BUILDING UTILITY COMMUNICATIONS THROUGH DEPLOYMENT OF POWER LINE COMMUNICATION

Abdelfatteh HAIDINE
Accenture GmbH – Germany
abdelfatteh.haidine@accenture.com

Jörg MÜLLER
Accenture GmbH – Germany
joerg.mueller@accenture.com

ABSTRACT

In this paper we discuss the technical requirements for communication solution to build the access networks of smart grid applications, and we analyse the deployment of the ICT infrastructure. For the investigations in this paper we focus on the high-speed narrowband Power Line Communications (PLC). First, we discuss the quality of service requirement imposed by the mostly used application for the distribution grid. Then, we give an overview about the current PLC implementations in Europe. The PLC deployment architecture is described, with the role of different PLC systems. After that, the deployment of PLC networks is discussed; covering network design, cost modelling and tool to assess different technology scenarios.

INTRODUCTION

Deliver higher levels of supply reliability and security, reduce the environmental impact of the whole electricity supply system, provide consumers with greater information and choice of supply, allow consumers to play a part in optimising the operation of the system, etc. The realization of such future smart grid can be built only on the basis of a modern communications and information infrastructure; as depicted in Fig. 1.

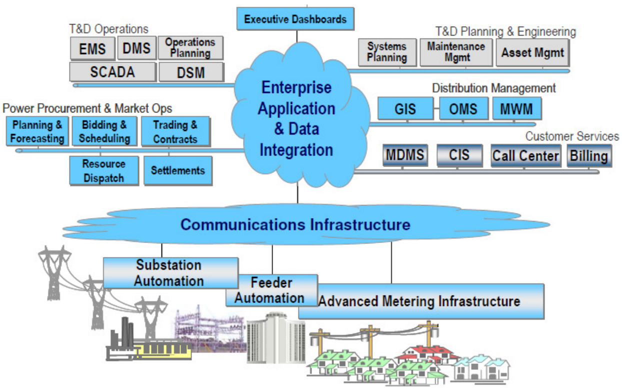

Fig. 1. Communications infrastructure in smart grid (Source: EPRI)

The important question facing utilities is "Which technology is the best one?". The correct answer to this question is typically: "it depends!". In fact, there is no communications technology that is optimal for all scenarios. Therefore, an assessment of the candidate technologies has to be done, by taking into considerations the smart grid applications to be implemented, the quality of service (QoS) requirements, the reliability, security, and of course the deployment costs. In this paper we discuss the communications available for the smart grid application on power distribution networks. We focus on Power Line Communications (PLC), which could build an almost ideal solution for power utilities, in spite of some weaknesses concern the system reliability. After discussing the application requirements and the different available solution, issues and challenges related to the deployment of PLC networks are analysed, namely the network design and the modelling of deployment costs. An assessments tool, which helps utilities to evaluate different communications scenarios according to their use case, is described.

SMART GRID COMMUNICATIONS

Key Requirements

Before designing a communications network, it is important to analyse the applications that will use this infrastructure. The applications should give the level of required quality of service (QoS) in terms of required capacity, tyre of traffic, maximal delay, etc. According to [1] and [2], there are twelve key application services for automating the MV and LV distribution grid; which QoS requirements are in TABLE I. , (with P: periodic, C: continuous, R: random and var.: variable; AMR/AMM: Automatic Meter Reading/ Advanced Metering Management).

TABLE I. QoS REQUIREMENTS FOR AUTOMATING LV/MV ([1])

Applications	datarate (kbit/s)	traffic type	Max. latency (s)	BER	MTTR (sec)
1- Tele-control	9,6	R	0,5	NA	1
2- Tele-control (Fault detection)	9,6	R	NA	NA	15
3- Operational Telephony	8	R	0,5	1,00 E-03	15
4- Corporative application access	2000	R	1	1,00 E-05	NA
5- Video surveillance	256	C.	1	1,00 E-04	NA
6- Video supervision	64	P	NA	1,00 E-04	NA
7- Alarm Management (Temp., humidity, gas, etc.)	9,6	R	30	NA	15
8- Tele-measurement. Product; Power quality	9,6	P	NA	NA	NA
9- Protection Tele-measurement.	64	R	1	1,00 E-05	NA
10- Operation/ supervision telecom network	var.	C	1	1,00 E-04	NA
11- AMR/AMM	var.	P	NA	NA	NA
12- Load Management, DSM	2000	P	1	NA	1

The bit rate for "Operation/ supervision telecom network" depends on the number of communications components and the operation and supervision purposes. Capacity demand for AMR/AMM depends on reading frequency and number of meters per transformer station.

Communications Technologies

There are different technologies that can be used in smart grid communications, e.g. Digital Subscriber Line (DSL), wireless cellular, narrowband/broadband PLC, RF mesh, satellite, etc. It is usually impossible to state that one technology is an "absolute best" solution, because the solution quality depends on several factors, such as deployment environment (rural or urban regions), type of applications, QoS requirements, Service level Agreement (SLA), wave propagation characteristics/coverage, costs, etc. Generally, each solution has advantages and drawbacks. For example, the optical fibre solves almost all technical problems related to QoS, but has high costs. In the last years, Power line Communication (PLC) is becoming for utilities an interesting solution, especially with new PLC systems that are overcoming problems related to reliability and low bitrates. Therefore, PLC will prove to have a leading position in deployment of AMR massive rollout and pilot projects in Europe. Overview about PLC in currently installed AMR/AMM deployments is given in TABLE II.

TABLE II. PLC IN AMR DEPLOYMENT (SOURCE: [3])

Country	Endpoints [millions]	% of installed AMM base
Italy	36	99%
Sweden	3	58%
Finland	1.5	52%
Denmark	1.3	79%
France	0.3	Pilot
Spain	0.2	Rollout starting
Norway	0.15	76%

Selection of Optimal Technology

For the selection of one communication technology for the smart grid applications different factors must be taken into consideration. The main factors include (Fig. 2.):

- Applications: this generates the traffic which should be transported through the networks. The applications define the traffic volume, the required QoS.
- Regulatory: this regulates the use of the infrastructure and the stranded allowed in their territory. For example, when design a wireless networks, only a very limited spectrum slots are available. Furthermore, the use of the available frequencies will be allowed only after purchasing a license from the regulatory authorities
- Costs: the communication network to be built should fulfill the requirement for the applications with minimum costs; considering CAPEX (for hardware/software purchasing and deployment) as well as OPEX (from operation and maintenance).

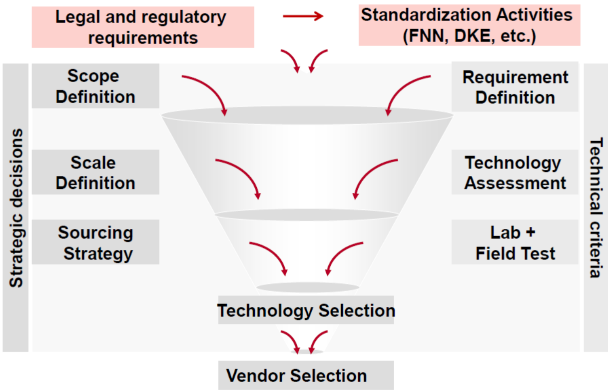

Fig. 2. Factors influencing technology selection for smart grid ([4])

PLC OVER DISTRIBUTION NETWORK

Network Architecture

Generally, PLC over the distribution grid can be implemented according to three scenarios; [1]:

1) PLC over the MV distribution network only; where this technology could be used as the main or redundant communication channel for applications like SCADA, video surveillance, metering and others. In case PLC is applied in coexistence with other communication technologies, it will increase the overall reliability.

2) PLC only over the LV distribution network. In case where the MV and LV networks are owned by different utilities or where the MV network is already highly automated, utilities may choose to rollout PLC over LV network only. This means that each LV network will have a PLC Access Point, which has to be connected to the service centre. Therefore, other communication network (public or private) has to be used, e.g. public or private wireless, etc.

3) PLC over MV and LV network, which is combination of the two previous scenarios, as shown in Fig. 3.

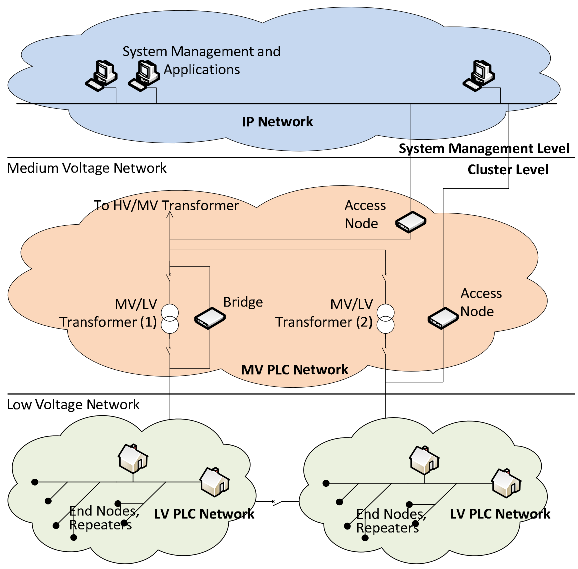

Fig. 3. Example of Conceptual PLC architecture (Source: [1])

The components building a PLC network are:
- PLC modem: allows the connection to the power lines of the system hosting the applications source.
- PLC Bridge: It connects two logical networks that are not connected (e.g. LV and MV). Networks can either not be physically connected or the interruption is on the communication level, e.g. transformers block the signal
- PLC Access Point (or data concentrator): This component is connected on one side to the wide area network or utility Intranet (to connect to utility servers) and on the other side to the PLC network. It is usual placed at the transformer.
- PLC repeater (functionality): due to the bad channel conditions it is very probable that not all the nodes in one LV segment can reach the PLC Bridge or Access Point. Therefore, PLC signals must be repeated.

PLC Technology Variants

With the start of the smart metering deployment the focus on PLC has increased, mainly because it represents a very competitive solution for the utilities. However, reliability and low bit rates were major weaknesses. Therefore, different research and development projects and alliances have been established to mitigate these two problems. The use of OFDM allowed the system designers to overcome these problems, in spite of increase in system complexity (and cost). Consequently, different PLC variants are currently implemented for AMR. TABLE III. lists the widely deployed variants and their main characteristics.

TABLE III. MOST DEPLOYED PLC VARIANTS IN EUROPE

Variant	Main Characteristics
G1	Open PLC standard based on IEC 61334. It uses S-FSK modulation achieving bitrate up to 2.4 kbps
G3	Open specifications; using 36 OFDM channels, in the band: 36-90.6kHz, with bitrates: 5.6-45kbps. System uses 6LoWPAN adaptation layer to transmit IPv6 over PLC. Signal crosses the MV/LV transformers
PRIME	Open specifications; using 97 OFDM channels; over the band 42-89kHz; and reaching up to 128kbps
Meters and More	Open specification uses BPSK modulation, and achieves bit rate up to 4.8 kbps
Echelon	Proprietary low bit rate solution, using BPSK modulation. It operates in CENELEC A Band.

PLC NETWORK DEPLOYMENT

Building the PLC Network

Generally, the deployment of PLC networks consists in solving two main problems; placement of communications devices and frequency allocation (in case of Orthogonal Frequency Division Multiplexing (OFDM) based systems); [5]. The placement of PLC systems consists also in defining some nodes to act also as repeaters, or to place a separate device with repeater functionality only. This depends on used system technology. The characteristics of this optimization problem are as following:

TABLE IV. PLACEMENT PROBLEM OF PLC SYSTEMS

Given:	- LV and MV topology, showing location of users and transformer station, and distances between them - Set of available points to connect to wide area network - Costs (CAPEX and OPEX) - Traffic demand from different SG applications (inter-arrival time and duration/service time) - QoS requirements for used smart grid applications - PLC system characteristics (number of used OFMD channels, performances, coverage, etc.)
Tasks:	- Place an optimal number of PLC devices in optimal locations - Allocate application sources to bridges/access nodes - Select repeating nodes - Connect access nodes to wide area network
Objective:	*Minimize*: network costs
Constrained by:	- System capacity (number of users per concentrator, either on LV or MV level) - System coverage (different from PLC systems to another, and also influenced by LV network branching, noise, etc.)

The use of OFDM offers high flexibility to the modern PLC systems. In fact, with OFDM it is possible to avoid the frequencies that are suffering from noise, and the carriers can use bit-loading mechanism, to use the channel optimally. A sub-set of OFDM channels has to be assigned to each installed PLC device in the network. Each device has to get enough capacity to hold the QoS requirements for its SG applications. Each channels must be re-used as often as possible; however, without causing interferences with its neighbouring devices. The channel allocation problem in PLC networks can be described as follows:

TABLE V. ALLOCATION PROBLEM OF OFDM CHANNELS

Given:	- Number and locations of placed PLC devices - OFDM channels (number of channels and used frequencies) - Capacity demand per placed PLC device (is a function of number of allocated SG applications sources per device) - Noisy channels to avoid (if pre-measurements show them)
Tasks:	- Allocate a subset of OFDM channels to each installed device
Objective:	- *Maximize*: Resource reuse; *Minimize*: interferences in network
Constrained by:	- OFDM channel capacity - Channels reliability (function of the noise in the environment) - QoS Requirement from SG applications to be used

Modelling of Deployment Costs

The network design task provides only the network topology (such number of items from each network element, locations, etc.). Therefore, the Total Cost of Ownership (TCO) for the communications must be calculated by taking into consideration all type of cost for building, deploying and operation the network. These different costs elements can be categorized as shown in Fig. 4. The different factors influencing these costs are listed in TABLE VI.

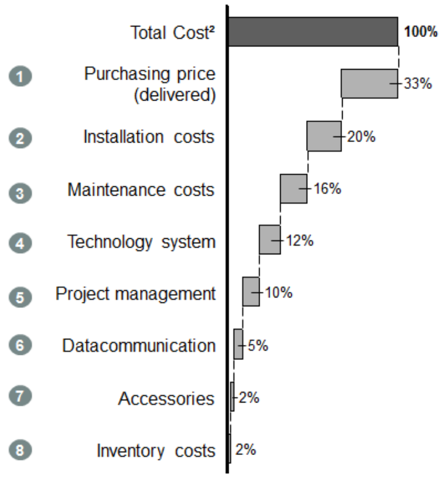

Fig. 4. Cost components of the network deployment

TABLE VI. COSTS FOR DEPLOYMENT OF PLC NETWORK

Cost Category	Influencing Factors
Purchasing price	HW/SW cost of system. It depends on client specific requirements; volume of items (for comm. Module, bridges and access points)
Installation costs	Hourly rate of mechanics; First time right (avoid returns for installation)
Maintenance costs	Life span of the meters / Cost and complexity of configuration management / installation
Technology system	Warranty; Interchangeability in the system of various suppliers
Project management	Data gathering and data mining capabilities; Man hours; Transparency & priority determination throughout the development and roll-out
Data communication	Number and capacity of data communication connections to wide area network (CAPEX/OPEX)
Accessories	Standardization of accessories across installation types
Inventory costs	Volume; Warehouse (stock) costs; Transport costs

Assessment of communications Scenarios

The assessment tool is composed of four blocks: 1) input block, which makes available all the necessary information to for the network costs calculation; 2) Output modules, which summarizes the calculation results and makes them ready for plotted and comparison of different communications technologies over the dashboard; 3) Dashboard/control panel, which allows the selection of the scenarios to be calculated and analysed, to select the communication technologies and their parameters and to visualize the different result diagrams; and 4) the calculation core, which builds the main part of business case. In the calculation core, the input values are used to calculate the costs of the different components of the network per year (e.g.: network access, core network, licenses, network management, project management, etc.). Interaction between these blocks is given in Fig. 5.
For each component the OPEX and CAPEX are calculated.

E.g.: CAPEX for a core network are all the costs needed to set up the core network: Purchase costs for the core system, number of FTE needed to set up the core system, and annual costs per FTE. On the other side, OPEX for core network are all costs needed to run and maintain the core network, i.e. yearly maintenance costs, licenses. In the calculation sheets the different components are listed vertically (with a line for CAPEX and a line for OPEX), and the years are listed horizontally, so that cost of each component is calculated for each year. In a scenario, the cost for each network component is calculated, so that the options on the dashboard allow the selection of the wished costs.

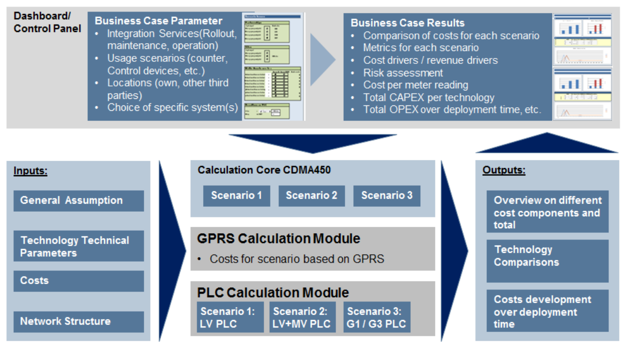

Fig. 5. The different components of the assessment tool

CONCLUSIONS

In this paper we discuss the utilization of power line communication to build the communication infrastructure for the smart grid application in the distribution grid. We give an overview about the different quality of service requirements, and a qualitative comparison of the available technologies is given. After that we discussed the different factors that play a role in the selection of a communication technology. The different tasks related to the design of PLC networks are described and the different components of the deployment costs are categorized. An assessment tool is presented, which helps utilities to evaluate the different communications scenarios.

REFERENCES

[1] DLC+VIT4IP Project: "Scenarios and Requirements Specification," Deliverable D 1.1., September 2010.
[2] CIGRE Working Group D2.21, WG, D2-21, Broadband PLC applications, June 2008.
[3] Landis and Gyr: "Introducing the Power of PLC," Lydis+Gyr White Paper, 2012.
[4] M. Grandel: "Communications for the smart meter rollout in Germany," at the Conference Telecoms for Smart Grids, September 2012, London, UK.
[5] A. Haidine: "Multi-Objective Combinatorial Optimization in Topology Planning of Wireline Broadband Access Networks," WiKu-Verlag, Köln, 2009.