Requirements for an Automated Metering and Information System

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INTRODUCTION

The unbundling and the liberalisation of the energy markets in Europe force network operators to restructure their internal operational processes and to introduce new technologies and systems to cope with the upcoming requirements.

The basic challenge is to increase the efficiency of network operation in all aspects, that means network operation including fault management, network planning, automation of customer processes and to define new business opportunities.

This article gives some general considerations on how an AMR (Automated Meter Reading) system can be extended to a complete solution in terms of automating all operational processes and build a basis for future applications.

General requirements for AMR Systems

It is obvious, that the introduction of an AMR system for tariff customers to a distribution network only reduces the operational costs and increases the performance when a reasonable coverage (ideally 100%) is achieved within a specific time span.

If classical AMR systems are extended with additional functionality necessary for an efficient operation of LV / MV distribution networks, business plans of network operators have shown, that the optimum time span for the exchange of the existing metering infrastructure ranges from 5 to 10 years. The cost effectiveness strongly depends on additional synergy effects taken into account. Factors, which are relevant for a positive business plan on the cost side, are:

- Costs for the hardware (meters, modems, ripple control receivers, concentrators....) to be installed at customer premises and in intermediate stations (transformer stations)
- Costs for services necessary to replace the hardware, which will be minimised if the old hardware can be replaced 1:1 without changing the existing wiring and without need for new wiring (e. g. for communication)
- Communication costs in terms of communication fees, which can be avoided if the AMR system supports the usage of the existing infrastructure owned by the network operator
- Central IT infrastructure (including maintenance) necessary to interface the existing systems (billing, load switching, SCADA,....) and future systems to the AMR infrastructure.

On the income side of business plans the following factors can be taken into account if the AMR system supports the corresponding functionality:

- Reduced operational costs through fully automated customer processes (frequent billing cycles, change of energy providers by customers, generation of payment reminders, deactivation of customers....)
- Integrated load switching capability with two way communication as replacement for ripple control systems
- Integrated automation of the network infrastructure to achieve fast fault location and fault bypassing as well as gathering measurement data as a basis for network planning and loss reduction in meshed network structures.
- Integrated power quality functions and documented supply history for tariff customers
- Detection of power theft
- Measurement of reactive power consumed by tariff customers
- Comprehensive service packages for energy suppliers:
  - Support of all kinds of tariff models
  - Flexible billing intervals based on the principle "pay what you have consumed"
  - Frequent power consumption data or load profiles also from tariff customers to optimise load estimation and reduce the amount of required balance energy
  - Additional services such as home automation to increase the customer loyalty
  - Customer self provisioning through an internet portal

If business plans based on the functionality of available systems are made today, it has to be considered that the standardisation for AMR specific communication has not jet settled down. That means that at least equipment, which has to be installed at customer premises should support the implementation of future standards by a firmware download function.
Elements of an AMR System

The elements of an AMR system can be classified according to the locations where they are installed. If it is an integrated system, generally a structure consisting of terminal equipment (meters, load switching devices...) at customer premises, data concentrators (with or without automation functionality) at transformer stations and substations and a head-end mediation device to interface existing and future applications (billing, load management, webservice...) at a central station is given.

A typical structure of an integrated system that is shown in the following drawing.

Requirements for the communication network

The structure of the communication network is strongly dependent on the communication media used to connect the terminal equipment. If a classical medium like telephone lines, GSM or Internet is used, a direct connection between the terminal equipment and the central station is theoretically possible.

The drawback of such solutions is given by the fact that additional wiring at customer premises and in case of GSM specific Radio modems with appropriate antennas are required. In case of Internet generally the penetration of households still is very low compared to the demand that an AMR solution should cover the complete distribution network. It also has to be considered that a lot of different (that means provider dependent) network access parameters have to be administrated and that the network access equipment can be manipulated by the customers. This will cause interrupted connections and therefore decreased system performance and an unmanageable AMR system. (Every meter is a monitored device.)

To overcome these infrastructure problems mentioned above it is recommended to use terminal equipment with integrated narrow band DLC (Distribution Line Carrier) or PLC (Power Line Carrier) communication. These technologies allow the usage of the distribution network itself to communicate with some data concentrators in the transformer station and therefore support a 1:1 replacement of the existing equipment. Unfortunately a low voltage distribution network is a very harsh medium in terms of data communication. This fact is documented in the following two pictures which show a typical line attenuation and a typical noise level.

The different graphs in the diagrams show the signals within a time span of two weeks.

This massive short-term variance of the line parameters is in many cases superimposed with a long-term variance given by the different network load situations between summer and winter. Detailed measurements and field tests have shown that the necessary availability of the DLC (PLC) communication under all circumstances can be granted if:

- A very robust and redundant modulation method based on spread spectrum technologies is implemented
- The frequency band used for communication is limited at 95 kHz due to the attenuation characteristic of the medium and to be compliant to [1] EN 50065 (which reserves the frequency band between 9 and 95kHz for utility DLC-applications)
• A dynamic repeating function is implemented in the communication protocol. This function is needed to potentially use every terminal device (e.g. meters) as a repeater for other terminal devices.

If it is assumed that a DLC based communication is used to connect the terminal equipment to the network, the low voltage transformer stations have to be equipped with some data concentrators to co-ordinate the DLC based communication and the upstream communication. These data concentrators should have the flexibility to use every available communication media towards the central station.

When designing the upstream network the following facts should be regarded:

• If all applications like frequent power consumption data, power quality, home automation and so on are implemented, a remarkable amount of data is being generated

• The traffic structure is star shaped and all the terminal equipment exchanges data only with the central station. That means the bandwidth of the communication network has to increase with decreasing distance from the central station.

Therefore it is recommended to use the substations (or some equivalent stations) as second concentrator layer. In this case the already existing utility owned glass fibre infrastructure can be used to connect the central station and the traffic from the transformer stations is distributed to a reasonable number of substations. The connection between the transformer stations and the substations will certainly be done via a hybrid network consisting of glass fibres, copper cables, cable TV infrastructure, narrow band radios and in exceptional cases dial up connections (GSM, POTS, ISDN...).

A very promising alternative to the classical communication methods mentioned above is the medium voltage DLC. This method has the inherent advantage that it uses the medium voltage distribution network itself as communication medium and is therefore available in every transformer station. A physical evaluation shows that basically the same obstacles and therefore the same requirements exist as on the low voltage network. Additionally the configuration of the medium voltage network may change in fault situations and during infrastructure maintenance. That means that additional routing and redundancy mechanisms are needed.

A competitive approach to design a MV-DLC network is to use modems, which are capable to communicate on the same cable at the same time on 6 to 8 different channels. The spectrum of every channel has to be spread over the complete available bandwidth to achieve equal channels in terms of performance. A physical network structure then can be divided into network cells, where every cell is dedicated to a specific master in a substations, using a specific communication channel. In normal operation all masters are able to gather the information in parallel from the transformer stations. If a network configuration change takes place, that means for example a transformer station is going to be supplied by some other substation, the data concentrator in this transformer station has to be handed over to the master in the supplying substation. This procedure can be remarkably speeded up, if the communication protocol supports some background mechanism, which allows the masters in the substations to find out the network topology, that means all physically possible routes to a transformer station. Such a feature can also be used for all kinds of redundancy concepts as it supports a very fast switch over to redundant routes.

Finally to complete the considerations about the application of MV-DLC the problem of coupling the modem signal to the network has to be mentioned. Generally there are two possibilities:

• Inductive coupling which is done by snapping a ferrite transformer around a MV cable to couple the signal into the cable shield. This is a very simple and cost effective method but it requires that the cable shield between the two stations where the signal has to be transmitted is not connected to ground. Practical experiences have shown that this cannot be granted in many cases.

• Capacitive coupling between a phase conductor and ground. This is the physically most effective method but it requires a medium voltage capacitor which fulfils all requirements for surge resistance, partial discharge and so on. It is possible to manufacture such capacitive coupling devices with extreme reliability, but when it comes to the installation of such devices generally mechanical problems occur. Practical experiences have shown that it is the best approach to manufacture a coupling device in the shape of a MV voltage or current transformer. For 36kV networks (or higher voltages) it is also possible to produce coupling devices in the shape of an insulated support. This lowers the installation costs dramatically.

Requirements for the terminal equipment

The terminal equipment can be categorised into meters, load switching units (to replace ripple control receivers) and some other devices, which might be connected to the communication network in the future.

Special attention has to be paid to the meters, as they have to be approved and calibrated according to country specific rules and their functions determine to a certain degree which energy products can be offered to the customers. For the reasons mentioned before, it seems very likely that a lot of meters and other terminal equipment will have an integrated DLC communication. As there is up to now no established standard for this kind of communication several basic requirement arise:

• All communication functions (physical layer, protocol layers) should be implemented by firmware.

• The parts of the firmware necessary for the basic metering functions (which have to be approved and are
necessary for calibration) have to be stored in the meter in a way that it cannot be changed via remote access.

If these basic requirements are fulfilled, it is possible to archive a very slim meter design. It consists mainly only of one CPU kernel with the necessary infrastructure and an A/D-D/A converter. The advantage of such a design is that new communication standards and additional functions of the meters, which do not have to be calibrated, can be implemented simply by downloading a new firmware from remote.

The following meter functionality is recomended:

- Several tariff registers for active energy consumed with the possibility to switch between the registers according to date/time and/or actual load criteria's. This is more or less the basis for the definition of different power products to be offered to customers in a way that it cannot be changed via remote access.
- Several tariff registers for energy delivered. This seems to be useful if customers operate solar generators or in future perhaps fuel cells.
- Tariff registers for reactive power consumed / delivered as reactive power may be also billing relevant in the future.
- Generation of load profiles to have the possibility to deeply analyse the consumption behaviour of single customers or customer groups.
- Documentation of voltage dips and supply interrupts. This seems to be a quiet useful feature in case of customer complains, as the contractual situation between network operators, energy suppliers and customers may become very complex in the future.

All this features can be implemented by firmware that means they should not have a too big impact to the costs of the meter hardware. What is in fact cost relevant are two additional recommended features:

- A breaker circuit to disconnect customers from the grid. This breaker can be used to exactly limit the maximum power consumed by the customer as well as to disconnect the customer if he refuses to pay.
- Extension slots in the meters for future applications such as prepayment modules, communication modules to integrate gas and / or water meters, home automation and so on.

Another important device out of the group of terminal equipment might be a load-switching unit to replace ripple control receivers. These load-switching units then have a two-way communication channel to the central station that means they can be fully remotely controlled. This allows the integration of a monitoring function for the output and the input voltage of the relays and the generation of respective alarms in fault situations.

Finally it should be pointed out, that all terminal equipment with an integrated clock operated in the system should be synchronised with a GPS or DCF clock via the communication link.

**Additional requirements for data concentrators in transformer stations**

Additionally to the basic functions described in the chapter "Requirements for the communication network" the data concentrators in the transformer stations should be expandable for automation and telecontrol functions. Therefore the hardware must support:

- Digital I/O's to connect for example short circuit or ground fault detectors or to control switches.
- Analogue inputs for voltage / current measurements.
- Detection of power theft, together with the meters connected.

It is important that the automation and telecontrol functions can be scaled according to the requirements as these features are cost relevant and are required in many cases only in 10 to 20% of all transformer stations.

**Head-end System (mediation device)**

One of the biggest challenges is the design of a cost effective and future proof central system for a complete solution as described before. It is clear, that a head-end basically has to interface all kinds of information's between existing systems (for example billing, load switching, SCADA...) and the extended AMR infrastructure.

One approach to achieve a comprehensive solution is, to treat the system from the transformer stations to the central station as an automation system, based on standard protocols. By this way the interfacing of the "automation part" of the system to existing or new SCADA systems is supported without any restrictions and without additional costs. The information of the terminal equipment, which is being gathered in the transformer stations, can be split up and be transported through the automation system in data containers which are forwarded to a specific mediation device in the central station.

The mediation device adminstrates the terminal equipment and provides information to higher-ranking systems only upon request. If possible, the interface to the higher ranking systems should be designed as table oriented SQL interfaces. They are easy to test and can be easily maintained by skilled system operators.

One very important aspect is the administration of parameters of the terminal equipment. First it can be stated that there should be only one database which is kept consistent and
could be part of the mediation device. Second this database has to be co-ordinated with the higher ranking systems, as the parameters determine the function of the terminal equipment that means the information that can be provided. Therefore it might be useful to introduce standardised parameter profiles for every higher-ranking system and for every type of terminal equipment.

An example for standardised parameter profiles shall be given for a billing system:

- Every billing system handles a certain amount of specific customer contract types
- Every contract requires specific meter functionality (e.g. one-tariff contracts, two tariff contracts, ...)
- According to the existing contracts types for every type of meter the billing relevant portion of the meter parameters can be standardised.

The same can be done for all other applications running on higher ranking systems, that means a complete parameter file for a terminal device consists of the sum of standardised parameter portions. Functionality of terminal equipment which is actually not yet used can be parameterised with default parameters.

Another very important issues are the processes how meters are parameterised when they are installed or replaced. These processes generally require some hand held terminals and a corresponding parameter export function from the head-end system. Before the parameters can be exported, they have to be linked together with customer specific data to a complete work order.

After Installation a terminal device specific identification (serial number) has to be stored in the hand held terminal together with the corresponding work order. These data sets have to be read back from the central systems to correlate the installed equipment with the parameters and the customer data.

To facilitate the system operation a network management function has also to be provided from the head-end system. This could be a standalone application or be split up between a SCADA system and a terminal equipment management.

**Operating systems from different manufacturers in one network**

Due to the lack of standardisation, systems of different manufacturers can be operated in one network only when it is guaranteed that they do not influence each other. In reality that means that for example a transformer station and the connected terminal equipment has to be from the same manufacturer. Between the transformer stations the equipment manufacturer can be changed, if independent communication channels to the central station are provided.

In the central station a number of mediation devices equal with the number of different manufacturers has to be operated and co-ordinated. This could be provided by some system integrators if the manufacturers are willing to publish their protocols and information models.

**References**

[1] European Standard EN50065 (CENELEC): Signalling on low-voltage electrical installations in the frequency range 3kHz to 148.5 kHz