NEW STRATEGIES FOR SUBSTATION CONTROL, PROTECTION AND ACCESS TO INFORMATION

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ABSTRACT

In view of the pressure on cost reduction and productivity improvement, which is caused by deregulation and unbundling vertical structured utilities into smaller dedicated entities for generation, transmission and distribution, the greatest change is expected to happen in the substation information, control and protection technologies. The trend moves towards "intelligent substations" which will comprise all electronic components and the virtual elimination of copper wiring. The major changes are expected to come in the following three key areas:

- Open access to substation information
- Operation and maintenance strategies
- Integration of protection and control

Open access to substation information is a way of quickly providing benefits to the business. The application of Intranet technology will allow information related to the condition and performance of the primary plant, such as circuit breakers and transformers to be released from the closed substation information system. The key component is the substation information management unit, which will act as a data base converter. It will compress data with closed format from substation equipment, convert data to information and provide this information via the wide area network.

This approach supports the new trend to maximise asset utilisation by reducing operating security margins through improved protection and maintenance techniques. These developments promise significant change not only in power system control, protection relaying but also in broadband communications.

In case of major system disturbances, data from fault recorders, information from network topology, protection relay parameters and operational switching constraints all need to be considered when arriving at the appropriate decision for corrective actions to maintain power system integrity. This is problematic with the systems available today due to big data volumes to be handled in a short time and the limitations of the amount of information and real-time performance, which can be managed by centralised SCADA.

The advantages of a substation oriented decentralised automated concept with regard to the acceleration and substantiation of the decision making process are obvious. The realisation of such knowledge-based systems is feasible, which use data downloaded from system transient monitors, disturbance recorders, fault locators and protection relays.

The paper describes a system concept for integrated control, protection, condition monitoring, condition supervision, asset management and outage management system, which assures higher availability of plants and enhancement of the overall utility performance.

***Keywords**:*

Substation automation, condition monitoring, on-line monitoring of transformers, Internet and browser technology, adaptive protection, power system protection

INTRODUCTION

In the past, utility engineers often struggled with the fact that too little data was available when they attempted to analyze problems within their power systems. They also did not have enough information to predict or ascertain the level of maintenance needed of when it would be required for the major equipment located within their substations. As new and higher levels of digital technologies have made its way into substations in terms of numerical protection devices and control systems, these same engineers are suffering from data overload. They have more data than can be processed and assimilated in the time available. Today the challenge is to automatically convert data to knowledge, which frees manpower to implement corrective or preventive maintenance.

ACCESS TO SUBSTATION INFORMATION

The main idea of a decentralised substation oriented automated concept (Figure 1) is to provide a five-level functional structure for power system management:

1. **Process level** for power generation, transmission, distribution and consumption
2. **Automation levels** for power plant, transmission, distribution, and demand side automation, which comprises local control, object protection and on-line condition monitoring.
3. **Data exchange level** for real time and non-real time transmission of data for control, fault and condition assessment, performance statistics, etc from remote.

4. **Support level** to provide people who are responsible for system planning, operation, maintenance and asset management with direct access to disturbance records, event and alarm lists as well to condition related data of primary equipment. [1]

5. **Management level** to support energy management, transmission, and distribution as well as demand side management with accurate and fast real time data to allow immediate response to instabilities in order to maintain power system integrity.

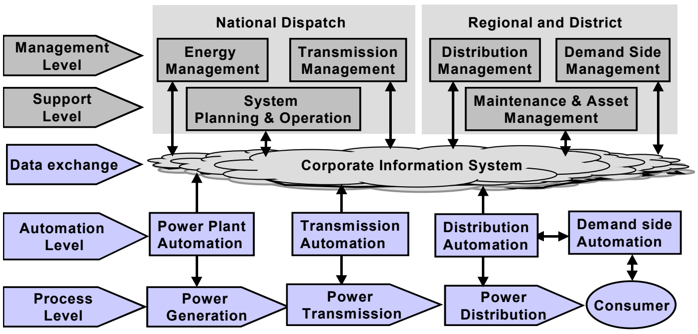

Figure 1: Power System Management Structure

The prerequisite, however, is a corresponding decentralised substation automation (SA) structure for power transmission and distribution, which allows fast and direct data exchange between intelligent electronic devices (IED) for protection and control. (Figure 2)

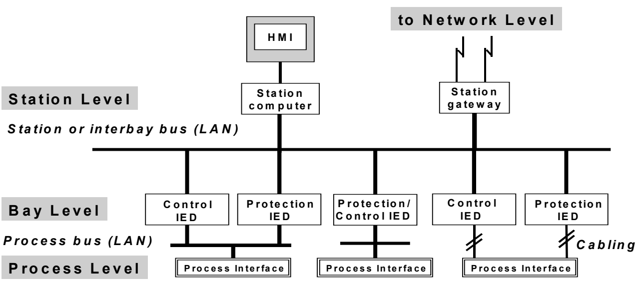

Figure 2: Substation Automation Structure

The station computer is the substation information management unit. The station gateway function can alternatively be incorporated in the station computer.

Requirements for Opens Systems

For systems with free exchange of data the term "open system" is very common. In the past, substation automation systems had been open by standardised voltage and current levels used at the device interfaces, e.g. 110/220 V, 1/5A, 20 mA, 10 V, etc. Today, the serial communication has to be open. As shown in Fig.3, this openness needs to satisfy various operational aspects:

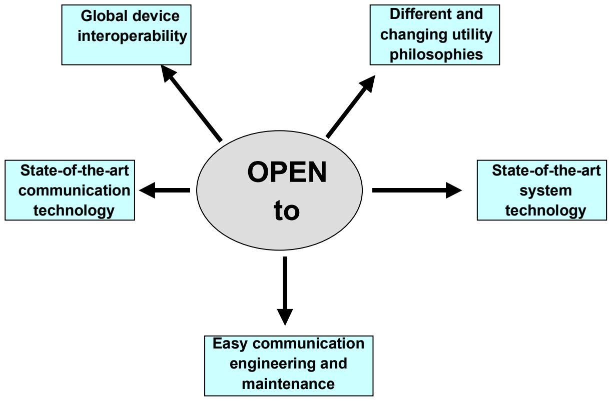

Figure 3: Design Aspects for "Open Systems"

Global Device Interoperability. Functions from devices of different suppliers need to be combined to common modes of operation. The term global refers to the requirement that there shall be only *one* common standard world wide.

Different and Changing Utility Philosophies. There are different system philosophies with respect to the allocation and integration of functions in IEDs. Therefore, the open system approach has to support *free allocation* of functions.

State-of-the-Art System Technology. The SA system structure may need to be adapted according to the state-of-the-art of switchgear technology selected. Intelligent switchgear with integrated sensors for measurements are examples for a new scope of functionality. Optical fibres with compatible process interfaces substitute secondary cabling. The open system approach has to incorporate *rules for later extension and integration of new functions*.

Easy Communication Engineering and Maintenance. An IED is defined by its functionality and a system is defined by the interactions between several IEDs. Therefore, an open system approach requires some *means* to describe the properties of a specific system and the associated IEDs. Only if such a formal description is integral part of the system, adaptive maintenance is assured over its entire life cycle.

State-of-the-Art Communication. Despite of the requirement for long-term stability of the communication system, an open system approach has to be flexible enough to take advantage of new developments in the communication technology. This, however, means that any technological update must have no impact on the application to the effect that all investments in user specific applications are safeguarded.

Communication Standard IEC61850

The new communication standard IEC61850 satisfies all the above mentioned aspects for an open system approach. It comprises the following parts: [2]

- **Part 3** summarises the general requirements,
- **Part 4** provides recommendations for system and project management to ensure a cost efficient interaction between suppliers and users.
- **Part 5** defines the communications requirements for the application domain "substation" and describes a comprehensive application model for objects and services.
- **Part 6** facilitates engineering and life cycle maintenance by the standardisation of the Substation Configuration Language (SCL).
- **Part 7** defines interoperability.
- **Part 8** and **part 9** provide a clear selection of stack, according to the state-of-the-art, and the mapping of the application model to this stack.
- **Part 10** assures common conformance testing world-wide.

Most of the mentioned parts are drafted and circulated for comments. They are expected to be available by the end of 2001.

MAINTENANCE STRATEGIES

Data Acquisition

Besides their primary functions IEDs offer more and more functionality compared with dedicated single function units. (Figure 3) Many of these integrated functions provide for basic monitoring systems:

- Disturbance recorders
- Event recorders
- Statistical value recording (peak current indicators, number of starts/trips, current at tripping, etc.)
- Power quality analysers
- Programming capabilities for customer specific applications.

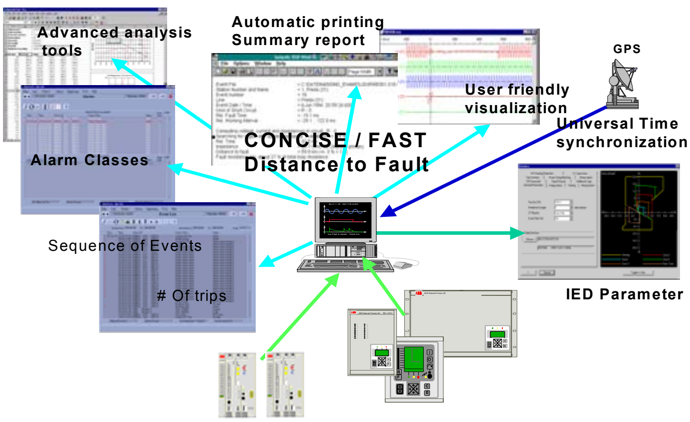

Figure 4: Data available from IEDs for Protection

Transformer Monitoring via Intranet

The World Wide Web as an information source and its commercial application has created a mass market where the technology costs are shared by millions of developers and companies throughout the world.

Taking transformer monitoring as an example, (Figure 5) the condition related raw data are retrieved from the transformer continuously to a maintenance server in an asynchronous mode and stored in a database management system (DBMS). The client is installed on a PC in the maintenance department or on a notebook PC of the maintenance engineer. A standard browser serves as human machine interface. The utility homepage contains a button for transformer monitoring, which can only be activated by authorised personnel. If this page is called up, a Java applet is loaded which establishes the connection with the hypertext transfer transmission protocol (HTTP) server on site and the transformer monitoring page is refreshed with actual data from the server database.

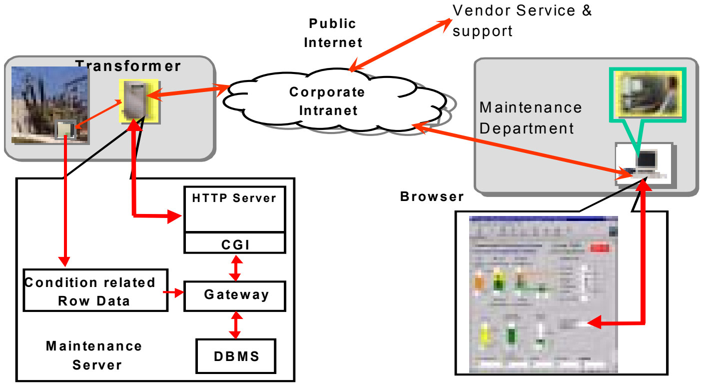

Figure 5: Transformer Monitoring via Intranet

Information Available via Browsers

The transformer-monitoring page on a browser shows the following actual service and condition related data.

Service data: Oil and air temperatures, currents, voltage, reactive and active power, tap changer position

Service condition status (ok/not okay): Air channels, cooling performance, oil pump operation, oil temperatures.

Service condition data: Fan performance, air entry/exit temperatures, oil entry/exit temperatures, oil pump switched on/off.

Life expectancy related information: Load in % of the rated load, estimated hot-spot temperature, ageing ratio, estimated consumed lifetime in %

Reliability Centred Maintenance

Reliability centred maintenance means to change the maintenance policy from the traditional time-based maintenance to condition-based reliability centred maintenance (RCM). [3] The following four options of maintenance policy can be applied:

1. **Predictive or condition based maintenance:** to monitor if something is going to fail
2. **Preventive maintenance:** overhauling items or replacing components at fixed intervals
3. **Corrective maintenance:** fixing things either when they are found to be failing or when they have failed
4. **Detective maintenance:** to detect hidden failures by means of special functional checks and diagnostics

Which of these options has to be selected for specific equipment depends on reliability and availability aspects and on economic and customers' business related power sensitivity considerations, which take the consequences of failures into account.

INTEGRATED PROTECTION AND CONTROL

With the introduction of numerical relays, with the realisation of modern substation control systems, and with the development of new communications technologies, direct interaction between protection and control leads to adaptive protection schemes, to intelligent load shedding, and to automatic power restoration procedures. The following examples illustrate how these new functions can be implemented in conjunction with SA concepts as corrective measures to limit the consequences of faults.

Power System Protection

A new technology has been developed for the detection of incipient voltage instabilities. Such systems comprise a number of Phasor Measurement Units (PMU) and a central evaluation unit. The PMUs are located at strategic points throughout the power system. They calculate the stability of the power transfer across a specific transmission line based or busbar on the measurements of voltage and current phasors. (Figure 6)

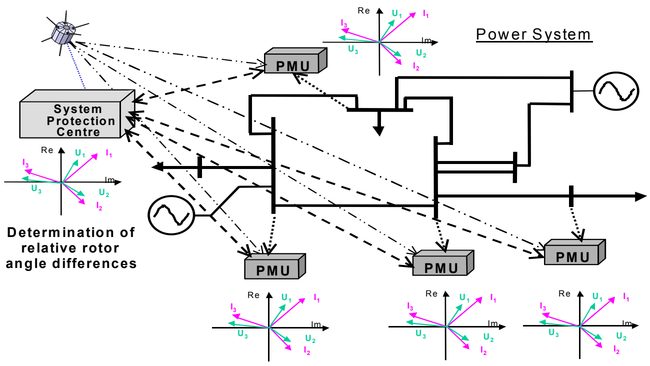

Figure 6: Voltage and Current Phasors Assessment

Response to Incipient Voltage Instability

In case of the detection of incipient voltage instability, two stages of responses are initiated: (Figure 7)

1. Alerting the system operator by indication of the proximity to voltage collapse and the safety margin ΔS remained. This gives the system operator a chance to counteract wide area disturbances. In addition, this information is delivered as input to the energy management system (EMS).

2. Automatic control actions are initiated if the safety margin ΔS reaches a pre-set critical level in order to prevent voltage instabilities to occur. Examples of such control actions:

   - To compensate the lack of reactive power by FACTS (Flexible AC Transmission Systems)
   - To block the OLTCs (On-lin Tap Changer Controller) in order to avoid over compensation.
   - To maximise the reactive power output from synchronous machines in order to compensate for the insufficient reactive power.
   - To shed load in order to maintain voltage or frequency stability.
   - To separate the power system into subsystems as last defence measure against complete system breakdown.

The block diagram below shows the interactions between the various applications.

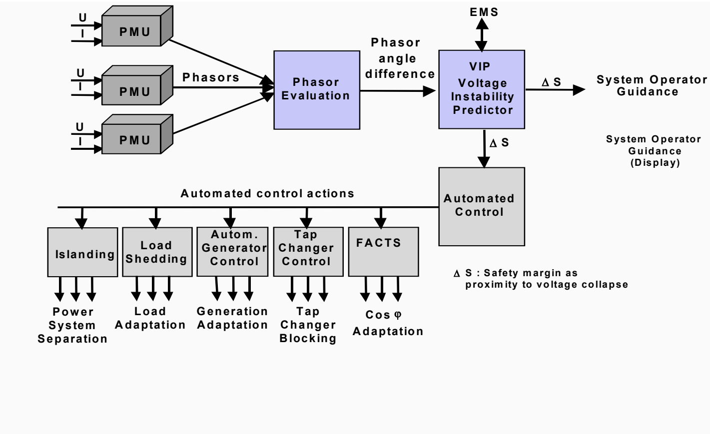

Figure 7: Power System Protection Scheme (SPS)

Interactions for Power System Management

Power system protection schemes are intended to complement legacy protection and control systems rather than to substitute them. (Figure 8) This means that the legacy object protection for transmission lines, power transformers, busbars and generators remain in place and act as active safety elements to prevent damages to the objects protected to happen in case of system failures. The main task of power system protection is to counteract major power system disturbances enabled by new measurement techniques and new communication techniques. Therefore, the interaction with legacy systems must not jeopardise its reliable operation. There are two levels of interactions:

1. On network level to provide early indication of incipient of problem areas in a network and to allow measures to counteract power system disturbances before they actually occur. This is a new quality of information, as it is derived from PMUs and cannot be retrieved from any analogue measurements of voltage, current or frequency.
2. On substation level to initiate preventive local actions e.g. transformer tap changer adaptations load shedding, islanding and automated power restoration after temporary outages.

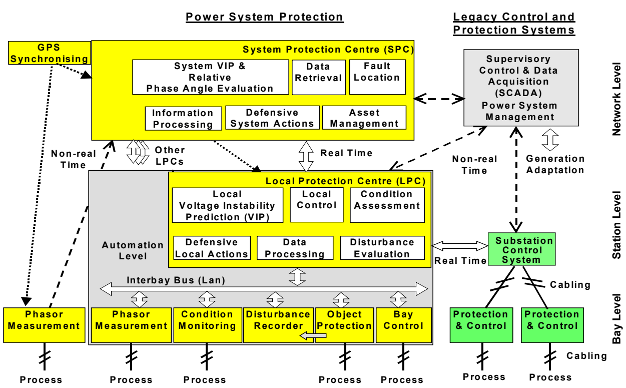

Figure 8: Interactions between SPS and Legacy Systems

The communication links for the interactions between the various levels require two classes of performance of the data exchange for real time and non-real time data. Local defensive actions, which may be initiated by the local VIP, e.g. tap changer adaptations and load shedding rely on locally available information only and are not dependent on communication links to the SPC. This makes it possible to implement a power system protection concept step-by-step in line with the communication system upgrades.

Decision Support Systems

In the case of power system disturbance, data from disturbance and event recorders, information on network configuration, protection relay signal data and operational procedures all need to be considered when arriving at the appropriate decision for corrective action. This can be problematic due to data volumes and the limitations to the amount of information and real-time performance, which can be managed from SCADA and handled by an operator. The advantages of an automated system located in the substations, which accelerates the automation process, are obvious. The corresponding system structure in figure 8 shows the allocations of functions and the communication links. There are two categories of data, which have to be exchanged: real time data for fast automated defense actions and non-real time data for supervisory control, data acquisition, and condition assessment between substations and network management level.

CONCLUSION

The SA infrastructure comprising numerical protection and control devices allows a new maintenance approach for T&D equipment and provides cost effective solutions for

- On-line monitoring of primary and secondary substation equipment
- Diagnostics to determine the need for maintenance
- Reliability-centred maintenance and condition based asset management

The benefits are reduction of operation and maintenance costs as well as improved service quality and overall power system availability.

The integration of protection and control is a way to minimise installation and maintenance complexity by reducing the number of IEDs in a substation. On the other hand, it allows automated defensive actions against voltage collapse like transformer tap changer adaptations, intelligent load shedding, adaptive protection and intelligent power restoration automatics.

The advantages of power system protection concepts are the early indications of incipient system faults, which enable operators to take preventive actions in order to prevent threatening system collapses. In case of unavoidable loss of transmission lines and/or power generation plants, large area outages, which are caused by voltage and frequency declines, can be automatically counteracted by means of automated defensive control actions and power system restoration after temporary outages.

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