹ C. Cabrera, S. Chiu, N.K.C. Nair, Implementation of Arc-Flash Protection Using IEC 61850 Goose Messaging. Conference Record of IEEE International Conference on Power System Technology (POWERCON), 2012, pp. 1-6

¹⁰ G. Rocha, E. Zanirato, F. Ayello, R. Taninaga, Arc-Flash Protection for Low- and Medium-Voltage Panels. Paper No. PCIC-2011-25, IEEE Petroleum and Chemical Industry Committee Technical Conference, Toronto, 19-21 Sept. 2011

¹¹ L. Sevov, T.W. Zhao, I. Voloh, The Power of IEC 61850. IEEE Industry Applications Magazine, Jan/Feb 2013. pp. 60-67

¹² F. Dixon, M.T. Yunas, V. Wedelich, J. Howard, H.E. Brown, S.N. Sauer, Y. Xu, T. Markello, W. Sheikh, Mitigating Arc Flashes Using IEC 61850. IEEE Industry Applications Magazine, Jan/Feb 2014. pp. 64-69

¹³ L. Kumpulainen, O. Vähämäki, T. Harju, A. Jäntti, Enhancement of Arc-Flash Protection by IEC 61850. Conference proceedings of PAC World 2012, Budapest, 25-28 June 2012

¹⁴ D.C. Mazur, J.A. Kay, J.H. Kreiter, Benefits of IEC 61850 Standard for Power Monitoring and Management Systems in Forest Product Industries. Conference Record of IEEE Pulp and Paper Industry Technical Conference, 2013, pp. 69-75

Each of the sensors can be individually configured to transmit activations of any zone, and one sensor can even belong to multiple zones. This is true for both light and current sensors. The number of the zones can be as high as 16. The same zone can contain either light and current sensors or just one type of sensor. This provides more flexibility for configuration.

Diversity of usable network topologies

The IEC 61850/GOOSE system also uses modular cables. Each I/O unit has two modular cable connectors as does the proprietary approach, but uses IEC 61850 and GOOSE communication, which operate over Ethernet. Because communication is Ethernet based, all topologies supported by Ethernet are also supported by the new arc-flash protection system. This includes line, star, tree, and mixed or hybrid topologies. Looped connections are not supported by standard Ethernet, but new I/O units are equipped with special hardware that can accommodate ring networks.

Power supply

The new system again uses a somewhat similar approach to the previous one; the central unit can supply power to the I/O units by using a technology sometimes referred to as “Passive PoE.” This can be described as a somewhat simplified version of the standard PoE (Power over Ethernet). Some manufacturers have already chosen to support this simplified version in their products. Limitations imposed by the actual PoE standard¹⁵ make implementation impossible in daisy-chained devices, for example. Limitations still exist regarding the length of cabling and number of I/O units that the central unit can supply. In these cases, the I/O units can again be equipped with external power supplies. In future implementations, separate devices will be able to supply extra power to devices through modular cables.

Communication

In the IEC 61850/GOOSE system, two distinct types of communication pathways exist: 1. fast communication for relaying zone information, and 2. lower priority control and configuration communication pathway. The fast communication is implemented with GOOSE messages over Ethernet. One advantage of this is that the protocol is standardized. GOOSE protocol also already implements many features that are useful for arc-flash protection devices. For example, GOOSE messages are broadcast messages, which support distributed architecture. GOOSE messages are also constantly repeated and this can be used to keep a count of the devices present in the network. The GOOSE protocol is also relatively simple. It can be fairly easily implemented on embedded devices while retaining good performance regarding time constraints.

When comparing the previously described proprietary communication pathway to GOOSE messages, the latter has considerably higher overhead in the amount of transferred data and the amount of time taken to process the communication. This is a natural result of GOOSE being a more universal way of communicating, while the proprietary system was designed specifically for the application at hand. However, as considerable communication overhead already exists from using GOOSE messages and Ethernet, including additional payload information to the communication frames, there is not a major relative increase in transmission or processing times. It therefore makes sense to transfer other useful information in the messages in addition to only the zone information. The same frames contain, for example, information about the activated sensors and detected errors.

The GOOSE protocol does not support the transferring of, for example, configuration information. Other parts of the IEC 61850 standard could be used for these purposes.

¹⁵ IEEE Standard for Ethernet. IEEE Std 802.3-2012
Schneider Electric White Paper Revision 0

However, such an approach represents heavy workloads for small CPUs and is difficult to implement. To address this issue, a proprietary GOOSE-based protocol was developed.

A major advantage of Ethernet is that connections are limited to 100m only for each link, and the range can easily be extended with Ethernet switches. Each of the I/O units in the new system has a built-in switch so the distance between each unit can be up to 100m. There is no theoretical limit to the maximum length of total cabling. A drawback to this approach is that each additional hop causes message delays.

Performance of the developed system

As with the traditional arc-flash protection system described earlier in this paper, the performance (i.e., trip time) of the IEC 61850/GOOSE system was also tested. The tests were conducted using four prototype devices. A point type arc sensor was connected to one of the devices, with 0.5m cables used to link the devices. Line topology was used and power to the devices was provided by using a commercially available Passive PoE-capable Ethernet switch. The devices were configured so that sensor activation on one of the devices would cause output to be activated on all devices in the network. As this system does not require a central unit, these tests were conducted without one. **Figure 6** illustrates the system used for testing.

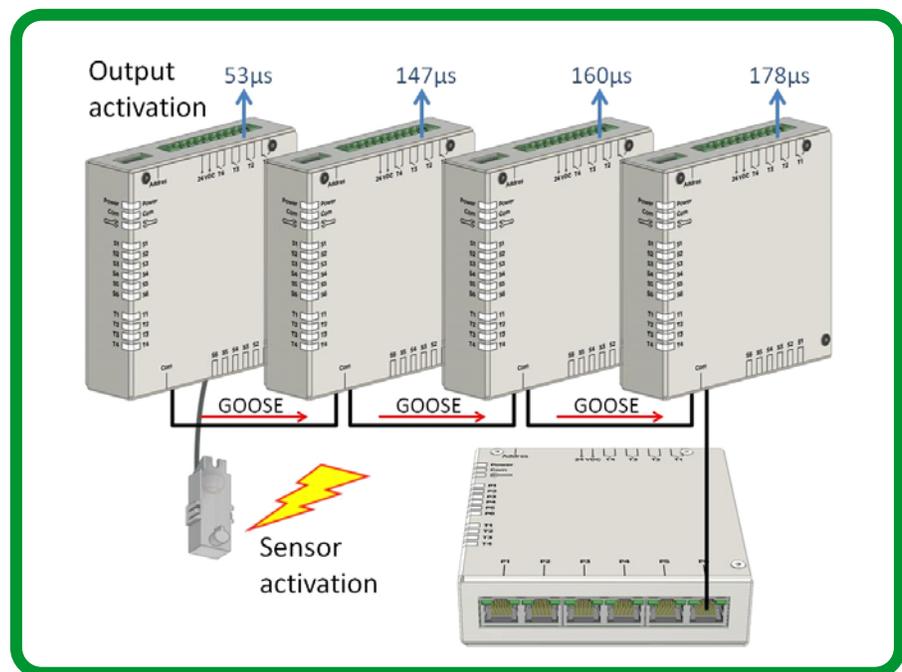


Figure 6
Configuration of the GOOSE-based arc-flash protection system test setup

An oscilloscope was again used to take measurements. The first channel of the oscilloscope was connected to the same sensor input as the point type arc sensor. The second channel was connected to the transistor controlling an output relay on each device. Measurements were repeated 10 times. A two-channel oscilloscope was used and the measurements were then also repeated four times, while always moving the second oscilloscope channel to the output of another device.

Table 2 lists the results of the testing. The first column indicates the test number. The second column is the time from the first device's arc sensor input activation to the same device's output relay control signal activation. The third column is from the first device's arc sensor input activation to the second device's output signal activation and so on. Measurements are expressed in μs .

Table 2

Measured delays in the testing of the GOOSE-based system

Test #	Device 1->1	Device 1->2	Device 1->3	Device 1->4
1	32.8	116	138	172
2	40	160	158	174
3	58.4	136	156	148
4	32.8	156	150	184
5	106.4	180	138	172
6	40.8	159	162	170
7	97.6	128	168	214
8	25.8	156	162	168
9	39.2	120	178	184
10	58.4	102	118	174
11	60.8	168	166	176
12	36.8	134	170	198
13	60	180	182	192
14	42.4	170	190	170
15	52.8	136	198	186
16	29.6	150	180	190
17	49.6	142	148	158
18	95.2	154	136	190
19	41.6	130	148	144
20	51.2	160	158	194
Min	25.8	102	118	144
Max	106.4	180	158	194
Avg	53	147	160	178

The results show that the average time for a local trip is 53µs and the transfer time from one device to another is 147µs. Also, based on the results, it can be determined that each hop seems to create an additional 15.5µs delay.

$$\frac{(160 - 147) + (178 - 160)}{2} = 15.5$$

These results cannot be directly compared to the results of the tests conducted on the traditional system (see **Table 1**). The measurements of the previous tests took into account the operating delay of the mechanical relay contacts, whereas these measurements were taken directly from the transistor controlling the relay. However, comparing the results demonstrates the fundamental difference in these approaches: In the previously described system, adding more devices does not directly affect the operational delay. With the Ethernet-based system, each additional hop slightly increases operation time. This can be mitigated by using different kinds of network topology that minimize the amount of hops in the network.

Conclusion

The older arc-flash protection system described in this paper has been available on the market for over 10 years. Both laboratory tests and field performance have proven the system to be robust and reliable. The proprietary communication system is also very fast, because it was initially designed for that particular purpose. This older, proprietary system does have certain limitations, however.

In order to overcome these limitations, a new IEC 61850- and GOOSE-based system was developed. The functionality and performance of the new system was verified through testing. Also, cybersecurity features present on the proprietary system can be taken into account when applying IEC 61850.

The GOOSE-based system has many benefits. One of these benefits is being an established standard. Using Ethernet also provides access to different network protocols while offering new freedom when designing networks.

Various doubts have been raised regarding the usability of IEC 61850-based communication in arc-flash protection. It has now been shown, however, that GOOSE communication over Ethernet can be implemented in such a manner that it is fast enough to be applied for even arc protection systems.



About the authors

Anssi Jääntti received his M.Sc (Tech.) degree in computer science from the University of Vaasa, Finland, in 2012. He works as a design engineer at Vamp Oy/Schneider Electric and also teaches computer science at the University of Vaasa.

Kimmo Kauhaniemi received his M.Sc and D.Sc. (Tech.) degrees in electrical engineering from Tampere University of Technology, Finland, in 1987 and 1993, respectively. He is currently with the University of Vaasa, where he is professor of electrical engineering and has also worked for ABB Corporate Research and the VTT Technical Research Centre of Finland. His special interest areas include power system transient simulation, protection of power systems, grid integration of distributed generation, and microgrids.

Lauri Kumpulainen received his M.Sc. and Licentiate degrees in electrical power engineering from Tampere University of Technology, Finland, in 1987 and 2000, respectively. He works with the University of Vaasa, Finland, and was previously Research Director with Vamp Ltd. and Program Director with Oy Merinova Ab, acting as the national coordinator of the Energy Cluster in the Finnish national Centre of Expertise Programme. He has authored a number of conference and journal papers, particularly related to arc-flash protection and the impact of distributed generation.

Juha Rintala received his B.Sc. degree in information technology from University of Applied Sciences in Vaasa, Finland, in 2006. He currently works at Vamp Oy/Schneider-Electric as offer manager/AED expert in arc-flash protection and has held the roles of HW design engineer and after-sales engineer/arc-flash expert.

Olavi Vähämäki received his M.Sc. degree from Oulu University, Finland, in 1982. He works with Vamp Oy/Schneider Electric in Vaasa, Finland, where he is the R&D Director and has held other R&D positions with the company. His special interest areas include power system communications.