ELECTRICAL NETWORK CONTROL

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Contents

Summary

Transmission and distribution of electrical energy requires powerful networks independent of the deregulation of the electricity industry. Hence, network operation as a natural monopolistic task requires efficient and reliable operation and control tools. The network security has a static and dynamic aspect. In the static security assessment, preventive and/or corrective control actions must be carried out in order to keep the network state in a secure operating state. In dynamic security assessments, the network control is concerned with optimal power-frequency and voltage control. These two basic control problems differ in many respects. However their successful implementation in a modern SCADA/EMS is a mandatory prerequisite for optimal energy transfer though transmission and distribution networks.

1. Introduction

The high technical standard of electric energy transmission and distribution networks has a double basis:

- Advanced technology of the components (e.g., circuit breakers, transformers, power lines, cables etc.) comprising all parts of the electrical network (primary technique)
- Implementation of high level information processing and control methods to ensure efficient economic and secure network operation and control (secondary technique).

The optimal combination and coordination between these two fields is a major engineering challenge for the implementation and operation of modern electrical network control.
Figure 1 shows schematically the structure of transmission and distribution systems concerning the different voltage levels.

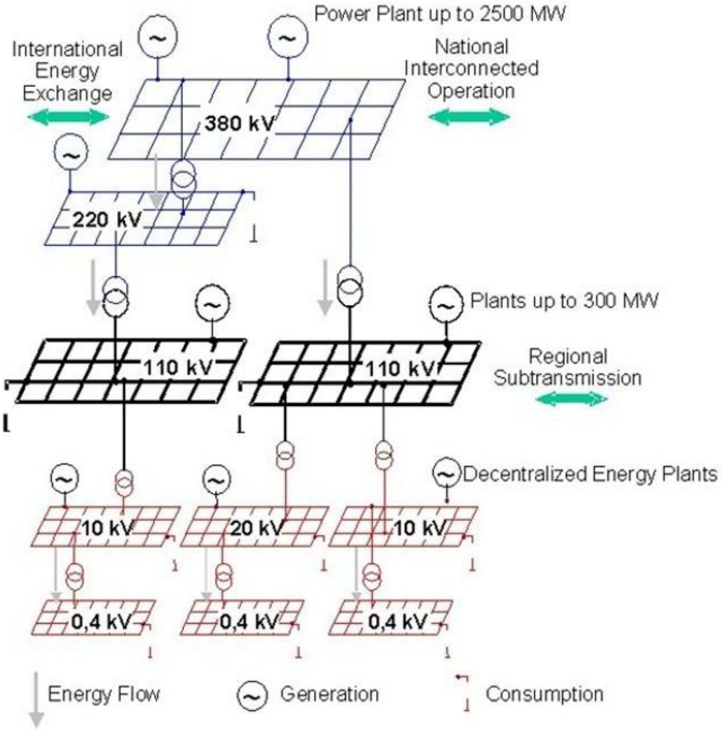

Figure 1. Structure of an electrical network

The electrical energy high voltage transmission system comprises the voltage levels from 220 kV upwards. The main functions include:

- Connection of large power generation plants
- Supply of very large customers with high short-circuit power requirement
- Energy transmission between interconnected partners on a national and/or

international level.

The subtransmission systems are operated between 110 kV and 160 kV. They are used for bulk power distribution. Medium sized power plants and large customers are connected to this voltage level.

The distribution systems include the voltage levels between 10 kV and 60 kV. In view of their large size the need of standardisation of its equipment is very high. Medium sized customers are connected to this voltage level. Furthermore they supply the low voltage distribution networks operated with up to 0.4 kV.

The mathematical model of electric power network may be described by the load-flow equations. They are based on the concept of nodes and branches, which may be modelled by the nodal admittance matrix $\underline{Y}_k$. The relation between nodal currents $\underline{I}_k$ and voltages $\underline{V}_k$ are given by

$$\underline{I}_k = \underline{Y}_k \, \underline{V}_k \quad (1)$$

Since the current vector $\underline{I}_k$ is not given, it has to be replaced by the nodal power defined as

$$\overline{S}_i = \overline{S}_{Gi} - \overline{S}_{Li} \quad (2)$$

$\overline{S}_{Gi}$ denotes the complex generated power and $\overline{S}_{Li}$ the consumed complex powering node i. Through the relation

$$\overline{S}_i = \overline{V}_i \cdot \overline{I}_i^{y} \quad (3)$$

it becomes possible to replace the nodal current by $\overline{S}_i$., Hence the complex network equations may be written as

$$\overline{S}_i = \overline{V}_i \sum_{j=1}^{n} \overline{y}_{ij}^{*} \overline{V}_j^{*} \quad (4)$$

when $\overline{y}_{ij}$ denotes the elements of $\underline{Y}_k$ and n is the total number of network modes. Powerful algorithms are available for the solution of these complex nonlinear network equations with respect to the node voltages $\overline{V}_i$. They are termed state variables because their numerical values completely determine the operating state of the electric network.

The liberalization and restructuring of the electrical industry led to the unbundling between generation, transmission/distribution and energy trade. The result of this development is a large number of grid companies. Within the liberalized energy systems they are characterized by a natural monopolistic structure. The incomes of a grid company are obtained from the corresponding transmission/distribution costs and the ancillary services. It is obvious that the restructuring measures have a great impact on the effective and minimal cost operation and control of electrical networks.

Compared to conventional power system engineering, advanced digital information processing and control systems are relatively young engineering disciplines. However, modern power systems need to be operated with a well-developed information technology; but even the most advanced information technology cannot improve the operation of a poorly planned and/or implemented power system.

The hierarchical structure of an electrical network control system is shown in Figure 2. It consists of the decentralized tasks of power plant control as far as ancillary services are concerned, substation control and load control, on one side, and the centralized power system control on the other. In both levels the main classes of

- Information processing
- Monitoring, protection, command and control

are evident. Without digital data transmission and processing systems, the realization of these control systems is inconceivable.

A simplified structure of a modern energy management system (EMS) is shown in Figure 3. The power system measurements are transmitted via a digital information system to the central control office.

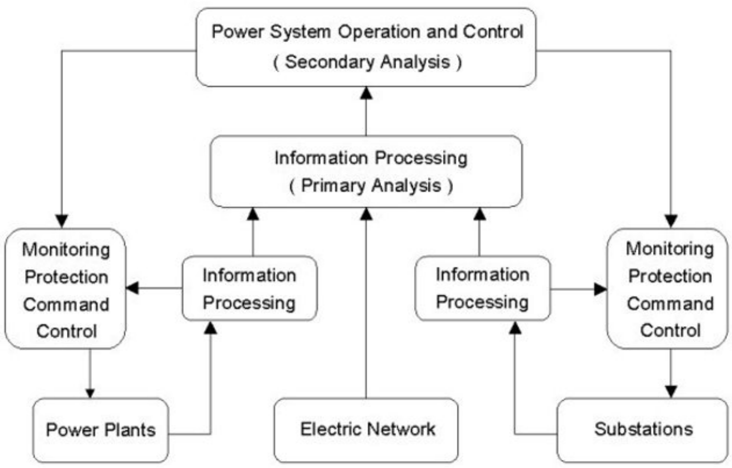

Figure 2. Hierarchical structure of electrical network control

The primary analysis serves the monitoring of the network and covers the following tasks:

- Programs for message switching
- Control of the information display systems
- Recording of status and events
- Information processing for telecommand and control.

These functions are summarised as supervisory control and data acquisition (SCADA).

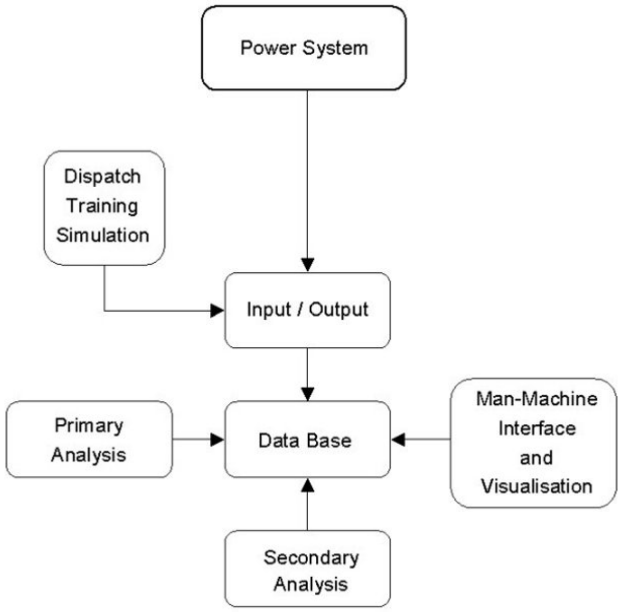

Figure 3. Energy management system with the primary analysis for monitoring, and the secondary analysis for system operation and control

The advanced decision support and optimization tools in the secondary analysis are used for network operation and control. They include:

- State estimation and topology monitoring
- Optimal power flow
- Static and dynamic network security analysis
- Load prediction
- Transmission management

2. Power system engineering

Power system engineering deals both with individual components such as substations, power lines, transformers, protection systems etc. and with operational and control aspects of the entire system related to:

- Economy and operation
- Security of supply
- Quality with respect to frequency and voltage level
- Environmental compatibility.

Based on system engineering concepts the operational states of an electrical network may be classified according to the classes shown in Table 1 and illustrated in Figure 4.

State	Energy equilibrium	Technical and economical constraints	(n-1) Principle
Normal	satisfied	satisfied	satisfied

Alert	satisfied	satisfied	not satisfied
Disturbed	satisfied	not satisfied	not satisfied
Network splitting	not satisfied	not satisfied	not satisfied
Restoration	not satisfied	satisfied	not satisfied

Table 1. Operational states of an electrical network

The (n-1) principle implies that the loss of one arbitrary power systems component does not lead to a power supply disruption.

After the transition from the normal to the alert state, preventive actions by the control engineer are needed to avoid power supply disruption as the result of a possible following fault in the power system. If the power system is disturbed, corrective actions must be taken because important technical and/or economical constraints may be violated.

The basic features of a modern EMS may be described as follows:

- Monitoring the system state by means of analogue and digital information
- Interaction with the electrical network in a preventive or corrective manner
- Regulation of frequency and voltage
- Reliable and complete system information despite wrong or missing data
- Evaluation of operational risks for the present or future state
- Actions to improve power system security and stability
- Economic operation e.g., with minimal losses.

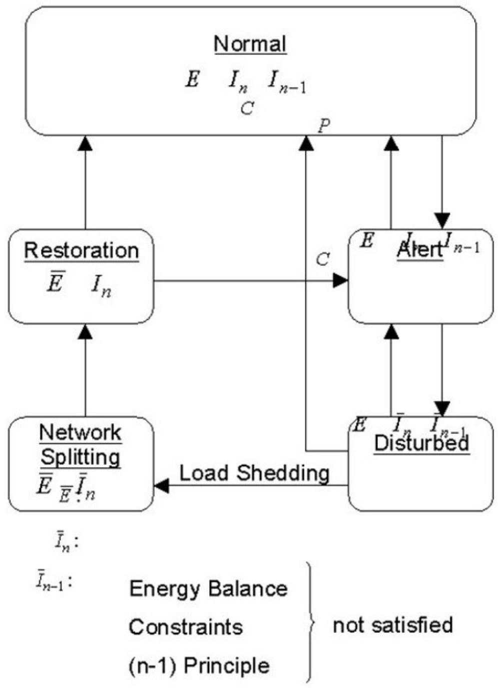

Figure 4. Classification of the operational states of an electrical networkThe necessity

for EMS arises from many factors affecting electrical network operation:

- Future development of electric energy demand in industrial and developing countries
- Availability of primary energy resources for power generation
- Rapidly changing economical and political constraints
- Functioning of the power system within operational limits because of limited availability of generation and/or transmission capacity due to restrictions in the necessary system expansion
- Strong impact of new technology based on microelectronics for a more reliable and economical operation as well as rational use of electricity
- Increased use of information technology to handle the complex decision-making process of modern network control.

3. Evolution of electrical network control technology

The most important significant events in the evolution of electrical network control technology are represented in Figure 5. Until about 1940 the dispatchers of the electrical network were located either in a power station or a large substation. The advent of electric network control technology evolved through local monitoring and control, the use of a static mimic board and the telephone for commands to the field operators. The evolution of data acquisition and remote control starts with analogue techniques. Automatic generation, interchange and frequency control also used the analogue technique. During the period 1950 – 1970, digital computers were extensively used for off-line power system planning studies. The New York blackout (1965) forced the power utilities to reconsider on-line reliability problems, the most important consequence being the accelerated introduction of SCADA/EMS. Following the introduction of process computers in power plants, process computers and the graphical displays were also implemented in network power dispatch control centers.

The period after 1970 was very fruitful in the development of state estimation and optimal power flow theory. The second great blackout in the USA in 1977 reinforced the importance of network security assessment. Other blackouts and incidents in Europe highlighted such aspects as dispatcher training simulators, corrective actions in emergency situations or the importance of voltage stability. The Three Mile Island incident emphasised the importance of human engineering in displaying the information to the operator. Since the eighties SCADA/EMS are also penetrating the medium-voltage networks. However, the tasks of distribution automatization are different from the specific functions of the SCADA/EMS in high-voltage power transmission systems. There is a growing awareness of the need to unify dispatch of supply and demand (economic dispatch and load management). The unbundling of electric utilities supported the formation of new grid companies. Since they have tight financial constraints the network control implies optimal use of the transmission/distribution capacity. Since the network may be heavily loaded the problem of voltage stability becomes an important issue. The grid companies must solve the transmission/distribution tasks in an undiscriminatory manner and with transparent fees. New tasks such as congestion and transmission management must be integrated in new EMS.

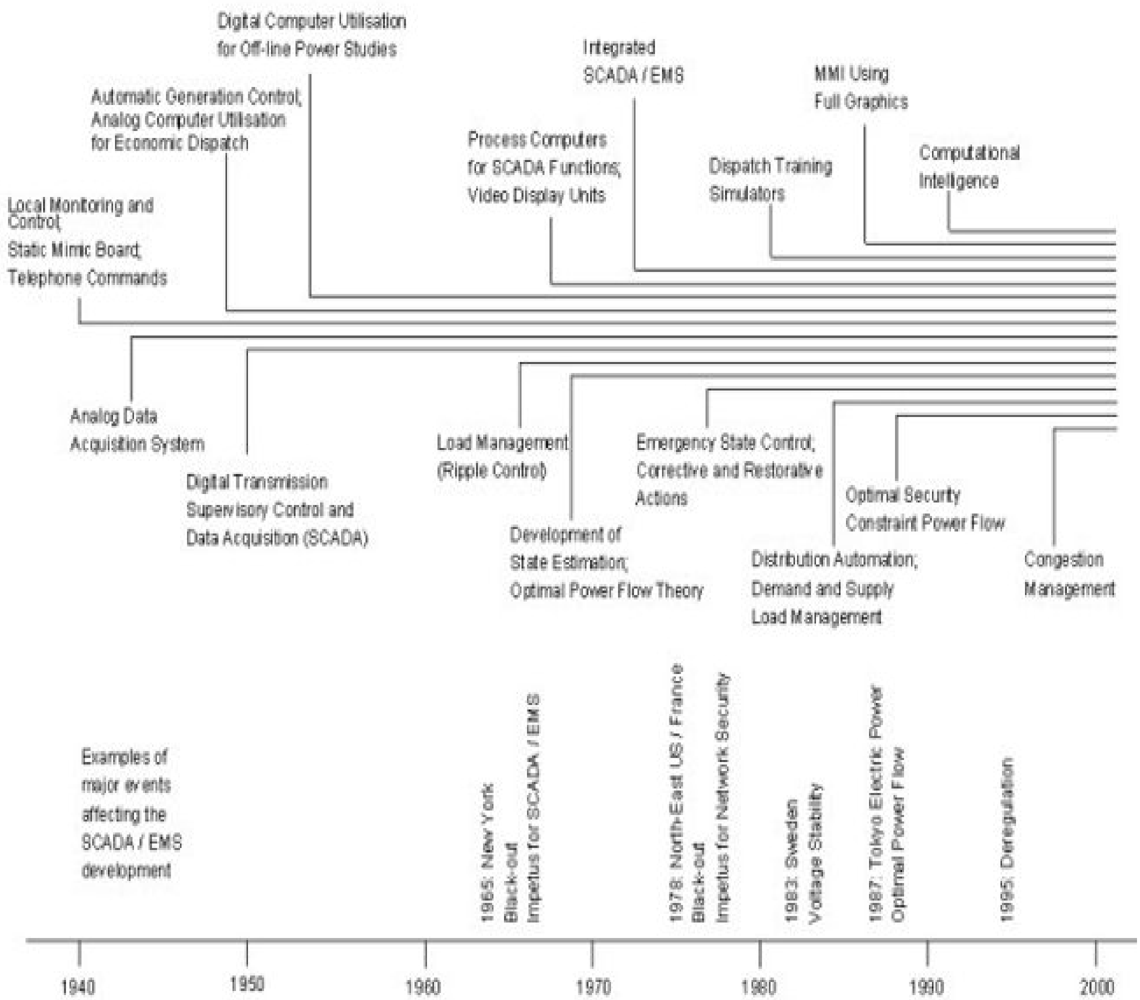

Figure 5. Significant events in the evolution of electric network control technology

The necessity to operate the power system closer to technical and economic limits accelerated the implementation of optimal power flow considering security constraints in EMS. The different objective functions for the optimization include:

- Real power losses
- Equal voltage profile
- Pre-specified short-circuit capacity.

Powerful computer hardware permits the realization of complex optimization procedures in real-time. However, efficient handling of sophisticated EMS still requires highly skilled and trained operators.

The use of knowledge-based systems into SCADA/EMS constitutes a further development in network control technology. It offers a new form of implementing algorithmic procedures together with heuristic methods. Knowledge-based information processing supports the complex decision-making process of the network operator.

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Biographical Sketch

Edmund Handschin received his diploma in Electrical Engineering in 1965 from the Swiss Federal Institute of Technology, Zürich, Switzerland, and his Ph.D. in 1968 from the Imperial College London, United Kingdom. From 1969 until 1974, he was a staff member of the Brown Boveri Research Centre in Baden, Switzerland. Since 1974, he has been Professor and Head of the Institute of Electric Energy Systems at the University of Dortmund, Germany. In 1994, he founded the EUS GmbH, Gelsenkirchen, an engineering company active in the field of decentralized generation and distribution.