C03 - SCADA/EMS systems

History and motivation

The first electricity supply systems appeared in the late 19th century and were built to serve local areas such as houses, streets, neighbourhoods, and public services such as lighting and transportation. The ownership form was private. This was the *local monopolies* stage. By the 1930s, electrical networks expanded to city and regional level, increasing in complexity, which triggered the next phase in their development. Nations saw the strategic importance of electricity supply and decided the formation of *centralized monopolies*, state or privately owned, which covered entire regions or countries.

The regulatory framework in the first centralized monopolies was still loose, the major goals being network expansion and profit, rather than system security.

Major blackouts occurring in the USA in the late sixties, with significant social and economic consequences, brought forward to the power systems engineers the problem of system security. Thus, the SCADA/EMS (Supervisory Control and Data Acquisition / Energy Management Systems) concept was born and it is in use until today.

What is SCADA/EMS?

The SCADA/EMS concept was based on the previously discussed paradigm that a power system can find itself in one of the normal, emergency and restorative state and was built to provide system engineers with tools which enabled them to monitor, control, make decisions and issue commands in order to operate the system in these three stages. A typical SCADA/EMS system has two main layers:

- the physical layer, which consists of hardware components installed in the field or at control centres, used to get information about the system state and crucial events occurrence and send back commands from the operators.
- the software layer, with specialized computing tools that help the operator make the right decisions, by processing the data collected in the field.
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The main components of an EMS/SCADA systems are depicted in Figure 3.1.

In order to assess the operating state of the whole system or certain equipments, **sensors** and **measuring equipments** are installed in the field and send data to the control centers.

Examples of such measurement data are:

- analogue measurements from instrument transformers and sensors, instantaneous measurements of continuous signals such as voltages, power

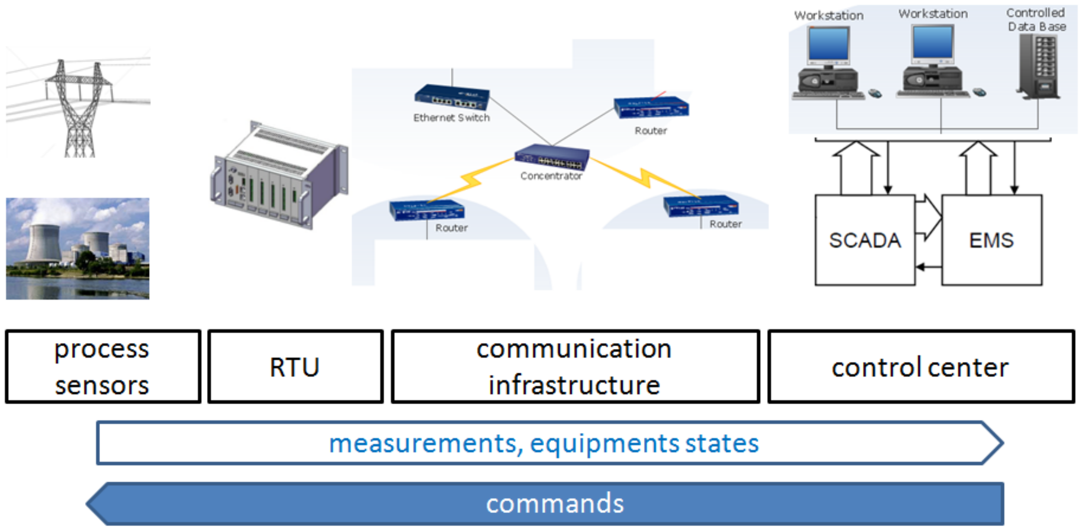

Fig. 3.1 - The architecture of a SCADA/EMS system

flows, currents, which need to be converted into digital discrete values using analogue-numeric converters;

- discrete values, ON/OFF status changes for circuit breakers and protective relays

Remote Terminal Units (RTUs) are devices installed in specific locations in the field, which serve as local data gathering units for acquired measurements and for sending back commands to remotely switched equipment at the monitored site. Modern extensions of RTUs are PLCs, programmable logic controllers, which use microprocessors and programming languages to extend their functionalities.

As an example of technical capabilities of industry RTUs, the PowerLogic ION7550 unit produced by Schneider Electric [webSch] has the following capabilities:

- Up to 10 Mbytes of memory
- 1 pulse output
- max 24 digital or analogue inputs (max)
- max 30 digital or analogue outputs (including pulse output)
- Ethernet port (using the Modbus/TCP/IP protocol)
- serial RS 485 / RS 232 port
- Internal modem
- Alarm notification via email
- HTML web page server

Fig. 3.2 - The PowerLogic ION7550 RTU

Its main applications are:

- WAGES (water, air, gas, electricity, steam) metering
- Integrated utility metering with advanced programmable math functions
- Data concentration through multi-port, multi-protocol communications
- Equipment status monitoring and control
- Programmable set points for out-of-limit triggers or alarm conditions

The RTU 560 units for transmission systems, manufactured by ABB [webABB], offers the following main features for transmission:

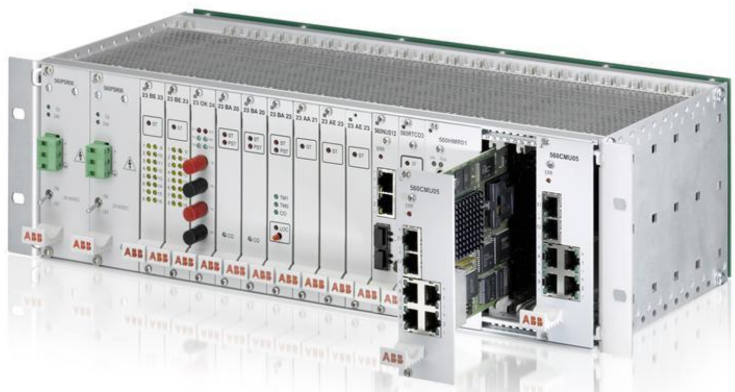

Fig. 3.3 - The RTU 560 RTU unit manufactured by ABB , image source [webABB]

- rack mounting
- modular configuration
- redundant power supply
- up to 16 input/output modules
- human machine interface (HMI) with Intel Atom 1.6 Ghz processor, 2 GB of RAM, 16 GB SSD, direct monitor, keyboard and mouse connecting, based on the Windows 7 operating system
- simple communication units (CMUs) with Intel 586 133Mhz processor, 64 MB RAM, 128 MB flash memory, serial and Ethernet communication
- integrated GPS real time clock.

A SCADA system is built for monitoring field installations from a central location, which requires a communication network data. As technology and monitoring & control requirements evolved, so did the **communication infrastructure**. There were 3 mains stages of development [SS14]:

- monolithic (Fig. 3.4), when each field RTU was connected with dedicated wires or communication channel to the master station from the control centre; Radio waves, modems and serial communications were used.

- distributed (Fig. 3.5), with computing tasks distributed over several stations connected in a local area network (LAN)
- networked (Fig. 3.6), which allows geographic fragmentation of the SCADA system over large areas, with local centres connected via Wide area Networks and Internet, the latest advances being the use of cloud storage and computing.

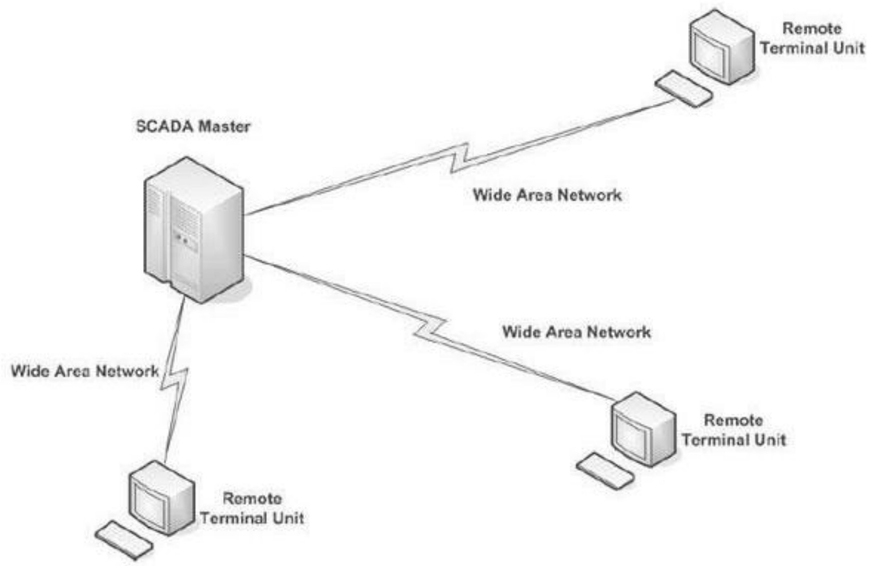

Fig. 3.4 - The monolithic SCADA architecture, image source: [SS14]

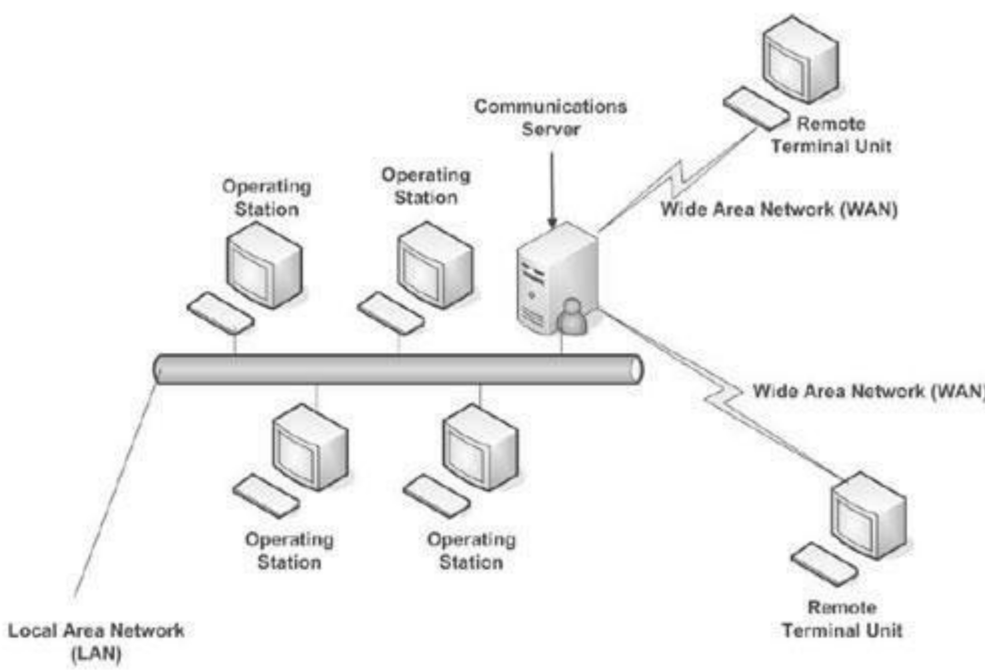

Fig. 3.5 - The distributed SCADA architecture, image source: [SS14]

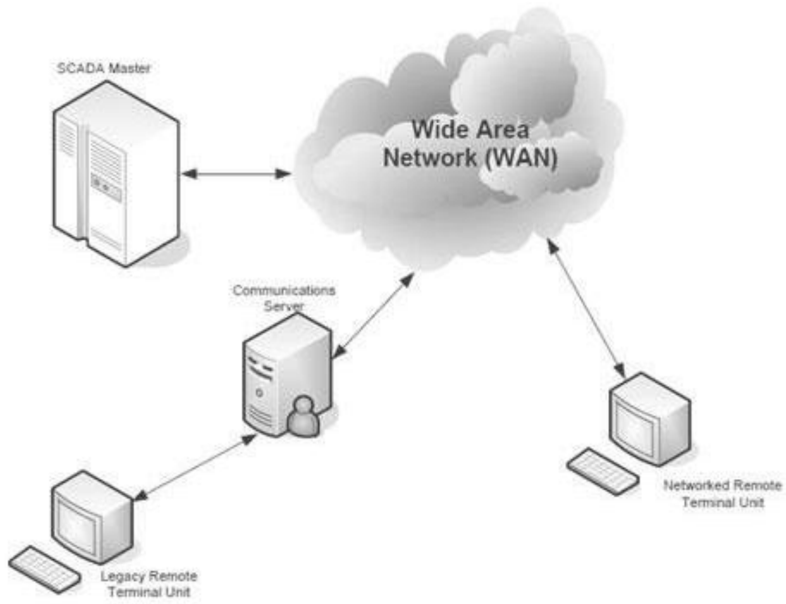

Fig. 3.6 - The networked SCADA architecture, image source: [SS14]

SCADA communication systems usually exchange data using encoding protocols. The first protocols were proprietary, developed by certain vendors and recognized by industry manufacturers. The Modbus serial protocol, developed in 1979 by Modicon, now Schneider Electric, is the most used SCADA communication protocol until today. Currently, Modbus enables communication among approximately 240 devices connected to the same network and identified by unique addresses and sends the results to a computer. Other communication protocols used by SCADA are the standardized IEC 60870-5, IEC 61850 and DNP3 (Distributed Network Protocol). These protocol have extensions for TCP/IP communication.

For security reasons, SCADA communication networks are built as closed LAN/WAN, preventing direct access from the public Internet.

The collected field data is sent though the communication network to the **master control centre**. The SCADA master station has several key functions:

- data acquisition: the master station receives all data collected in the field by RTUs
- data logging or archiving: the received data is stored and used subsequently or in real time for system control. Data analysis can be performed using EMS software tools for making decisions, identifying historical trends or analyzing past events
- system monitoring and alarming when control parameters fall out of their normal operation range
- presenting a comprehensive system status overview, ready for operator decision making.

Energy management functions provided by SCADA systems

The latest function in the above list is possible through specialized software tools implemented in SCADA control centres that provide a set of functions which enable system dispatchers to take informed decisions in every aspect of system operation.

These functions can be divided into [Murty, EMSReport, DPSScada]:

- energy management functions, which deal with the economic load and generation dispatch and control:
  - load/frequency control: because electricity cannot be stored in large quantities for long periods of time (cannot be stockpiled), power systems face the constraint that supply must always match the demand. If supply exceeds demand, voltage and frequency rise. If demand exceeds supply, frequency and voltage drop. Voltage variations can damage consumers' equipment, and frequency variation leads to system instability and ultimately blackout. Existing SCADA systems provide LFC analysis at 2-10 seconds time interval.
  - economic dispatch: in addition to ensuring technical security, the existence of a liberalized electricity market aims for commercial profit. Based on RTU collected load and generation data, SCADA control centres can provide minimum cost dispatch analyses for intervals of minutes.
  - load forecast: based on historical data archives, load forecasts can be made for short (hours), medium (1 day-1 week) and long (months, years) intervals

- security functions, which serve to maintain technical safety in everyday operation and recovery from contingency scenarios
  - topology processing: power systems have built-in redundancies (for instance, lines and transformers operated in parallel). Accidents can outage lines, transformers or large generating units or loads. An electrical network acts like a living organism, its configuration changes all the time. With configuration changes, voltages and power flows change in the system. A network topology processor (NTP) determines the actual operating configuration of the system, based on breaker on/off status.
  - power flow studies: based on the actual topology configuration and load/generation scenario, load flow studies compute bus voltages, branch power flows, branch current and active power losses. This information is crucial in network extension planning studios, load and generation dispatch, maintenance scheduling and post-mortem analysis.
  - state estimation gives the same results as a load flow calculation, but uses measurements collected in real-time across the system, giving an operational snapshot of the operating conditions.
  - contingency analysis: unexpected line or generator outages can have catastrophic effects on the operating conditions of a power system, leading in extreme cases to blackout

- optimal power flow, which seeks the optimization of a specific objective function, such as minimization of active power losses or bus voltage variation across the system
- short circuit analysis, for analyzing the fault currents and proper protection setting
- distribution-specific functions: while transmission systems are considered symmetrical and balanced, distribution systems, especially at low voltage levels, are functioning with unbalanced loads, requiring more complex analysis algorithms.

Limitations and future challenges

Two main changes currently challenge the efficiency of existing SCADA/EMS systems.

Starting from the 1990s electricity market liberalization has changed the way in which transmission power systems are operated. Electricity prices and deliveries are determined through a commercial mechanism of supply and demand, based primarily on the lowest prices. National power systems have interconnected to create regional markets. Parts of transmission systems are operated closer to their stability limits. Congestion and contingency risks are higher in a deregulated free market than in a vertically integrated monopoly. The effects of such contingencies can now affect large areas. As proof stands the 2003 blackout fron the North-eastern part of the United States, and south-east Canada, which developed in just three minutes, affected 50 million people, with an estimated economic cost of between $4.5 and $8.2 billion.

The rapid advance of renewable sources, also change the operation of distribution networks. Most small photovoltaic and wind farms are located at the distribution level, transforming it in an active network, which can deliver power back to the HV transmission system.

SCADA systems were designed for the old operation paradigm, which does not correspond to the actual operation conditions. Their main drawback is that RTUs collect data by scanning at a 2-10 seconds interval, considered more than sufficient 20 or 30 years ago, but which cannot keep pace with the intermittent nature of renewable sources and rapid development of wide area contingencies.

This low data rate has two major limitations:

- it cannot provide enough data for rapid event analysis
- it cannot provide accurate time stamping and measurement synchronicity.

On the other hand, the technological advances brought forward new tools such as modern communication technologies (GSM, 3G, satellite links), the geographic information system (GIS), which can read, store, and manage all types of spatial or geographical data, a new generation of measurement and monitoring digital devices called Intelligent Electronic Devices (Digital Fault Recorders (DFRs), Digital Protective Relays (DPRs), Circuit Breaker Monitors (CBRs), Sequence of Event Recorders (SOEs), Phasor Measurement Units (PMUs)), which now are combined in upgrading the existing SCADA/EMS systems and building the intelligent power systems of the future, called Smart Grids.

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