HOW TO BUILD SMARTER ELECTRICAL SUBSTATIONS BY MIMICKING BIOLOGY

Georges BARBARIN
Schneider-Electric SEISAS – France
Georges.barbarin@schneider-electric.com

Pierre-Michael SCHMITT
Schneider-Electric SEISAS – France
Pierre-michael.schmitt@schneider-electric.com

ABSTRACT

What do human biology and electrical power distribution systems have in common? Perhaps surprisingly, quite a lot. These similarities can inspire electrical distribution networks' design and management and risk minimization efforts. To understand why biomimicry helps utilities build smarter electrical substations, consider the functions of the human body.

INTRODUCTION

Our bodies are innately designed to mitigate the danger of a shutdown (death), run optimally, self-maintain, and protect themselves from risk to give us the best chance of continued operation (life) using a variety of maintenance strategies and service delivery vehicles. Electrical distribution equipment and networks are designed in the same way, so employing biomimicry for switchgear modernization and maintenance and in the deployment of sensors and connected substation technology makes sense.

For example, think about the human nervous system. The central nervous system integrates information from the entire body to coordinate activity, while the peripheral nervous system acts as a relay that connects the central nervous system to the limbs and organs.

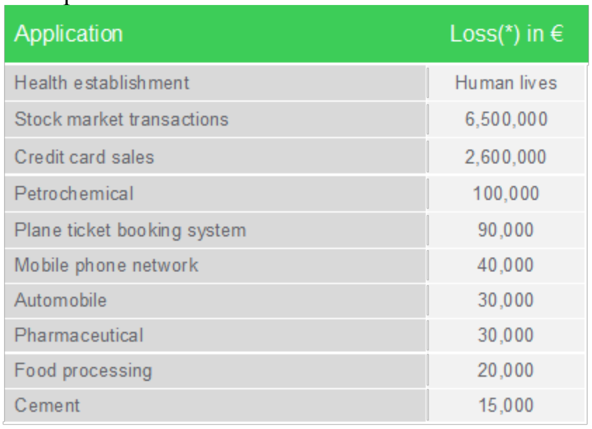
Likewise, an analogous ecosystem in the electrical distribution context also has similar layers that must communicate with each other. There's the physical grid – the hardware, equipment, and assets in operation in the field – that is capable of upstream communication. This is fundamental for the grid's survival and operations and functions much like a human heart. At the next level is edge control – systems that connect to, coordinate, and manage the way field equipment works – similar to how the autonomic nervous system communicates with downstream organs. At the highest position are the grid apps, analytics, and services that function like the brain.

RISK MANAGEMENT

What is risk management?

Let's begin with a straightforward definition. According to ISO 31000, risk management entails "the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities. Risk management's objective is to assure uncertainty does not deflect the endeavour from the business goals."

Risks can come from various sources including uncertainty. In the electrical distribution domain, two very clear drivers of risk mitigation or management are the threat to the reliability of power networks and the goal of avoiding the substantial expenses incurred by outages that cause production shutdowns.



Application	Loss(*) in €
Health establishment	Human lives
Stock market transactions	6,500,000
Credit card sales	2,600,000
Petrochemical	100,000
Plane ticket booking system	90,000
Mobile phone network	40,000
Automobile	30,000
Pharmaceutical	30,000
Food processing	20,000
Cement	15,000

Table 1

Financial impact of one hour's production shutdown (Source: Contingency Planning Research and Schneider Electric)

Which risks to manage ?

For electrical distribution equipment at the substation, of which switchgear forms the heart, care must be taken to minimize the likelihood of the various situations that lead to equipment failure. The following are the top five causes of switchgear failure1:

- Loose connections
- Insulation breakdown
- Water/humidity
- Breaker racking
- Faulty ground fault protection

The means through which risk to substation equipment is minimized is through design engineering and technology modernization, sound maintenance strategies, and appropriate levels of service.

Like physical, inanimate equipment in the field, our own bodies must also mitigate risk of system shut down to give the organism (us!) the best chance of continued operation, which in this case might be better characterized as 'existence.' The innate biological mechanisms employed by our bodies also utilize different maintenance strategies and service delivery vehicles to make sure we're up and running in an optimal way.

HUMAN BIOLOGY'S STRATEGY APPLIED TO ELECTRICAL INSTALLATIONS

Different circumstances, different actors

Think back to biology basics and consider the human nervous system. You've got a central nervous system composed of brain and spinal cord, and a peripheral nervous system which is normally categorized into two systems: the somatic and autonomic. The somatic controls things we can do voluntarily, like move skeletal muscles, and the autonomic covers the involuntary, like heartbeat regulation.

An analogous ecosystem in the electrical distribution context contains similar layers, each of which must communicate with the other. There is foundational level of hardware, equipment and assets in operation in the field, composing the physical grid itself and capable of upstream communication, much like the heart or other organs that are fundamental to an organism's existence. A step up from field equipment is edge control, which are systems that connect to, coordinate, and manage the way field equipment works, much in the same way the autonomic nervous system communicates with its downstream organs. At the highest level are the grid apps, analytics, and services that feed the edge control systems with data and the means to make the best possible decisions based on information collected from the rest of the system. This mirrors the functions of the brain; whose job is identical.

In humans, the somatic and autonomic nervous systems comprise a magnificent array and staggeringly large volume of cells whose purpose is not only to act as sensors but also man-age the feat of communicating information to and across the other components of the nervous system and with the primary control center, the brain.

In the distribution grid, connected equipment capable of communicating upstream and downstream of their location and with the control center is also crucial. Data about equipment status and knowledge of network state must be shared not only with the control centre, but also with neighboring devices.

Sense and sensibility

We have our nervous system to thank for thorough sensory perception, among other things. It manages the collection of important information about the condition and state of the organism to which it belongs.

In electrical distribution systems, particularly in substations, modern smart grid technology is accomplishing the same thing. In medium-voltage switchgear, for example, distribution grid operators can take advantage of a variety of sensors that detect and communicate in-formation about the equipment, such as thermal information or humidity conditions. These sensors provide grid operators and the technology they use with a strong situational awareness of the state and health of grid equipment.

In humans, one particularly interesting detail of this vastly complex communication and control network is the allocation of nerves, and the amount of resources dedicated to processing the information they send. Sensory nerves are located in many places, but highly concentrated in the places where they are used most and the most information is required, such as in our hands and in sensory organs we use to perceive the world.

In electric distribution grids, sensors accomplish these goals of measuring and transmitting data to be analysed into useful, actionable insights. They also tend to be located in the places where they are most needed, which is often within substations and the equipment operating therein. Protection relays, for example, sample and measure relevant equipment values such as current and voltage characteristics and trigger downstream or upstream network responses when values deviate from acceptable levels defined by their configurations.

Responding to stimuli

Consider the body's approach to incident response. The first item in the order of operations is an event, some sort of occurrence that disrupts the normal state of operation. A hand accidentally placed on a stovetop's hot burner, for example. The ability to notice this abnormal and potentially damaging event is the first step, which the nerves sense and respond to.

This first layer of decision making can take place via a reflex arc without the consultation of the brain, in order to provide the most expedient possible response in a potentially dangerous situation. This very fast and reasonably local decision-making layer informed by thermal sensors in the skin causes the rapid removal if the hand from the heat.

The nature of the response to distribution network events depends on the nature of the event itself, and the likely severity of the consequences of the event. The layers of decision-making vary accordingly.

For example, for fast, high-criticality, high-impact and unexpected phenomenon, sensors, decision processes, and actuators are bundled together to increase communication speed and reduce communication errors, reaction times, and risk of colliding information within the network. This could involve a mostly dedicated system like a protection relay preventing a short circuit. Arc-flash protection is another example.

For medium speed phenomenon like the unexpected shutdown of one of the two utility supply feeds, the network reconfiguration is managed by upper layers. The same would be true in the case of a loss of power causing the activation of a UPS, which in turn causes the start up of a diesel generator, or even a second diesel generator as a redundant third line of defence.

For slower phenomena with a minimum impact on the process, such as the unexpected increase of energy consumption, data can be analysed remotely by smart software or services that provide corrective mechanisms. Some phenomena require lengthy sampling or measurement periods in order to detect or diagnose detrimental irregularities before launching an appropriate response.

Energy consumption analyses don’t necessarily require fast acquisition of energy consumption data. These analyses are based on hourly, daily, or weekly time ranges, and corrective actions are taken in the same time frame.

Healing and repair operations

Let’s look at the some of the ways our bodies go about the process of healing and repair, and how smart substations and electrical distribution equipment can do so in a similar way.

In humans, healing and repair take place in response to injury, but also on a regular basis, to keep the organism functioning in an optimal way. The skin, for example, our largest organ, responds to injury in three main steps, highly simplified here. First is inflammation, during which blood clotting takes place. This is an emergency response having little to do with repair, but rather preventing further damage and stopping blood loss. Next comes proliferation, where new tissue grows to replace the old. Finally comes maturation, where the scar tissue is remodelled to become as strong as possible.

Electrical equipment also has built-in mechanisms for ensuring the health of the organism, which in this case is a power network. On high-voltage lines in rural areas, for example, stanching the blood flow means clearing the fault as fast as possible. Vegetation interfering with powerlines can be quickly burned off by high-voltage pulses, avoiding downtime. In a distribution substation, capacitors can take advantage of the self-healing insulation of metallized film capacitors, whose faults or short circuits in their own dielectric film vaporize the metal electrodes surrounding the defect and isolate that part of the insulation. In both scenarios, the goal is to immediately return the network to a functional state.

IMPLICATIONS, GUIDANCE, AND DATA

The path to modernization

Modernization upgrades open the door to enhanced equipment connectivity, leveraging new sensing technologies. This allows access to more detailed levels of energy efficiency, asset performance management, and energy quality data. Analytics are then made available. Furthermore, the association of sensors and algorithms enables the detection of premature equipment aging.

Like humans, electrical distribution networks are complicated ecosystems that require guidance and treatment from trained professionals who specialize in improving and maintaining those systems.

The best starting point is always a check-up, in order to gain an understanding of the current state of the system. Equipment manufacturers are especially well positioned to conduct in-depth assessments of electrical distribution networks to identify weaknesses, inefficiencies, potential sources of cost savings, and points of beneficial enhancement that will affect not only network health but also the health of the businesses that depend on them.

In all cases, regardless of current symptoms, achieving optimal electrical network efficiency and all the benefits of a strong asset management program demands a strategic approach to electrical distribution equipment and modernization, especially for substation equipment.

To reduce the risk of equipment failure and shutdown, old substation technology can be upgraded and modernized. The installation of connected sensors can make a substantial contribution toward achieving the numerous operational and financial benefits of modernization. The spectrum and purpose of substation sensing technologies, which can often be installed by the relatively simple retrofitting of existing equipment, is improving continually. Like the development of vaccines, pharmaceuticals, or medical technology, the most probable, solvable, and detrimental problems are tackled first, and afterward specialized sensors and analytic technologies seek to address rare conditions to decrease the probability of failure. These connected (or connectable) and digitized devices offer various types of monitoring, including thermal, humidity, usage and condition-based monitoring.

These sensors can monitor all critical points, including circuit-breaker connections and busway joints and connections. And that monitoring takes place in real time, which helps modernize maintenance practices and transition from basic time-based maintenance to condition-based maintenance. Further, these sensors do not compromise the internal arc withstand, and never sacrifice safety for convenience. They can also communicate wirelessly, so there’s no danger of maintenance operations damaging associated communication cables or optic fiber lines.

Design guidelines

Visibility and real-time understanding of network state and equipment health are prerequisites to effective grid management. This means that where sensors are deployed on the network, as well as the depth and breadth of information and the frequency with which they collect and transmit it, all play key roles in determining how much value can be added to a given system.

But where these sensors are concentrated is more interesting. In an electrical substation, sensors need to be deployed wherever there is a high probability of issues occurring:

- To protect against short circuits, the protection relay is in the switchgear
- To identify bad or poor connections, thermal sensors are placed near junctions
- To monitor corrosion and humidity, sensors are on the low-temperature side of the equipment or in the substation

The beneficial results of such systems can go far beyond merely coping with network complexity and integrating greater amounts of variable renewable generation sources into a distribution grid architecture that were never design to do so. It also unlocks the ability to achieve previously unheard of levels of operational efficiency and reliability, and opens doors to strategic maintenance practices that strengthen these benefits to an even greater degree.

The data collected by these sensors feed the rest of the system. First; they can be exchanged with other upstream and downstream devices at the level of connected equipment in the field. From there, these data move up to be consumed by edge control systems, such as an Advanced Distribution Management System (ADMS) where they fuel the intelligence of apps, analytics, and services to enable modern, digital distribution networks to fulfil the promise of unprecedented network efficiency. That top level can include special grid analysis modules that plug into ADMS, such as those that model peak shaving and demand management, or others that make proactive and predictive maintenance strategies a reality.

CONCLUSION

Substation engineers and risk managers can take inspiration from our own clever biological systems to inform the design and management of electrical distribution networks and the equipment therein.

When they do, they find retrofit solutions that equip substation equipment with sensing technologies and connected digital features. Such modernization and monitoring opens the door to stronger levels of grid efficiency, asset performance management, and energy quality, and is accompanied by cost savings, extended equipment lifespans, protection of capital investments, and most importantly, reduced shut-down risk.

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