MANUAL

ELECTRICAL NETWORK MONITORING AND CONTROL SYSTEM - APPLICATION

DEP 33.64.10.11-Gen.

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DESIGN AND ENGINEERING PRACTICE

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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for formulating the scope of supply for an Electrical Network Monitoring and Control system (ENMC system) as described in DEP 33.64.10.32-Gen.

The operational supply functions of generating systems and transmission functions are normally beyond the scope of supply of an ENMC system. However, a number of these functions may become applicable in large electrical network. The relevant functional diagrams and descriptions are incorporated in this DEP in case these functions might be required.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

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This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply/marketing installations.

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1.3 DEFINITIONS AND NOMENCLATURE

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Network function definitions

Consistency analysis	Determining anomalies and inconsistencies in network operation data.
Distribution power flow analysis	Analysing actual power flow in the distribution network and checking for out-of-range operating conditions.
Economy A	Evaluation of a possible energy transaction with an external company in terms of costs/profits without altering the unit commitment schedule.
Economy B	Evaluation of a possible energy transaction with an external company in terms of costs/profits taking into account alternative unit commitment schedules.

Economic dispatch	Allocating power resources to feed the network at a particular time, i.e. meeting the network load at that time with minimum overall production costs.
Energy demand control	Optimising the use of electrical energy over a particular time period.
Fault calculation	Calculating currents and all contributions to fault currents, comparing fault currents against circuit breaker ratings for each circuit breaker involved.
Fault location	Determining the probable equipment location of a fault.
Fault isolation	Indicating which equipment is faulted and should be isolated.
Feeder reconfiguration	A proposed feeder configuration that optimises the feeder according to a number of objectives.
Generation area control	Control of the total power output of selected generation units in a predefined area.
Interchange transaction scheduler	Planner and scheduler for energy exchange.
Load/frequency control	Control of the power output of a generator according to setpoints and generator constraints.
Network security analysis	Determining the security of the power system under specified contingencies.
Network sensitivity analysis	Calculating, for the actual network state, the sensitivity of network losses to changes in unit generation and to interchanges with other networks.
Network voltage scheduler	A real-time optimisation of the network voltages and MVAr flows, recommending control settings to minimise active power losses and maintain bus voltages and branch flows within limits.
Optimal power flow	Determining a network solution that optimises performance under certain operational constraints.
Power flow analysis	Examining the steady state conditions of the power network that may exist under a wide variety of conditions.
Production cost monitoring	Monitoring and summarising production costs and fuel consumption of generating units, comparing them with optimum production costs.
Real time sequence control	A sequential run of network application functions.
Reserve monitoring	Calculating actual figures for active/reactive spinning and operating reserves, comparing these with defined classes and indicating shortfalls.
Security checked switching	Checking the power system state for limit violations as a result of an intended switching action.
Security dispatch	Achieving an optimum balance between security, costs and other operational constraints, and determining the most effective remedial actions if operating constraints are violated.

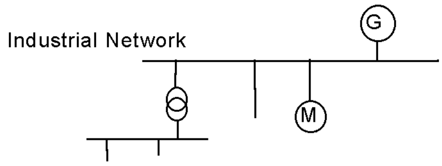
Service restoration	Determining alternatives for re-energising equipment and sections that are switched off but not identified as faulted.
State estimator	Providing a complete network solution from real-time measurements and network data, calculating the best possible 'image' of the actual load flow situation within the power system and creating pseudo measurements to allow estimated solutions for unobservable parts of the network.
Transformer load management	Utilisation of short-term overload capabilities of a transformer; load balancing between transformers by feeder reconfiguration.
Unit commitment	Scheduling operation of generating units to supply the load under certain constraints.
Volt/VAr control	Determining settings of transformer taps, voltage regulators and shunt capacitors/reactors to achieve selected objectives.

1.3.3 Terminology

Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided. Availability is calculated from the formula: Availability (%) = (total time - total down time) / (total time) x 100.
Distributed Control System	A computerised system which is dedicated to monitoring and controlling defined aspects of process installations.
Electrical Network	the complete electrical network consisting of generation, transmission and distribution. Four types of networks are distinguished: G-type, GPO-type, P-type, PGD-type and PGT-type.
Electrical Network Monitoring and Control system	A computerised system which is dedicated to monitoring and controlling defined aspects of an electrical network.
Electromagnetic Compatibility	The ability of an equipment or system to function satisfactorily in its electromagnetic environment without imparting intolerable electromagnetic disturbances to anything in that environment.
Emission level	The amount of electromagnetic emission that is permitted

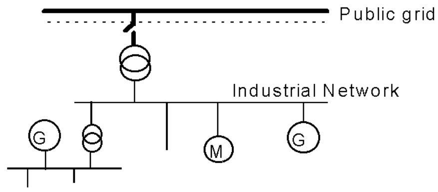
G (Generation) Type Network

Electrical network, self supporting, no coupling to the public network possible.



GPO (Generation, Public Optional) Type Network

Electrical network, normally self-supporting, coupling to the public network possible.



Immunity Level

The electromagnetic disturbance that is permitted without degradation of the performance of an equipment or system

Inputs / Outputs

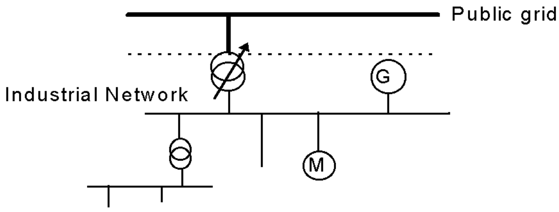
The actual interface of the ENMC system to other systems or equipment. It does not mean a 'serial link'.

Network function

Function needed for (electrical) network operational reasons, i.e. to operate the network in a safe and/or economical way.

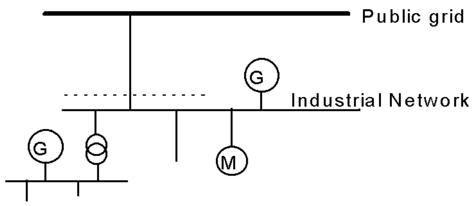
PGT (Public/Generation, Transformer connected) Type Network

Electrical network coupled to the local public network through transformer with on load tap changer, own generation in parallel.

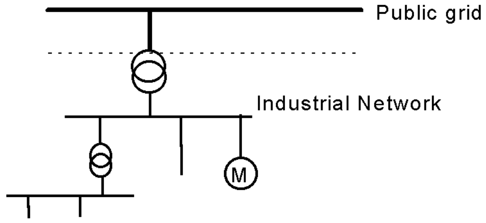


PGD (Public/Generation, Directly connected) Type Network

Electrical network coupled directly to the local public network, own generation in parallel.



P (Public) Type Network	Electrical network coupled to the local public network, no own generation available.



Reliability	The probability that an item can perform a required function under given conditions during a given time interval.
Satellite equipment	ENMC subsystems that are not at the ‘central location’ (which is usually the control centre), but are distributed over the electrical network.
Supervisory Control And Data Acquisition	A set of functions responsible for the acquiring and processing of data and issuing of commands.
Support functions	Functions not explicitly needed for the network but supporting the operation of the ENMC system or the operator.
System functions	Control and monitoring functions, inherent to a computerized ENMC system.
Test procedures	Activities to verify the actual performance of a system or part thereof.

1.3.4 Abbreviations

AVR	Automatic Voltage Regulation
CRT	Cathode Ray Tube (= monitor)
DCS	Distributed Control System (process control)
EMC	Electromagnetic compatibility
ENMC	Electrical Network Monitoring and Control
HMI	Human Machine Interface
I/O	Input/Output
MCC	Motor Control Centre
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (8).

2. OBJECTIVE OF THE ENMC SYSTEM

2.1 GENERAL

In general, the objective of an ENMC system is to improve the operation of an industrial electrical network in terms of cost, safety, availability and power quality.

The functions required in an ENMC system depend on the type of network (1.3.3), the size of the network and the way in which the network is operated.

2.2 AVAILABLE FUNCTIONS

The majority of ENMC systems will only deal with SCADA functionality; relative simple and straightforward functions for monitoring and controlling the network. Possibly these SCADA functions may be complemented with applications to control power generation in the network.

If the network is relatively large and/or complex or it is operated close to its limits, energy management functionality may be included in an ENMC system, enhancing the security level.

Functions aimed at achieving cost and/or economic optimisation are traditionally used in very large systems (e.g. national control centres of public utilities). However, functions dealing with economic aspects in an ENMC system may be included for the following reasons:

– the industrial network also operates as a public utility;
– the increasing awareness of and need for “power quality”.

If the industrial electrical network operates as a public utility, liberalisation of the electricity sector, i.e. the growing competition in selling electricity, may be another motivation for including economic optimisation functions.

System and Support functions are inherent to an ENMC system. The number and extent of these functions depend on the extent of the ENMC system.

In sections (4) and (5) a description is given of the possible functions to be implemented in an ENMC system.

2.3 REAL TIME OR STUDY MODE

Many functions can either run in:

– real time mode: data originating from the actual network is utilised and results are directly related to the actual situation;
– study mode: this offers the operator a means to study behaviour of the network (using the same network model) under several conditions.

Configuring the system so that functions are accessible in study mode only might lead to a reduction of the system cost.

2.4 INTEGRATION OF FUNCTIONS

An important factor in the selection of an ENMC system is the degree to which functions are integrated in that system. The advantage of highly integrated products is the uniform user interface (menu structure having the same look and feel across all applications) and a uniform naming convention of objects across applications.

Poor integration is generally characterised by a non-uniformity of the user interface and naming convention. If equipment for such a system is selected on case-by-case basis this leads to one-off systems and raises the question of after-warranty support for such special applications.

3. NETWORK FUNCTIONS

3.1 GENERATION

Functions related to generation can be divided into three categories:

- generation control;
- energy scheduling;
- operational planning.

3.1.1 Operational planning functions

In general, functions dedicated to operational planning are required when economic constraints dictate to an important extent the operation of (large and extended and/or complex) electrical networks. Although these functions are normally beyond the scope of functions needed to monitor and control an industrial electrical network, a description of them is given in this DEP as they may be applicable to some networks or become required in the future.

3.1.1.1 General description of function aspects

The principal function for the economic optimisation of a set of generating units is *unit commitment.*

In most cases customisation is required to incorporate special features of the generation sets utilised.

Examples of customisation are:

- combined optimisation of electricity and heat;
- minimum-take constraints on some fuel types;
- exchange of power (import / export) with Utilities or other areas.

Prerequisites for application of *unit commitment*:

- generator incremental heat rate curves known;
- initial status of the units known in study mode (e.g. off-line or on-line and since when, actual generation level if on-line);
- system load must be known on half-hourly or hourly basis for several days, typically up to 8 days. This data could be supplied by load forecast (not a prerequisite but it facilitates the supply of data);
- desired spinning reserve (from *reserve monitoring*);
- all relevant data of the interchanges with other utilities or other areas if applicable. In large networks, the *interchange transaction scheduler* is used to supply this data. If the latter function is not included in the system, then the data needs to be supplied in another way, e.g. by importing a file from another application (for instance a Contract Management tool running on PC) or by manual entering by the user;
- loss penalty factors computed either by penalty factor calculation (from *network sensitivity analysis*) or in off-line mode and manually entered by the user.

Data from the *unit commitment* function is needed by the *load/frequency control* function and must be supplied automatically or manually. If the number of generators is limited to a few units, then probably a stand-alone *unit commitment* will do or even in some cases a program implemented in a spreadsheet. The user would then have the responsibility to supply data to other applications either semi automatically (e.g. file transfer) or manually. For example the optimal generation levels would be manually entered in the input displays of the load flow program or into the *load/frequency control* function.

It is important to:

- assess how often *unit commitment* needs to run;
- determine the degree of automation/integration that is required;
- define the desired user friendliness;
- highlight the special features of the generation units (needing customisation work!).

Economy A and *economy B*, in conjunction with *load/frequency control*, are tools for evaluating possible energy transactions not included in the *unit commitment* (last minute offers). It only makes sense to include one or both of them if *unit commitment* is also included in the scope of supply.

The need for *production cost monitoring* greatly depends on the economic constraints the network has to be operated under. For *production cost monitoring* an overlap may be possible with the functions of the Distributed Control System. To determine the necessity of this function this question shall be clarified and resolved.

To simplify the supply of input data to the *unit commitment* function, several applications, for instance *Interchange transaction scheduler* and *reserve monitoring*, can be used.

Unit commitment and *economic dispatch* functions in available ENMC systems are often closely related. Spinning reserve requirements are based on Economic Dispatch results taking into account transient spinning reserve capabilities of the committed units; reserve levels are not predetermined fixed values but are calculated on the basis of units available and their characteristics, the desired system response in case of system faults and other contingencies. Because of this close relation between *unit commitment* and *economic dispatch* these functions may be integrated into one single function.

3.1.1.2 Unit commitment

The objective of this function is to determine the optimal generation levels of generation units (typical study horizon one day to one week) and to determine a pre-dispatch schedule of these units.

Unit commitment offers the possibility of optimising the operation of thermal generating units to supply the load at minimum costs while meeting system loads and reserve requirements.

Minimum costs are achieved by considering the following constraints:

- start-up and generation costs;
- most economical start up and shut down times;
- minimum uptime and/or downtime;
- generation levels;
- spinning reserve requirements.

Unit commitment needs the following information:

- available generating units;
- units generating at present;
- units that have to be kept on-line (e.g. for voltage control);
- unavailable units;
- specific unit characteristics incl. costs and expected load (electrical, steam consumption and required import/export transactions).

Example:
This function offers for each generation unit a schedule showing when and how it can be applied to contribute to the network load or to meet contract agreements.

3.1.1.3 Economy A

This optimisation function enables the operator to evaluate a possible energy transaction with an external company in terms of the costs of the actual energy exchange and the costs of increasing or decreasing the committed generation resources in the network.

Commitment schedules are not changed (as is possible with *economy B*) meaning that only generation units that were scheduled can be regulated to generate more electrical power.

Example:
By adjusting the power output of the already running generation units, electricity can be sold to, for instance, a public utility. Because the generation units are already running, their start-up and shut-down costs are not applicable.

This may be a permanent situation where the industrial plant acts as a utility or in case of emergencies the industrial plant can help the public utility to survive.

3.1.1.4 Economy B

This optimisation function enables the operator to evaluate a possible energy transaction with an external company in terms of the costs of the actual energy exchange and of increasing or decreasing the generation resources in the network.

Unlike *economy A*, commitment schedules may be changed meaning that start-up of generation units that were not scheduled may be considered.

Example:
In the situation as described under the example of *economy A*, the use of non-scheduled generation units is additionally possible so the costs of start-up and/or shut-down of units also have to be considered.

3.1.1.5 Production cost monitoring

This function allows the operator to monitor and summarise the production costs and fuel consumption of the generating units and compare them with the optimum production costs.

Taken into account are:

- production costs;
- fuel consumption;
- start-up costs.

Note An overlap may be possible with a similar function implemented in the DCS.

Example:
When generation units can be regulated and the total load can be divided over a number of units, this function offers information for evaluating the efficiency of each unit in terms of costs.

3.1.2 Generation control

The following kinds of control can be distinguished in an industrial electrical network:

- primary control: directly related to the controlled device; not implemented in an ENMC system;
- secondary control: related to parallel operating devices that have the same type of primary control; can be implemented in an ENMC system;
- tertiary control: related to the exchange with an external network; can be implemented in an ENMC system; always related with economical aspects.

3.1.2.1 General description of function aspects

By controlling the power output and voltage of individual generator units the total electrical load is allocated to all power sources (generator units as well as connections to an external grid) and the network voltage is maintained within a certain bandwidth.

Volt/VAr control offers the possibility of controlling voltage and reactive power. When maintaining voltage within a certain bandwidth *Volt/VAr control* acts as a primary control function. For this purpose a number of control means can be available. The secondary control function, reactive power control, is superposed on the voltage control and is necessary if two or more generators run in parallel to maintain the distribution of reactive power among the generators.

Load/frequency control can be regarded as the central function for controlling selected generator units to maintain system frequency and scheduled power output. This function acts on the prime mover of the generator unit.

If the plant network is connected to an external grid, frequency is determined by that external grid and in this situation the *load/frequency control* function controls the electrical output of the generators in operation (primary function), the balance between them (secondary function) and, when applicable, the export/import of power (tertiary function).

If the plant network operates in island the electrical power output is determined by the load and the *load/frequency control* function maintains the frequency of the plant network within a certain bandwidth (primary control) and also balances active power output among the generators in operation (secondary control).

When considering the need for the *economic dispatch* function the following aspects are decisive:

– the number of regulating generators;
– whether the characteristics of the units involved differ considerably.

If the number of units is limited to a few units or the characteristics do not differ to a great extent, then the *economic dispatch* data can be manually entered by the operator.

For non-regulating generation units the output level is either manually entered in the e*conomic dispatch* function or is supplied by the *unit commitment* (if included in the scope of supply).

Generation area control is the tertiary control function for enforcing contractual obligations on the tie-lines (import/export contracts) in order to reduce any deviation between actual and scheduled net interchange. More than one *generation area control* function may be possible if a network is subdivided into smaller sub-networks.

The decision whether to include *generation area control* in the scope depends on the size of the network and the type of contracts.

The following questions need to be answered:

– are there “regulating contracts” i.e. contracts imposing obligations to stay in a MW band or are there security constraints whereby area exchange must be kept within certain limits?
– are there enough regulating units available to be controlled by the *generation area control* and optimised by the *economic dispatch*? If so, is the turbine side of each generator unit suitable for fulfilling the regulating requirements?

If the answer to either question is ‘no’ then this function is not required.

One way to measure the return on investment of the *generation area control* function is to compare its cost to the penalties applied when deviations on energy transactions occur, but the increased stability and security of the total system may be far more important. The generator units are operated at working points where the system as a whole can withstand a relative large disturbance before any generator will trip.

Generation area control requires as input:

– the scheduled net area interchange (from *interchange transaction scheduler*);
– the list of regulating units along with their participation factor (from *economic dispatch*).

Functions as mentioned above that automate the supply of input data to the *generation area control* function can be considered as optional. The absence of these functions generally entails an additional workload for the operator.

The *generation area control* function utilises the *load/frequency control* function to control generation in a particular area of an electrical network.

The need for *reserve monitoring* greatly depends on the economic and security constraints the network has to be operated under. The *reserve monitoring* function can be used to simplify the supply of input data to the *unit commitment* function.

Depending on the system losses, a link with the *network voltage scheduler* function may be required in order to minimise overall losses.

3.1.2.2 Volt/VAr control

By means of *Volt/VAr control* the voltage of a network can be maintained within a certain bandwidth and the reactive power flow/balance can be controlled.

Control may be achieved by means of:

- on-load tap changers of transformer;
- synchronous generators;
- shunt capacitors/reactors;
- synchronous motors.

Operator selected objectives to be achieved may be, for instance:

- voltage security;
- improvement of power factors;
- system losses minimisation;
- limitation of active power loads;
- determination/setting of optimal pre-fault voltages in the case of motor starting or voltage recovery.

Results are presented to the operator and control actions are recommended to achieve the selected objective. Alternatively, automatic control actions may be performed.

Reactive power control as a secondary control will maintain generation units within their limits. The function may be extended to provide a constant reactive power output or constant power factor.

As a tertiary function this function can maintain the exchange of reactive power with an external network within a certain bandwidth or it can maintain the power factor of the power exchange within certain limits.

Example:
Volt/VAr control offers the possibility of optimising voltages, power factors and losses in the event of a change in the system configuration (e.g. a system fault).

3.1.2.3 Load/frequency control

Load/frequency control enables control of selected generator units by means of MW set-points or command pulses (raise/lower) with the objective of maintaining system frequency and/or scheduled net interchange and/or allocation of loads to generator units.

Load/frequency control concentrates on maintaining system parameters that are provided by other functions (for example *generation area control*). These parameters (for instance frequency) are met by regulating the selected generation units.

Note: This function does not replace the generator’s governor.

3.1.2.4 Economic dispatch

Economic dispatch calculates the optimal output level and the generation participation factor for the regulating units. *Economic dispatch* runs typically every 15 minutes.

Economic dispatch:

- requires the incremental heat rate curves of the units to be known in order to determine their optimal output and the participation factor;
- is used to allocate the dispatchable power resources (based on *unit commitment* information) to be connected to the system at a particular time. The objective is to meet the system’s load at that time in a way that minimises the overall production cost of the system;
- also determines the required levels of spinning reserve taking the transient control capabilities of the units, implemented under frequency load-shedding and potential network faults into consideration;
- provides the generation base point values for each generator participating in the optimisation process mentioned above according to the operating modes of the generation units involved.

Example:
It may be economic to disconnect a certain generator from the network at a certain time of day. For instance a gas turbine may be shut down at the time of maximum gas consumption

when gas is expensive. On the other hand it may still be economic to connect this generator in times of high gas prices when electricity prices are high and electricity is sold or the import of electricity can be reduced.

3.1.2.5 Generation area control

Generation area control enables control of the power output of selected generating units within an electric network or a predefined area thereof. The selected generation units are controlled in response to changes in the system frequency and/or power exchanges with other areas.

Regarding the reference values, the objective of this function is to meet the area's obligations to contribute to system regulation (e.g. system frequency) and/or to comply with area interchange agreements (scheduled net interchange). *Generation area control* utilises the *load/frequency control* function.

The total desired generation is distributed to all selected units with account being taken of the unit operating modes.

This function may be used as:

- system supervisor;
- area controller.

The performance of *generation area control* can be monitored in order to check the load and frequency behaviour of the system in order to optimise overall performance.

Example:
This function is able to regulate generation units in order to meet contract agreements, for instance in the weekend reactive power shall be imported and on normal working days a certain amount of active power shall be exported.

It can also be used to regulate a part (or parts) of a large network, for instance in order to optimise the load of tie-lines or interconnections, or to meet (internal) contract agreements.

3.1.2.6 Reserve monitoring

This function is used to:

- specify active and reactive (spinning and operating) reserve requirements within the network, taking into account interchanges with other areas and security constraints;
- calculate actual active and reactive reserves;
- calculate spinning and operating reserves;
- compare actual reserves with requirements for a variety of reserve classes;
- indicate shortfalls.

Example:
This function may be useful for reviewing the need for reserve generation power, for instance if generation units are not always available.

3.1.3 Energy scheduling

Energy scheduling offers a means for scheduling power transactions and power exchange.

The *interchange transaction scheduler* function can automate the supply of input data to the *load/frequency control* and can be considered as optional. The absence of this function generally entails an additional workload for the operator.

In addition, *interchange transaction scheduler* is only needed if there are many regulating generators (more than 10). If there are only a few units then the *interchange transaction scheduler* supplied data can be entered manually by the operator.

The *interchange transaction scheduler* can be used to simplify the supply of input data to the *unit commitment* function.

3.1.3.1 Interchange transaction scheduler

Interchange transaction scheduler determines the scheduled net area interchange (including ramping rates of transactions).

The operator is enabled to:

- define and review interchange agreements with partners in the interconnected network;
- enter scheduled interchanges in advance.

Agreements can be formulated for the normal energy exchange but also for the interchange during emergency situations.

Information from this function can be used, for instance, by the *load/frequency control* and the *reserve monitor* functions in order to comply with contracts and at the same time fulfil the operational needs of the network.

Example:
The contract rules concerning interchange agreements can be laid down in this function. Momentary changes to these rules can also be specified in order to meet the contract agreements in the most economic way.

3.2 DISTRIBUTION

3.2.1 General description of function aspects

Most of the functions related to distribution are mainly relevant for large electrical networks.

Distribution power flow analysis is usually used to determine power flows in the event of a system fault or change in system configuration. In this way the network's capability to cope with changes can be determined for user defined scenarios. It will not provide any monitoring of power quality. The load flow offers a useful functionality for a large or complex network. In real time, the data acquisition system provides initialisation data for the load flow.

Energy demand control addresses mainly economic considerations, depending in turn on the utility's contractual terms. These aspects should determine whether the use of this function would give any added value or return on investment.

Transformer load management addresses network security and reliability issues. The use of this function greatly depends on the type of load constituting the distribution network.

3.2.2 Distribution power flow analysis

The *distribution power flow analysis* allows the operator to analyse the actual power flow in the network and to check for out-of-range situations. It recognises system asymmetry and unbalance throughout the system.

For each feeder the following variables are taken into account:

- node or bus voltage;
- substation transformer tap position and loading;
- voltage regulator status and voltage;
- capacitor bank status and voltage;
- feeder segment amperages, loading, losses and voltage drops;
- transformer voltage drops, losses, tap positions and loading;
- cumulative voltage drops.

The operator may also study the power flow resulting from control actions. To check the assignment of loads to a feeder, this function also offers the possibility of producing lists showing which loads are connected to a certain feeder. *Distribution power flow analysis* uses telemetered data when available. However, when loads are not telemetered (as may be the case in large networks), statistically load data needs to be used (Load curves). Usually the load flow also incorporates a short circuit analysis facility.

Example:
Examining the steady state condition of the actual distribution network may show that network components, for instance transformers, are operating beyond their optimal conditions.

3.2.3 Energy demand control

Energy demand control optimises the use of electrical energy over a particular time period in respect of the balancing interval agreed with the electricity supplier. It is intended to archive an optimum use of the power availability without overshooting the energy quantity agreed upon for the particular time period.

On the basis of the accumulated energy and the average power over the balancing period, and after comparison with the valid power setpoint, appropriate proposals for deploying energy consumers and producers are derived.

Energy quantities are calculated and adherence to the power setpoint is monitored. If there are no further possibilities of correcting the energy demand and if the power setpoint is about to be violated a warning is given to the operator.

If violation of the power setpoint is imminent, proposals are made to increase own generation or reduce the load. If adherence to the power setpoint is insufficient, proposals are issued to increase the load or reduce own generation.

Proposals may be implemented automatically.

Note: For P-type electrical networks the cost benefit has to be evaluated.

Example:
This function offers the possibility of reducing the load during high loads when electricity is expensive. It should also be combined with the exchange of electricity when switching off loads. This may result in a higher export of electricity at those times when selling electricity is profitable.

3.2.4 Transformer load management

This function allows:

- the operator to utilise the short term overload capabilities of a transformer, for instance during emergencies;
- evaluation of load allocation;
- load balancing between transformers by feeder reconfiguration.

Proposed actions are presented to the operator.

Example:
The use of transformers can be optimised in terms of reduced lifetime against shut-down of a plant, i.e. reduced production.

Also, the **ENMC** system may alert the operator to unsafe allocation of loads in terms of availability and reliability of supply.

3.3 TRANSMISSION

3.3.1 Introduction

Functions dedicated to transmission are normally beyond the scope of functions needed to monitor and control an industrial electrical network as they are only applicable to large and extended electrical networks. However, as these functions may be applicable to some networks or become required in the future, a description of them is given in this document.

The need to apply these functions depends to a great extent on the complexity of the network. The key question that needs to be answered to determine which functions need to be included in the scope is whether real-time security assessment is required or merely off-line (study mode) security analysis.

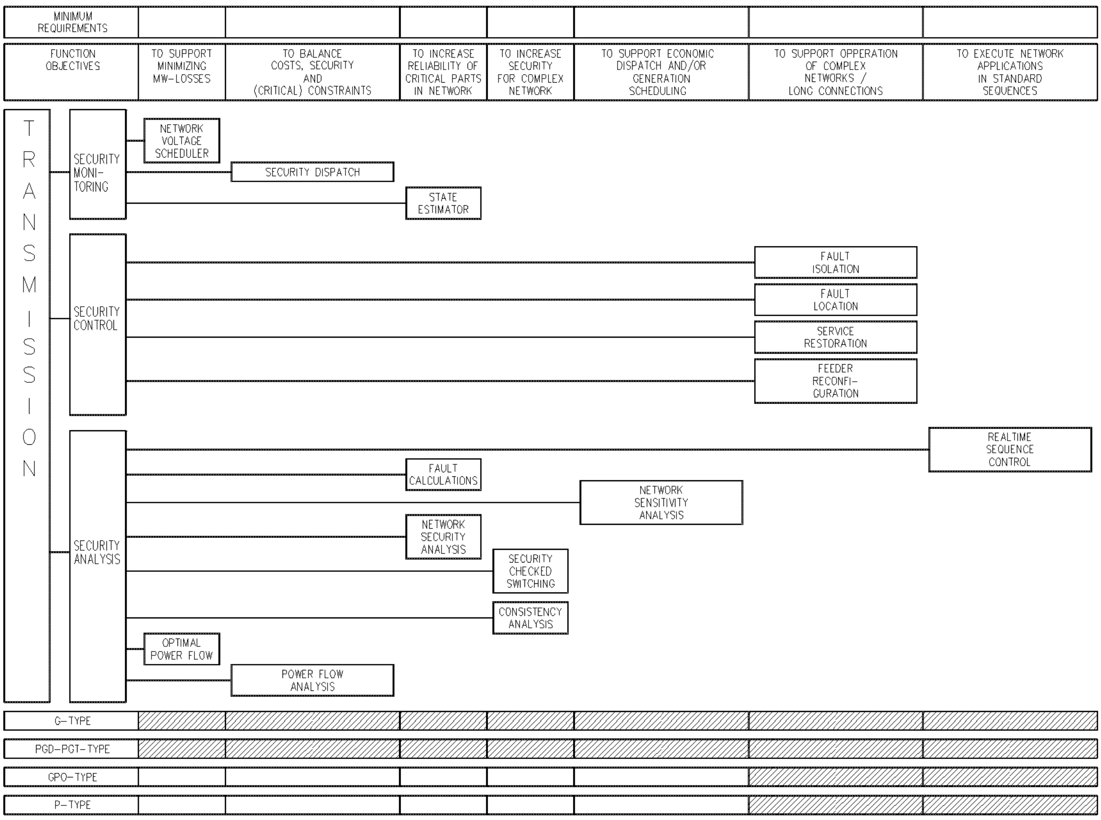
If study (planning) functions are required, it shall be determined whether or not these functions should apply to the same network as the real time network. If not, then an off-line package can be included in the scope as a stand-alone or a loosely integrated application.

Transmission functions are subdivided into 3 categories:

- security monitoring;
- security control;
- security analysis.

Functional diagram 1 gives an overview of all network functions related to transmission including the governing requirements.

Functional diagram 1 Functions related to transmission



3.3.2 Security monitoring

3.3.2.1 General description of function aspects

Functions related to security monitoring offer the operator information about the stability and security of the electrical network and alert the operator to potential problems.

The *network voltage scheduler* function may be required when the network configuration changes on a regular basis and several different configurations are possible. It supports the operator in operating the network in an economic and safe way and is a rational option if operators have limited experience. Depending on the system losses, a link with the *economic dispatch* function may be required in order to minimise overall losses.

Security dispatch is likewise a rational option in networks with several possible load supply configurations.

Network security analysis in real-time requires a *state estimator* function. This function is also a prerequisite for running all other dependent applications such as network *security analysis* and (*optimal) power flow*.

To run a *state estimator* in a reliable way, it is necessary to have:

– enough PQ measurement pairs on branches or power input points (in excess of 1.5 * Number of Electrical Nodes of the Network to ensure network observability);
– no quickly changing loads (in the range of seconds). If this condition is not met, then it will be necessary to filter the measurements (either at RTU level or control centre level);
– a balanced three phase network (if not balanced, the results of this function shall be carefully examined).

3.3.2.2 Network voltage scheduler

By means of the *network voltage scheduler* function, active power (MW) losses can be minimised.

The *network voltage scheduler* gives:

– a real-time optimisation of the network voltages and MVAr flows;
– recommendations for control settings to minimise active power losses;
– recommendations for control settings to maintain bus voltages and branch flows within limits.

The function determines optimum settings for:

– generator voltages;
– line tap changer (LTC) taps;
– phase shifter taps;
– voltage control capacitor (VCC) taps.

Example:
With generation at different voltage levels in the network, power flows, losses and branch voltages may change beyond limits depending on whether and how a generator is operating and on the actual network configuration.

3.3.2.3 Security dispatch

This function:

– enables the operator to achieve an optimum balance between security, costs and other operational constraints;
– determines the most effective remedial actions if operating constraints are violated.

If *economic dispatch* is constrained, *security dispatch*:

– identifies the critical constraints and their sensitivities to the active power controls;
– calculates the (security constrained optimum) unit generation levels that would minimise costs.

In all cases critical active power related constraints remain in force.

Operating modes may be:

- closed loop

  possible violation of active power operating constraints is detected, unit generation levels are calculated and generation is actually controlled;

- open loop

  possible violation of active power operating constraints is detected and unit generation levels are calculated. However generation is not controlled; results may be presented to the dispatcher/operator;

- expanded control

  critical constraints and their sensitivities to the active power controls are identified. This information can be used by the dispatcher/operator to examine possible control actions if generation rescheduling alone is insufficient to relieve overloads.

Example:
In a complex network that can be operated under several different conditions, this function supports the operator in operating the network in a safe way yet at minimum costs. When a network is always operated under the same operating conditions, *security dispatch* may be needed in the event of a power generation shortfall in a part of the network as it gives the optimum operating conditions for that particular situation.

3.3.2.4 State estimator

The *state estimator* generates a complete network solution from real-time measurements and network data. It calculates the best possible 'image' of the actual load flow situation within the power system, irrespective of metering errors.

Redundancy of information is used:

- to create pseudo measurements in order to estimate the solution of unobservable parts of the network;
- to detect the presence of abnormal measurements.

The *state estimator* provides the following main outputs:

- a consistent set of power input data (generation and loads);
- a list of real time limit violations, even on non-telemetered equipment.

State estimation is executed in real time mode only and is performed:

- cyclically;
- at the operator’s request;
- after a topological change in the network.

The *state estimator* is the basis for all network calculations.

Example:
This function offers the possibility of monitoring the quality of measurements and early detection of faulty measuring equipment or biased values.

3.3.3 Security control

3.3.3.1 General description of function aspects

The main objective of security control is to improve the quality of the network power and to reduce to a minimum the amount of undelivered energy.

Fault location, *fault isolation*, *feeder reconfiguration* and *service restoration* offer a set of functions that will inform the operator how to solve problems in the network as quickly as possible. These functions are closely related and particularly important in cases where power quality is essential and non-compliance with requirements may result in high costs.

3.3.3.2 Fault isolation

Fault isolation indicates which equipment is faulted and should be isolated; once the fault is identified, the operator is notified which equipment is faulted and should be isolated.

Information to the operator:

- the switches that can be opened to isolate the faulted equipment;
- the estimated amount of lost load in the isolated section;
- the estimated amount of load that can be restored downstream of the isolated section.

The operator can analyse the proposed actions and issue control actions to actually isolate the faulted equipment.

Example:
In a meshed network with many branches that may feed into a fault, this function offers the operator the means to isolate the faulted equipment in the shortest possible time giving at the same time the consequences (outages) and options available (for restoring loads).

3.3.3.3 Fault location

The *fault location* function determines, by means of status information from the system and protection tripping commands, the probable equipment location of a fault.

Information from a trouble call system and impedances measured by digital relays can further be analysed to determine the location of a fault more exactly.

Example:
In a network with many branches that may feed into a fault, this function may save time in localising the electrical location of the fault.

3.3.3.4 Feeder reconfiguration

The *feeder reconfiguration* function proposes a feeder configuration that optimises the feeder within the following objectives:

- minimisation of feeder losses;
- load balancing between supply transformers;
- minimisation of the worst voltage drop;
- minimisation of service interruption frequency;
- balanced service to important customers.

Example:
If customers can be supplied in more than one way (through different network configurations) the optimal way (under certain constraints) of doing so can be distinguished with this function.

3.3.3.5 Service restoration

The *service restoration* function determines alternatives for re-energising equipment and sections that are switched off but not identified as faulted.

After the faulty equipment has been isolated, a search is performed to determine alternatives whereby equipment and sections that are switched off but not marked as faulted can be re-energised.

Within a number of constraints a number of strategies for restoration are proposed using a minimum number of switching actions.

Constraints may be:

- line loading;
- over and under voltage;
- minimisation of loss;
- minimisation of de-energised customers;

– minimisation of the number of 'high priority' de-energised loads.

After having analysed these results, the operator can issue the appropriate control requests.

Example:
If customers can be supplied in more than one way (e.g. through different network configurations) the optimal way (under a number of constraints) of reconnecting customers if a network component is faulted can be determined with this function.

3.3.4 Security analysis

3.3.4.1 General description of function aspects

Network security analysis functions can be applied when information is needed about the effects of possible network problems on the performance of that network.

Consistency analysis is a very helpful function as it checks for inconsistencies in operating data from the electrical network.

The *fault calculation* is required if there are more than a few possible configurations of the network. Otherwise, the calculations need to be performed once only.

The need for the *network security analysis* function depends on how the *economic dispatch* and *generation area control* functions are implemented.

To review the network security, simulated contingencies can be checked by means of the *network security analysis* function. In this way several load flows in sequence will be executed. Each load flow starts from the last *state estimator* solution, simulates the contingency in the study environment and verifies whether limit violations occur.

Generally, *network security analysis* is not needed in small networks as most operators know their network. In large networks the main reason for including it in the scope is to decrease the workload of the operator and to have a better availability and reliability of the results.

Network sensitivity analysis calculates the sensitivity of the network to changes in available power. If sufficient power is available (tie lines, running generators) or if the risk of loss of the network and the processes powered by it is acceptable, this function might not be necessary.

In addition, the *optimal power flow* function makes it possible to:

– minimise MW losses while meeting imposed constraints (e.g. optimal voltage profile, tap changer control, Generator Q/V setting, capacitor bank switching);
– achieve economic optimisation and active power optimisation while meeting imposed constraints (e.g. generator P settings, subject to the same prerequisites as *economic dispatch*);
– take remedial action (remove limit violations i.e. bring the network back to just within the limits).

Power flow analysis is usually used to determine power flows in the event of a system fault or change in system configuration. In this way the network’s capability to cope with changes can be determined for user defined scenarios. It will not provide any monitoring of power quality.

Real time sequence control is a “nice-to-have” function but is only needed when the work load of the operator is high.

Security checked switching is a function which is a useful tool if there are operators with different level of expertise in the control room. As this functions slows down the sending of control actions, it is still recommended that at least one of the operators on duty remains able to directly send commands. User access rights can control who can send control actions with and without *security checked switching*.

3.3.4.2 Consistency analysis

This function checks for anomalies and inconsistencies in the data related to the operation of the network. It checks the summation of currents and power flows in branches and busbars, checks for consistency between currents flowing and closed switches and between currents to and from nodes.

Example:
When a connection is open the current passing through shall be ‘0’. The sum of all currents in a node shall also be ‘0’. Discrepancies mean incorrect status or measuring information.

3.3.4.3 Fault calculation

By means of this function fault currents and all contributions to fault currents are calculated. Fault currents at a faulted bus are compared against the circuit breaker ratings of each circuit breaker connected to the faulted bus. Fault current contributions of branches and/or generation units near the faulted bus are also calculated and compared against their respective fault ratings.

Fault currents and fault current contributions exceeding their non-zero rating are listed.

In study mode the effects of network changes on the fault currents may be studied.

Fault ratings can be defined on any circuit breaker, branch or unit.

Example:
The short circuit current may be too high for an installation to be interrupted safely, depending on the way generation units are connected to the network and when coupling breakers are closed, for instance.

3.3.4.4 Network security analysis

The *network security analysis* function determines the security of the power system under specified contingencies. For each contingency, it simulates steady-state power flow and checks the network for out-of-range conditions.

Violations of constraints are reported to the operator. The function warns the operator about what can happen so that precautionary measures can be taken.

Example:
Power flows which are normally within the equipment capacities may become too high if, for instance, a connection is switched off or a transformer is tripped.

3.3.4.5 Network sensitivity analysis

The purpose of this function is to calculate, for the actual network, loss penalty factors which are a measure of the sensitivity of system losses to changes in unit generation and interchange with neighbouring networks.

Loss penalty factors are used by the *economic dispatch* and *generation area control* functions. The data resulting from *network security analysis* has no significance for the operator.

Example:
As actual losses in the network depend on power flows, this function offers the means for evaluating the behaviour of losses as a function of energy production and/or energy exchange.

3.3.4.6 Optimal power flow

Optimal power flow generates a network solution (i.e. feeder configuration, transformer tap settings, shunt capacitor status) to redefine a performance criterion (system losses) under certain operational constraints (i.e. voltage and line/transformer flow limits).

The primary task is to keep or move power system variables within the user specified limits. Secondarily it optimises the objective within these limits.

Performance criterion, constraints and the controls to be used may be specified by the operator.

The control variables used in the optimisation may be:

- transformer tap ratios;
- sectionalizer status;
- generation unit KV and MW;

- phase shifter taps;
- interchange possibilities;
- load shedding;
- capacitor or reactor taps.

Constraints may be:

- bus voltage upper and lower limits;
- line/transformer MVA limits;
- transformer tap upper and lower limits;
- capacitor bank upper limits;
- bus real and reactive power balance constraints.

It can be used by the operator to examine “what-if” situations.

Example:

Optimal power flow gives suggestions to the operator on how to supply electric power to the loads in an optimised way. For instance, by changing tap changer settings or supplying loads from another substation, losses of connections may decrease.

3.3.4.7 Power flow analysis

This study function examines, at the operator’s request, the steady state conditions of the power transmission network that may exist under a wide variety of conditions.

Power flow analysis uses telemetered data when available. However, when loads are not telemetered (as may be the case in large networks), statistical load data needs to be used (Load curves). Usually the load flow incorporates the functionality of short circuit analysis as well.

Results are presented to the operator.

Example:

Examining the steady state condition of the actual network may show that connections are loaded just under their limits and/or that network components are operating beyond their optimal conditions.

3.3.4.8 Real-time sequence control

By means of *real time sequence control* the operator is able to define a sequential run of network application functions in addition to manually initiated runs. This function eases the task of the operator.

Example:

If the same operations are constantly repeated or there are many sequential functions, the work load of the operator is decreased.

3.3.4.9 Security checked switching

Security checked switching enables the operator to check the power system for limit violations as a result of an intended switching action.

This function does not prevent an operator from de-energising a part of the network as this does not result in a network overload.

Detected limit violations are presented.

Example:

The operator can be warned when, for instance, closing a coupling switch may result in a too high short circuit power for a busbar/substation.

4. SYSTEM FUNCTIONS

4.1 SUPERVISORY CONTROL AND DATA ACQUISITION

4.1.1 Introduction

Supervisory control and data acquisition (SCADA) is the minimal system configuration of an ENMC system. In fact an ENMC system is a SCADA system extended with Energy Management System functions.

The data acquisition function is responsible for:

- acquiring data from and sending data to the process to be monitored and controlled via:
  - local inputs and outputs;
  - communication links to remote input/output devices;
  - communication links to RTUs
  - communication links to other systems;
- treatment of the communication links:
  - various transmission modes (point to-point, multi-point etc.);
  - various acquisition operation modes (cyclic, periodic, polling etc.);
  - protocol conversion (to connect modules from different vendors);
  - data concentration;
  - error detection and correction (incorrect response, invalid security codes etc.);
- basic data processing:
  - data quality coding;
  - status change detect;
  - renewal check;
  - time stamp;
  - plausibility check;
  - sequence of events;
  - analogue data:
    - significant changes detection;
    - reasonability limit checking;
    - threshold supervision;
    - data conversion (i.e. to engineering units);
    - rate of change checking;
- processing of non-telemetered data:
  - manually entered data;
  - calculated data;
- pulse accumulator data processing;
- keeping up to date a real-time database with all process information (image management);
- distribution of data to (sub)systems (including mimic boards);
- time synchronisation and time processing.

Supervisory control offers control of remotely controllable objects in the power system network.

Control commands can be given to individual objects and/or groups of objects, as well as setpoint commands.

Besides commands from the operator directly, commands can also come from control sequence programs (e.g. sequential switching programs).

To prevent any personal injury or material damage, (topological) interlocking conditions can be configured for every command.

Supervisory control features include the following operator actions:

- give commands to network objects;
- start programs (e.g. sequential switching programs);
- set tags on data to call the operator's attention (i.e. Control Inhibit, Permit to Work);
- enter comments (notes).

4.1.2 General description of function aspects

Monitoring, alarming, tagging and hard copying are standard SCADA functions, as is the HMI.

The historical data processing function is necessary when daily logs or disturbance data processing is required.

Energy accounting is required when energy is accounted for e.g. by the Public Utility or when area or plant energy has to be accounted for.

The need for the load shedding function is directly related to the availability of power, either from the public grid or from the company power generation units. Once equipment and loads are shut down, the re-acceleration function is an option for restoring loads with optimal efficiency in terms of available power and required time.

The synchronising function may be implemented in the ENMC system but, if so, it will be implemented in hardware as close as possible to the objects to be synchronised. The reason for this is the need for accurate analogue measurements in terms of time and value in order to give breakers a close command at exactly the right time, also taking into account delays due to the mechanical construction of breakers.

Topological network colouring offers the possibility of connectivity tracing of circuits. Circuit colours are changed depending on the actual condition of the network. In this way easier tracing of circuits is possible on a graphic screen.

4.1.3 Human/machine interface

4.1.3.1 General

The purpose of this function is to offer the operator the means to supervise and monitor the electrical network and to control/maintain the ENMC system.

Actions to be performed may be:

- system management;
- adapting functions to the actual plant network by configuration and management of the (application) programs concerned;
- maintaining the system software by exchanging or loading software;
- making backups;
- operation of the ENMC system:
  setting of markers (warning, operator comment), acknowledgement of alarms, withdrawal of information and control of switches;
- operation of the electrical network:
  equipment and components in the network can be controlled;
- logging of information.

Note: Symbols used in visual presentation and the menu structure applied in controlling equipment shall conform to the standards as applicable to the installation concerned. These standards may be Shell-wide or restricted to the network concerned.

4.1.3.2 Requirements

For a full-graphic HMI the following requirements apply which are fulfilled by the systems from acknowledged Suppliers.

Full-graphic features shall include, but not be limited to:

– a windowing/window management system which permits multiple windows to be viewed concurrently on the same monitor, and allows user configurable screen display formats;
– use of dialog menus to facilitate user interaction;
– the full width of the monitor available for display use;
– a minimum of 32 colours selectable from a superset of colours (minimum 4096).

Use of panning, zooming, named windows, and declutter levels to allow the user to control the viewable area of the world space on a display are desirable functions but are not yet common for real-time control systems.

All displays shall have the functional equivalent of the following dedicated display areas:

– **a system zone,** containing all monitor and console related information, for example:
  • time and date;
  • console Operational Mode Icon (test, maintenance, training, etc.);
  • software buttons (poke points) for frequently accessed menus or displays;
  • message indicator (which shows that a monitor message from a previous request is waiting to be displayed);
  • monitor update status indicator (showing whether the entire monitor is automatically being updated or is frozen);
– **a main zone,** displaying up to at least four (4) windows, each containing a window or display;
– **a navigation zone**, containing a small diagram showing the currently viewed portion of the world space selected for the active window. This zone may be displayed or not at the option of the user;
– an alarm zone, displaying up to the last four unacknowledged alarms.

Warning messages to the operator on occurrence of a new alarm shall be operator definable. Acknowledgment of this warning message shall not replace acknowledgment of alarms.

The exact size, location, layout and contents of the various zones shall be definable and changeable on a system-wide basis.

Windows shall allow the partitioning of the monitor into numerous areas so that several displays may be viewed simultaneously.

Each window shall have the following identifying information:

– most recent display title and page;
– message output area (where messages pertaining to the window contents shall be displayed);
– window update status indicator (showing whether the window is automatically being updated or is frozen);
– window active status indicator (indicating that the window is the active window);
– window Operational Mode Icon (test, maintenance, training, etc.);
– an application-specific menu bar if required by the application executing in the window.

In addition, windows shall optionally have distinctive indications (such as background colour) of which application is running in the window.

It shall be possible to define multiple windows in the main zone of each monitor. It shall be possible to perform any supported operator activity in any window, regardless of the number of windows present on a monitor. The size and screen location of windows shall be user modifiable.

There shall be one and only one active window on a console at any one time. The active window shall be the entry point of all user interactions such as display call-up, zooming, program execution and dialog interactions. The active window shall be indicated by the colour of the window border. If so configured, a window shall become active when the pointer is placed within its boundary. No part of the active window shall be hidden by other, inactive windows. All windows on a monitor that are not represented as icons shall be automatically updated with real-time data.

With a minimum number of movements of the pointer, it shall be possible to expand a window to occupy the full main zone. The reverse process of easily restoring the expanded window and all others back to their original positions and contents shall also be provided.

It shall be possible to shrink a window down to a very small, non-updating representation (icon), and save it on the monitor for later use. It shall be possible to restore the representation to a full-featured window at any time using the pointer device. The shrunken window shall count as one of the windows allowed in the main zone.

The pointer shall move horizontally across all monitors of a console by merely moving the pointer device itself. That is, the pointer shall traverse from monitor to monitor when the pointer reaches the edge of a monitor, without requiring any additional user action to designate the active monitor.

A standard "screen saving" function shall be available on each monitor.

Development of the user interface shall need the participation of the Principal.

4.1.4 Alarming

To inform the operator of any deviation from normal conditions, audible and/or visible means are used.

Alarms inform the operator and can start system actions. Acknowledged and unacknowledged alarms shall be distinguished.

Alarm categories and priorities allow the operator to distinguish the relative importance of an alarm.

Treatment of alarms is to be specified.

4.1.5 Intelligent alarm handling

This function offers facilities for handling alarms according to their importance.

Alarms shall have assigned priority numbers. If many alarms are generated, for instance at a primary fault, this function shall reduce the amount of alarms presented to the operator. Alarms will be shown to the operator in descending order of priority.

In this way the operator is guided through the alarms and the chance of confusion will decrease.

4.1.6 Hard copying

By means of this function information can be printed or plotted. Information can be presented in several formats.

Hard copies can be distinguished in two categories: daily logs and reports.

Daily logs:

Daily logs are used to log control actions and status changes concerning a predefined subject or network area.

Daily logs of measured values may show snapshots of MW and MVAr values with a regular time interval, peak values, average values, limit violations.

In general these logs are continuously printed if an event occurs or at regular intervals (thus needing a dedicated printer).

The following daily logs may be provided:

- operator actions;
- network switching actions;
- load:
  - total load;
  - for areas and/or plants/factories within the network;

  - concerning Agreements;
- actual interchange:
  - with the public utility;
  - with (accountable) areas within the network;
- actual generation:
  - concerning Agreements;
  - concerning unit commitment schedules;
  - regulating error;
  - showing any discrepancies between scheduled commitment Agreements and the actual production and interchange.

Reports:

Reports are used to print information concerning a certain aspect, for instance the status of all objects of a type or information on power exchange during a day.

Reports are initiated by an operator or can be printed automatically at a certain time or incident.

Hard copies of CRT screens (screen dump) may also be possible.

4.1.7 Disturbance data processing

To present pre- and post-fault conditions in the network, information on network conditions (analogue and/or digital data) before and after the fault is recorded at the moment a disturbance occurs. Triggers can be defined to start the recording.

Stored disturbance data, which allows analysis by the engineer, can be retrieved by the operator or engineer.

This function can also be applied to monitor a certain point in the network, for instance the point of common coupling with the public grid. All phases shall be monitored on the subject of U, I, f and THD (optional).

All data is time-stamped.

Sample frequencies depend on the information to be required and the purpose it is used for. In general the following sample frequencies are utilised:

- 1 sample/s for analogue signals (e.g. monitoring energy exchange);
- 1 sample/ms for digital status information from protection;
- 100 sample/s for primary object status changes.

If a transient recorder function is required, the analogue signals shall have a sampling frequency of at least 4 000 samples per second.

Specifically, the required sample frequency depends on the maximum signal frequency to be recorded (sample frequency > 2 times max. required signal frequency).

For this purpose use can also be made of information within digital protection systems. By means of a serial connection to the ENMC system this data can be retrieved and used in the ENMC system.

4.1.8 Energy accounting

This function offers accountable energy information on energy transfer, generation and consumption. Contracts, tariffs and day time variables are used to calculate actual accountable energy.

Several utility-specific calculations can be performed with an assigned accuracy.

Energy discrepancies (difference between metered and scheduled energy) can also be calculated.

The energy accounting function in the ENMC system is also used to check official metering.

4.1.9 Historical data processing

Historical data processing offers the possibility of archiving all changes that are made to selected data. With this function the operator can get an overview of all changes to the selected data or to a subset of it, during a certain, definable time.

Archived data may also be used to retrieve a historical network topology.

Archived data can be presented in chronological order. This information can be analysed to check for proper sequence of activities.

Historical data is in general stored in a relational database. The SQL standard is a widely accepted standard for retrieving data from a relational database in several possible formats.

4.1.10 Manual updating

The operator is able to override the status of any network element manually. This may be necessary to keep the operational database consistent with the process in the event of a telemetry error or if telemetry is absent altogether.

Any manual update is reported.

4.1.11 Synchronising

Asynchronous and synchronous networks and generators can be coupled automatically using a synchronisation function. If the conditions for closing are valid, a closing command to the circuit breaker concerned is given.

Three types of synchronisation can be distinguished:

- condition checking and enabling the command (synchro check);
- condition checking and giving the command (passive synchronising);
- condition checking, generation controlling to meet the conditions and giving the command (active synchronising).

4.1.12 Tagging

The operator is able to place and remove tags from devices in the system.

Tags call the operator’s attention to an exceptional network or device status. Tags can present additional information about a (part of the) network or a device.

Additional information may be, for instance:

- switching not allowed;
- maintenance;
- information not updated.

4.1.13 Monitoring

This function is a standard SCADA function and performs the monitoring of the status of objects, status changes and violation of limits. Results are routed to the alarming and the presentation function.

4.1.14 Advanced monitoring

In addition to monitoring, this function offers capabilities for handling parameter sets from digital protection systems and governor controllers. Parameter sets can be changed, checked, loaded down from and loaded up into these systems.

4.1.15 Supervisory control

This function is a minimum requirement for an ENMC system as it enables the operator to control all (controllable) equipment in the electrical network.

Both pulse and continuous commands are possible as well as direct-operate and select-before-operate commands.

This function also includes:

- interlocking;
- sequential switching programs.

Interlocking:

This function allows interlock conditions to be specified that have to be checked each time a control command is given. If these conditions are not met, the command concerned is blocked. For emergency situations the operator can by-pass an interlock condition.

Sequential switching programs:

By means of this function control sequences can be specified. By means of a pre-defined control sequence a number of objects can be controlled in a specified order, including safety checks, condition testing, delays etc.

This function is advantageous for the operator when long control sequences have to be performed.

4.1.16 Topological network colouring

The topological situation of the electrical (sub)network is displayed in such a way that the operator gets a clear overview at a glance.

Dynamic colouring of single-line diagrams may depend on:

- operational situation of the network;
- energised;
- no voltage;
- earthed;
- switching condition of the network;
- voltage level;
- voltage tracing;
- interconnected nodes.

4.1.17 Load restoration

Within this function the following time dependent aspects can be discriminated:

- 0 - 0.2 s: re-acceleration
- 0.2 - 4 s: restarting

By means of the load restoration function, loads are switched on again after a switch off (i.e. under-voltage protection and/or load shed). Which loads will be switched on again and when depends on the kind of load, its priority and the available power.

Load restoration enables a more efficient and faster recovery of processes than by pre-defined and fixed switch-on delays. It enables the loads to be switched on to be dynamically matched to the power available. If power resources are limited (due to limited generation or to allow for network imperfections), optimum use is made of the power actually available.

4.1.18 Load shedding

The purpose of this function is to stabilise the electrical system by matching load and available power.

The load shedding function is responsible for switching off loads according to a certain switching hierarchy. By switching off low priority loads, high priority loads may be supplied for as long as possible.

The requirements that have to be fulfilled by the load shedding system are:

- load shedding should disturb the production process as little as possible;
- shed only the amount of load that is really necessary;

- the load shedding system should not operate if it is not required by the situation in the electrical network;
- the system should be reliable and the number of spurious operations should be limited during the lifetime of the system.

Load shedding can be automatic or manual. Loads that are subject to load shedding are listed in a so-called shed list. The loads in this list can be prioritised so that high priority loads can be switched off later than lower priority loads.

The load shedding function continuously calculates the energy balance in the network by subtracting the electrical loads in the network from the available electrical power. As soon as a shortfall is predicted, the load shedding starts operating and sheds the excess power demand.

The operating time (time between detection of shortage of power and the trip command at a particular output in any of the substations) must be maximum 80 ms. In general there is no time for checking the transducer readings and determining whether a circuit breaker has opened. This is because the transducer takes approx. 200 ms to settle, which would make the load shedding action too slow.

Backup load shedding may be possible by using the frequency as a variable. This way of load shedding, however, may be less selective.

4.2 COMMUNICATION

Communication facilities shall offer possibilities for equipment to exchange data by means of a serial link. In this way data, once present in 'the system', can be used everywhere in the system.

It should be borne in mind that protocols and standards in the field of communication are still changing. Equipment using protocols that comply with the same standard are not necessarily able to communicate with each other. Even if the same protocol is used, this will not give a 100% guarantee that equipment can exchange data.

By means of a Protocol Implementation Document (PID) the extent to which a protocol complies to the standard can be investigated. This conformance statement presents an overview of the points where a communication protocol does or does not fulfil the requirements of a standard.

Gateways or protocol converters can be used to connect systems with different networks or with incompatible protocols but in general this is an expensive method.

Undoubtedly it is advantageous to delegate the responsibility for the complete system to one supplier who in turn shall be responsible for all communication within the system and all interfaces to other systems. In choosing a protocol the following aspects shall be considered:

- sufficient functionality;
- sufficient support from several suppliers;
- actual standard and sufficient future prospects.

If only a limited number of status signals are required from protective devices or other equipment, these can also be retrieved by means of parallel signal wires connected to status inputs. This may be economical when the number and length of signal wires is restricted.

4.2.1 Communication to protection

Protocols to be used shall allow:

- downloading data to protection (loading a new configuration set);
- retrieving data (analogue and status) from protective devices.

This function is required when:

- capabilities are needed to handle parameter sets from digital protection systems;
- analogue protection data is required in the ENMC system.

4.2.2 Communication to motor control centres

Protocols to be used shall allow:

- downloading data to the MCC (loading a new configuration set);
- retrieving data (analogue and status) from MCC.

This function is required when capabilities are needed to handle parameter sets from MCCs.

4.2.3 Communication for inter control centre operation

Protocols to be used shall allow:

- data (analogue and status) exchange between control centres;
- exchange of commands.

Information exchange is required for all Inter Control Centre links. Shared control, however, is only required for large electrical networks.

Communication to third party control centres shall also be possible.

4.2.4 Communication for maintenance applications

Protocols to be used shall allow data exchange between the ENMC system and a PC for remote maintenance of controlled equipment.

This function is required when maintenance information from network equipment has to be handled at PC level.

4.2.5 Communication to governor controllers

Protocols to be used shall allow:

- downloading data to the governor controller (loading a new configuration set);
- downloading setpoints to the governor controller;
- retrieving data (analogue and status) from the governor controller.

This function is required when capabilities are needed to handle parameter sets from governor controllers.

4.2.6 Communication to DCS

Protocols to be used shall allow:

- data (analogue and status) exchange between control centres;
- exchange of commands.

This function is needed when the ENMC system has no HMI capabilities and information is presented via the DCS.

4.2.7 Communication to emergency generator controllers

Protocols to be used shall allow:

- downloading data to generator controller (loading a new configuration set);
- retrieving data (analogue and status) from a generator controller.

This function shall always be implemented when emergency controllers are utilised.

4.2.8 Communication to office LAN

Protocols to be used shall allow data exchange between the ENMC system and an office environment. Data to be exchanged may be financial, historical or optimisation data as well as scheduling data.

This function is required when capabilities are needed to handle information from the **ENMC** system in an office environment.

4.2.9 Communication to remote I/O

Protocols to be used shall allow:

- downloading parameters to remote I/O;
- retrieving data (analogue and status) from remote I/O;
- sending commands and/or setpoints to remote I/O.

This function is required when:

- remote I/O from different Suppliers has to be connected to the ENMC system

4.2.10 Communication to RTUs

Protocols to be used shall allow:

- downloading parameters to RTUs;
- retrieving data (analogue and status) from RTUs;
- sending commands and/or setpoints to RTUs.

This function is required when:

- RTUs from different Suppliers have to be connected to the ENMC system

4.2.11 Communication to AVRs

Protocols to be used shall allow:

- downloading parameters to AVRs;
- retrieving data (analogue and status) from AVRs;
- sending commands and/or setpoints to AVRs.

This function is required when:

- secondary and/or tertiary control functions are implemented in the ENMC system and are in control of AVRs.

4.2.12 Communication to tapchanger controllers

Protocols to be used shall allow:

- downloading parameters to tapchanger controllers;
- retrieving data (analogue and status) from tapchanger controllers;
- sending commands and/or setpoints to tapchanger controllers.

This function is required when:

- secondary and/or tertiary control functions are implemented in the ENMC system and are in control of tapchangers.

5. SUPPORT FUNCTIONS

5.1 OPERATION SUPPORT

These functions are dedicated to support the operation of the electrical network.

5.1.1 Automatic meter reading

The automatic meter reading function offers a better and simpler way of retrieving metering data from accountable customers. By reducing the time lag between reading the meters and accounting for the energy, it may improve cash flow.

The accuracy and functionality shall be sufficient to allow energy accounting calculations. A cycle time (reading a meter) from 10 minutes up to 60 minutes shall be possible.

Data from this function is used by the energy accounting function.

5.1.2 Circuit breaker maintenance

The circuit breaker maintenance function is used for preventive maintenance of circuit breakers by keeping track of the breaking currents of each breaker.

After each operation of a circuit breaker, whether fault-caused or operator directed, the breaking current of the circuit breaker concerned is determined. In the case of fault-caused operation this value is calculated by the short circuit analysis function. In the case of operator-directed operation, this value is the result of the *state estimation* function.

For each circuit breaker the interrupted currents are summed per phase and may be presented. If a specified limit is about to be violated, a warning can be given.

For this function a serial connection to protective devices dedicated to the breakers concerned is required or an adequate estimate must be available from an other function.

5.1.3 Condition-based maintenance

This function can be used to optimise maintenance of, for instance, diesel generator sets, tap changer contacts, pumps etc. By storing and analysing data concerning the operation of equipment, maintenance can be performed according to the actual state of the equipment rather than to a pre-defined interval.

5.1.4 Outage management

This function enables the operator to schedule and manage the tasks and information associated with the location, isolation and correction of faults and (scheduled and unscheduled) future generator, equipment and network outages.

This information is needed by forecasting and planning applications.

5.1.5 Switching procedure management

By means of this function the operator is able to manage switching procedures. The operator can create, view and execute control jobs (switching procedures) on the power system.

Besides general information on type, make etc., switching procedures include supervisory control commands (i.e. control, switching sequences, tag, manual update) and organisational steps (i.e. wait, halt, comment).

Using switching procedures is a way of increasing the reliability of operator actions; the operator is guided and there is less likelihood of forgetting to execute or start actions.

This function is required when a large number of switching procedures have to be managed.

5.2 SYSTEM SUPPORT

These functions shall support the operator or system engineer in operating the ENMC system.

5.2.1 Generator modelling

This function offers the operator the possibility of defining and managing the different generation sources of a network. It allows generator models to be created for use in generation applications.

Generation sources are generation units within the network and interchanges with other areas. To simplify the definition of sources, generating source types may be defined.

5.2.2 Network modelling

This function allows the network to be modelled. All components in the network are taken into account as well as the influence of external networks. External networks with minor influence on the load flow and short circuit characteristics of the plant network are represented by equivalent components.

The network model is used by all network applications.

5.2.3 Programming services

A set of different programming services enables the system engineer to update (systems) software and/or reload new releases of programs already in use.

This function is used for computer system maintenance only.

This function does not contain ENMC system configuration services such as system generation/edit functions.

5.2.4 System generation/edit

The following generation/edit functions can be distinguished:

- database generation/edit;
- report generation/edit;
- display generation/edit.

Database generation/edit:

Database generation/edit provides the operator with the means of changing, editing or adding data records in the source database. Data is tested and checked for validity at the time it is entered. After the operator has finished editing the source database, global checks are performed to ensure completeness of the data set.

If data does not pass all checks, data modifications cannot be transferred to the operational database.

The operator may prepare several data modifications and activate them by transferring them to the operational database, at an operator controlled time.

The operational database contains all data needed for real time process operations.

All changes made to the source database are logged.

This function also offers the possibility of making a backup of data.

In the case of hot-standby redundancy, an update of the database in the standby system is automatically performed whenever a record is changed.

Provisions may be implemented to import data into the source database, for instance graphic data originating from geographical information systems. Data formats used may be:

- Intergraph;
- Siemens SICAD;
- ARC/INFO;
- AutoCAD.

Attribute data (relating to graphic elements) may be entered in the form of relational database files.

Report generation/edit:

The report generation function provides the operator with the possibility of generating and editing reports, defining/changing the contents and layout, and directing the output of each report to either a printer, file or CRT.

Display generation/edit: This function offers the operator the possibilities of a full graphic editor. Full graphic displays, as used in the system, can be built and maintained.

Displays may be created, edited, changed or deleted without software modifications.

5.2.5 System management

System management provides services for the ENMC system concerning the security and reliability of the processes performed and the data concerned.

This function manages and is responsible for:

- operating modes:
  - process operation (on-line);
  - testing;
  - training;
- redundancy management:
  - hot standby;
  - spare;
  - resource sharing;
- monitoring:
  - communication (LAN);
  - programs;
- fault detection and recovery:
  - errors are recognised;
  - actions to recover faults are initiated;
- start-up/changeover:
  - the start-up of the system is co-ordinated and performed in phases;
  - if the system has to be reconfigured, the changeover of devices and equipment may be performed manually or automatically;
- data consistency:
  - data sources and information exchange are controlled;
  - the location of functions is registered;
- time/date synchronisation:

  time and date information is transmitted to every computer in the ENMC system. System time is synchronised by means of an external synchronising date/time telegram.

5.2.6 System resource monitoring

By means of this function the system engineer is able to check the capacities of the ENMC system for the functions that are implemented. Bottlenecks in CPU capacity and communication should be reported.

5.2.7 Training simulator

This function provides an environment that allows operators to be trained in the principles and practices of the ENMC functions.

New and inexperienced operators can be made familiar with all aspects of the ENMC system and of the network involved. Situations can be simulated to train operators what to do and when.

A training facility enables experienced operators to become familiar with new applications and/or with changes in the power system.

Experienced operators may also use the simulator to update their knowledge of and skills on the ENMC system and study preventive, corrective and restorative actions for various power system conditions.

Probably the most important aspect of the simulator is its ability to simulate a real time operator environment without influencing the network, so that operator actions will not decrease the availability and security of the network.

6. ELECTROMAGNETIC COMPATIBILITY (EMC)

To achieve electromagnetic compatibility two approaches shall be followed:

1. specify the appropriate standards and test severity levels for the equipment in the electromagnetic environment concerned;
2. take measures in the installed ENMC system and any interfaces to minimise (possible) disturbance levels.

6.1 SPECIFICATION OF STANDARDS AND LEVELS

6.1.1 Specifying the environment of the ENMC system

As EMC specifications are valid for a certain environment, permissible emission limits and required immunity levels for the ENMC system depend on the environment the equipment is located in.

In general for ENMC systems the environment shall be regarded as industrial.

To specify permissible emission limits and required immunity levels this environment shall be defined in terms of:

- lightning;
- broadcast and communication transmitters;
- electrostatic discharge;
- large currents;
- disturbing signal wires;
- sensitive signal wires.

All electromagnetic phenomena, susceptible equipment and equipment/environment interfaces shall be considered when specifying the emission and immunity levels.

6.1.2 Specifying the required levels

Assessment of basic EMC requirements for the ENMC system shall be based on:

- applicable hardware EMC standards on:
  - emission;
  - immunity;
  - EMC performance;
- applicable software standards on:
  - datacommunication links (error correction, parity check, etc.);
  - analog process control measurements.

As (industrial) electromagnetic environments are mostly uncontrollable, the levels needed for equipment have to be chosen on the basis of existing or expected disturbance levels in the environment concerned.

An emission/disturbance level for equipment in a certain environment can be specified by referring to the relevant test method(s). The relevance of a test method is determined by the extent to which the method covers the actual situation. The acceptance criteria for these levels, as mentioned in the standard, determine which levels have to be specified.

For example, to match testing conditions to real conditions, severity classes are defined in the relevant immunity standards:

- class III: equipment used in an industrial environment;
- class II: equipment used in a non-industrial environment or a protected environment;
- class I: equipment used in well protected environments where no special requirements

are necessary.

In very unfavourable conditions even a class IV may be specified with test levels higher than class III.

In EMC specifications the required performance of equipment also has to be specified. In the generic emission and immunity standards EN 50082-1 and EN 50082-2 the following performance criteria are defined:

- performance criterion A: the apparatus shall continue to operate as intended during the test;
- performance criterion B: the apparatus shall continue to operate as intended after the test;
- performance criterion C: temporary loss of function is allowed, provided the loss of function is self recoverable or can be restored by operation of the controls.

In emission standards, two classes are distinguished:

- class A: equipment meeting these requirements can produce disturbances in cases of unfavourable coupling with sensitive equipment. In general this equipment may only be used in industrial environments;
- class B: equipment meeting these requirements is in principle applicable everywhere.

6.2 MITIGATING THE ELECTROMAGNETIC DISTURBANCE LEVEL

To reduce potential EMC problems the following mitigation measures are possible:

- screening cables and earthing screens at both ends with circumferential (coaxial) connections;
- electromagnetic zoning;
- use metallic building and other metallic structures as much as possible;
- apply the right earthing systems consistently;
- cables to be located as near as possible to metallic structures;
- interconnect metallic structures and earth them at as many locations as possible;
- earthing provisions shall be high frequency: flat, straight, short;
- minimising the transfer of disturbing currents into induced differential voltages.

EMC measures and specifications shall not be restricted to the ENMC system. As the suitability of measures and their effects depend on the actual situation and equipment, the complete installation shall be considered.

It is to be noted that EMC is a matter of statistics. Achieving EMC will minimise the possibility of electromagnetic interference problems whereby the costs of EMC measures will outweigh the expenses that would be incurred by the absence of EMC.

It is important to be aware that EMC starts at the design of an installation and extends to the details of each component; all aspects of an installation shall be EMC.

Note: Safety requirements will always prevail over EMC requirements.

7. ECONOMIC BENEFIT

For functions which are not specified as minimum requirements the economic benefit shall be taken into consideration when determining whether they are necessary. This economic benefit shall be based on weighing the costs of implementing the function against the benefits and savings that result from utilising the function. The economical benefit shall be calculated for lifetimes of 5, 10 and 20 years.

Aspects to be considered in this weighing may be:

– costs of the function concerned (including engineering);
– costs of maintaining this function (e.g. keeping it up-to-date);
– probability of the need for the function (e.g. fault location);
– is the function needed in real time or in study mode (if applicable);
– costs of non-availability of production equipment;
– repair costs;
– savings in maintenance;
– can the function be implemented in another way and at what costs.

With functions concerning power generation the following aspects also apply:

– power production costs (including start-up and shut-down costs, increase and decrease of generation if applicable);
– maintenance costs of generation units;
– interchange costs;
– contract agreements (i.e. penalties);
– type of generators (type of commitment, regulating behaviour);
– primary processes feeding generation units;
– regulating fuel production for the different types of generators.

All economic evaluations based on the above criteria shall be submitted for comment and approval by the Principal.

Note: When implementing functions the effort to keep the function up-to-date during the lifetime of the system shall not be under estimated. An adequate level of system support shall be required for maintenance of these applications.

8. REFERENCES

In this DEP, reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments, supplements or revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Electrical network monitoring and control system	DEP 33.64.10.32-Gen.

EUROPEAN STANDARDS

Electromagnetic compatibility - generic emission standard	
Part 2: industrial environment	EN 50081-2
Electromagnetic compatibility - generic immunity standard	
Part 2: Industrial environment	EN 50082-2

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