The Body Electric

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1. Introduction

This post and the related updates were started when an associate at Energy Central asked me to participate in an upcoming call for papers, and this paper will be posted in mid-September so as to coincide with scheduling of that. Then it took a strange turn.

I read many technical and scientific articles as I am a member of both the American Association for the Advancement of Science (AAAS), and The Institute of Electrical and Electronics Engineers (IEEE), and both of these organizations send me a wide range of scientific / technical articles. However the weekly on-line publication from the former (*Science*) publishes many papers that take really deep dives into scientific disciplines I have little interest in. One area I am interested in (but rarely write about) is medical science. Thus, I read many papers about this subject, and therefore have some knowledge about human anatomy.

Recently I was struck by the similarities between the human central and peripheral nervous systems and the systems that control the electric grid. I spent much of my career in electric utility supervisory control and data acquisition (SCADA) systems, advanced metering infrastructure (AMI) systems and, late in my career, protective relaying systems.

I've been a member of Energy Central for about ten years, and have been posting papers to this site for about half of that time. Early in these postings (2018) I posted a series of papers each on SCADA and AMI. More recently I posted a paper on protective relays. Associated with this post, I am updating the papers on all three of these subjects. I will add comments on each of those subjects below as well as links to those papers. Note that I have corrected any errors, old information or bad links in those papers where reasonable.

2. SCADA Systems

In Energy Central's call for papers, one of the targets they describe is "Digital Twins." I don't use this term, as I prefer models, or simulations. There are a series of software applications that I cover in the SCADA Series Part 6 that collectively provide models of the grid being managed by an electric system operator. This operator is either a utility with a control area, an independent system operator (ISO) or a regional transmission operator (RTO). The largest of these models run on a cluster of very powerful computers. However they would be useless without the system that feeds real-time information from the grid to them and executes commands derived from the operation of the model, a SCADA system.

Associated with each SCADA system are sophisticated graphic display terminals that can change contexts to either display real-time, future operation (via models) or past operations via an archival utility.

A human body is similar in that it has a powerful processor (each of our brains) and peripheral nervous system to connect sensory organs to feed the brain. Our memory is

the body's archival system. Our muscular system (including voice) turn the brain's decisions into the body's actions.

Below are descriptions and links to the six papers in the SCADA Series. Parts 5 and 6 is written from the viewpoint of the California Independent System Operator (CAISO).

The first paper was an introduction to this series and is available through the link below

https://www.energycentral.com/c/pip/supervisory-control-and-data-acquisition-scada-introduction

Part 2 in this series, "Data Acquisition and Control", is available through the link below.

https://www.energycentral.com/c/pip/scada-%E2%80%93-part-2-data-acquisition-and-control

Part 3 in this series, "Complex Data, Data Evaluation and Alarming", is available through the link below.

https://www.energycentral.com/c/pip/scada-part-3-complex-data-data-evaluation-and-alarming

Part 4 in this series, "Human-Machine-Interface", is available through the link below. This paper covers world-coordinate displays, workstations, archiving, reports and display elements. The last include screens, icons, display retrieval and dynamic data representations, Note that this paper uses the human-machine-interface I am most familiar with (the Siemens Power-TG system).

https://www.energycentral.com/c/pip/scada-part-4-human-machine-interface-hmi

Part 5 in this series was "Larger Networks and Local Networks", which is available through the link below. This paper covers interactions of large self-generating consumers with CAISO and their host utilities. This part also covers utility communication with other utilities, with CAISO, and CAISO's communication with other grid operators.

https://www.energycentral.com/c/pip/scada-%E2%80%93-part-5-larger-networks-and-local-networks

Part 6 in this series, "Transmission and Distribution Network Management", is available through the link below. This paper covers the applications used to create models of networks and their operation. Applications include forecasting, buying and selling power (interchange scheduling), day-ahead load flow model, data integrity model (state estimator), real-time dispatch, economic dispatch and distribution management.

https://energycentral.com/c/pip/scada-%E2%80%93-part-6-transmission-and-distribution-network-management

3. Advanced Metering Infrastructure

Metering is a very important function for utilities as it measures how much electricity each consumer uses, and thus how much they should be charged for this electricity.

Utilities use modern metering systems to communicate with their customers. Since the information-flow can be both inbound and outbound, these systems are directly analogous to the human bodies' voice and hearing in that they are a primary method of collaboration.

Advanced metering infrastructure (AMI) adds several capabilities to a simple “automatic meter reading” systems, including profile metering, bidirectional communication and outage reporting. Profile metering divides each day into “demand intervals’ (typically 15-minute periods synchronized to each hour). A daily demand profile reports the 96 intervals, for that day. Profile metering facilitates time-based (a.k.a. time of use or TOU) rates, and these provide demand-response that reduces peak loads.

Below are descriptions and links to the original four papers in the AMI Series. These are written based on my experience in the emerging AMI industry around Y2K. In Energy Central’s call for papers one of the subject’s title is the Internet of Things (IoT), and the last paper in this four-part series covers this subject.

Advanced Metering Infrastructure (AMI), Part 1 – Roots is available through the link below. It covers the precursor systems (roots) of AMI, C&I metering systems.

https://www.energycentral.com/c/iu/advanced-metering-infrastructure-ami-part-1-roots

AMI – Part 2 – Creating Demand is available through the links below. It covers the governmental proceedings that boosted advanced C&I metering and then AMI into major markets.

https://www.energycentral.com/c/iu/ami-%E2%80%93-part-2-creating-demand

AMI Part 3 – Technology Basics is available through the link below. This paper describes a typical AMI System, major AMI Vendors, and major Utility AMI Systems.

https://www.energycentral.com/c/iu/ami-part-3-technology-basics

AMI Part 4 – The Internet of Things (IoT) is available through the link below. The IoT can be an extension of the AMI, and is may be used by small battery-powered electronic devices, communicating using low-power networks. This paper describes them in more detail.

https://energycentral.com/c/iu/ami-part-4-%E2%80%93-internet-things

In the spirit of completeness, there is a much later **AMI Part 5 – New Networks** to the AMI series that describes a major evolution of digital cellular networks. These networks are used by many AMI Systems. This is linked below.

https://energycentral.com/c/gr/ami-part-5-%E2%80%93-new-networks

4. Protective Relay Systems

Protective relays are critical in keeping the grid (both transmission and distribution) secure. Since the electric grid is transmitting energy that is moving at the speed of light, any anomaly propagates in milliseconds, and thus each protective relay must act at the same speed. Clearly, the laws of physics (speed of light) preclude any centralized control systems from participating directly in the sensing/response control loop. Thus, central relay control systems download parameters telling the relays how to respond to any targeted future event.

The human body has an analogous system called the spinal reflex or reflex arc. Even though the human brain is much closer to any peripheral part of the human body than a central controller would be to a protective relay, this still does not allow it to respond fast enough to prevent some injuries. Thus the spinal cord has an automatic response/ control function. For instance, when you get a physical exam, the doctor hits your knee with a rubber mallet, and your lower leg kicks upward (caused by the spinal reflex). Also

the pain signal from a grabbing a hot-potato reaches the spinal cord very quickly, and it automatically sends back a signal telling the hand to release the potato.

The post described and linked below describes the protective relay automation system for electric utilities.

Initial Resilience – Part 2: In Part 2 of this series we look at protective automation, which involves protective relays and systems, as well as some suggestions to reduce the overall operations of these, primarily effective vegetation management.

https://www.energycentral.com/c/pip/initial-resilience-%E2%80%93-part-2