CHOICE OF ICT INFRASTRUCTURES AND TECHNOLOGIES IN SMART GRID PLANNING

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ABSTRACT

The planning process of energy networks must consider the increased levels of decentralized intermittent renewable energy systems and new loads, e.g. Electric Vehicles (EVs). A distribution grid planning tool must address these new challenges, requiring methods to deal with the increased levels of uncertainty and new trends in observability and controllability of the network. Thus, an essential part of future distribution networks is ICT, which enables enhanced monitoring and control options. This paper presents an approach for ICT planning as part of a distribution grid planning process. The outcome of the ICT planning is a set of ICT solutions for the smart grid. This is implemented as a two-step method, where first the ICT planning module provides a pre-selection of certain smart grid applications, which are mapped to expected communication and technology requirements. In the second step, concrete ICT solutions specific to a given energy network are identified to fulfill needs such as speed, reliability or costs for combinations of wired and wireless ICT communication technologies.

INTRODUCTION

Conventional energy networks with centralized power generation are changing and incorporating more and more distributed generation. The increased levels of variable and intermittent renewable energy sources, accompanied by perspectives of increased consumption, for instance, with the rollout of heat pumps and Electric Vehicles (EVs), are causing major challenges for distribution network planning processes. Furthermore, the smart grid vision for distribution grids includes improved observability and controllability, implying a transition from passive grids to active grids. The so-called smart grids bring benefits that are currently not considered by the distribution planning tools.

Currently, such tools do not allow the clear identification and application of different control options, including demand response, EV charging control or distributed generation modulation. All these technologies rely on proper Information and Communication Technology (ICT) infrastructures, for which investment must be made and should be foreseen, and which have an impact on the grid expansion plans. An essential requirement for distribution networks of the future is the availability of holistic ICT systems. Investing in ICT will provide flexibility for control entities in the smart grid context, which is essential to cope with more frequently fluctuating energy flows. Therefore, ICT networks and their capabilities should be taken into account during the grid planning stage. It should be considered alongside other investment options, including the classical reinforcement of lines or substations. To do so, it is necessary to be able to quantify the technical and economic benefits of ICT to achieve a trade-off between ICT and conventional network investments.

Hence, this paper proposes an approach to develop an ICT analysis module that can be used as part of a distribution network planning tool. After an introduction into related work and the methodology, the tooling for choice of ICT infrastructures and technologies in smart grid planning is explained in detail. This explanation of different functionalities of the ICT planning model is illustrated in corresponding subsections. The paper ends with a short conclusion and an outlook for further work.

RELATED WORK AND METHODOLOGY

The choice of ICT infrastructure and technologies in smart grid distribution networks impacts numerous different solutions for a wide range of applications. In order to ensure reliability and interoperability between all entities, the presented ICT selection process is based on a Smart Grid Reference Architecture [1] standardized by the Smart Grid Coordination Group (SG-CG). The SG-CG introduced a Smart Grid Architecture Model (SGAM), which establishes a concept to merge the following three dimensions: *Smart Grid Domain*, *Information Management Zone* and *Interoperability Layer*. The interoperability layer is divided into five abstract layers, providing the representation of entities and their relationships in the context of smart grid domains, information management hierarchies and in consideration of interoperability aspects. The focus of ICT design for distribution network planning is on the communication layer, which describes protocols and interfaces for the exchange of information between entities within the component layer.

Within this SGAM the above-mentioned information exchange is based on several related works, presenting applicable information exchange models to integrate into

ICT planning tools. Related to this topic, the German Forum network technology / network operation (FNN) defined specific use cases for smart meter applications [2], covering administration, maintenance, meter reading and communication with controllable systems. These use cases are mapped to their expected probability of occurrence and directly result in data submission rates over specific time intervals. In order to integrate EV-related communication traffic, the ICT planning tool part considers an information exchange model for the integration of EVs in grid balancing services, as implemented by Lewandowski et al. [3]. This EV communication pattern is based on standardized communication protocols to ensure interoperability between different manufacturers (EVSE, EV, ICT) and in particular defined interactions on all interfaces containing messages based on ISO/IEC 15118 standard for Vehicle-to-Grid (V2G) communication.

Next, the state-of-the art of research related to the SGAM communication layer is discussed. Results presented in [4] provide a performance evaluation of wireless Machine-to-Machine technologies for communication networks enabling smart distribution grid operation. In contrast with wireless communication solutions, authors in [5] present results for a simulation environment evaluating the communication effort based on wired Powerline Communications (PLC) in the context of electric mobility applications. This is enhanced by a comprehensive total cost of ownership study for the rollout of integrated fiber-wireless (FiWi) smart grid communication infrastructures [6].

Finally, within the SGAM component layer, different ICT network topologies for communication exchange are conceivable. Authors in [4] describe different topologies of Electric Vehicle Supply Equipment (EVSEs), where EVSEs either communicate directly with a Central System (CS) or interact through an aggregator (AG), which forwards data to a CS unit. Results achieved for reducing communication effort using several ICT topologies should be considered for ICT planning tool aspects as well.

ICT MODEL FOR SMART GRID PLANNING

The ICT model for distribution network planning is divided into two main parts according to their functionalities, as presented in Figure 1. First, *ICT Pre-Selection* provides a general set of applicable ICT technologies and high-level protocols without consideration of network and infrastructure data. Secondly, the *Infrastructure Planning* considers a concrete energy network, in order to propose several ICT infrastructure and technologies. The main part of the ICT model depends on external input defined by the planning tool user, such as use case definition and energy network data. Finally, the output of both main parts is evaluated in order to provide ICT recommendations for given external input. In the following, each part is described individually.

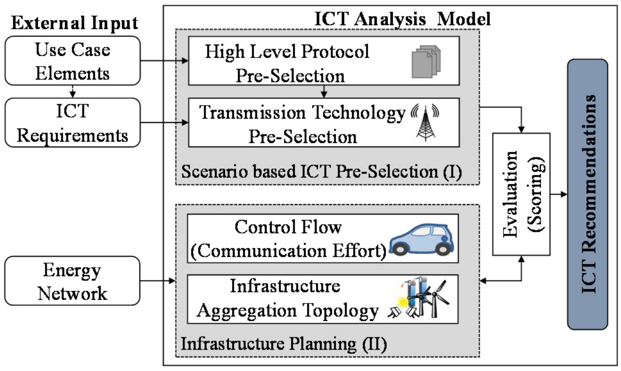

Figure 1: ICT Model for Distribution Network Planning

External Input Definition

The ICT model specification depends on input of the planning tool user. The external input allows a better assessment and recommendation of ICT technologies and protocols according to planning tool user needs. It is divided into three different parts. First, the planning tool user has to define his desired use cases based on a pre-defined set of *Use Case Elements*. All use case elements and their application areas are listed in Table 1. These use case elements are derived from related work: for smart meter applications [2] and for specific EV related communication traffic [3]. Extracted use case elements are adapted to requirements based on presented ICT models for distribution network planning to ensure the compatibility with recent research results. As depicted in Table 1, some use case elements are extended by several use element options that enable specific applications. The planning tool user is able to choose between a desired subset of these use case elements in order to define the desired scope for distribution grid planning. Next, important aspects for choosing relevant ICT components for smart grid applications are the *ICT requirements* and boundaries. Hereby, the planning tool user is able to define a set of technical parameters, which should be met or exceeded by the chosen communication technology at the end of the planning process. In order to facilitate the process for the planning tool user, ICT requirement definition is divided into mandatory and optional parameters. The input of mandatory parameters is necessary to identify relevant communication technologies. These parameters must be met or exceeded by the chosen technologies in each case, otherwise they will be excluded. In addition, optional parameters improve the results of the technology selection process. Subsequently, a definition of the mentioned ICT requirements and a description of technology parameters, are given in Table 2.

Finally, the main input for the presented ICT planning tool module is the energy network data. In addition to the energy network dimensions, it is necessary to distinguish between rural, suburban and urban areas. Due to different propagation characteristics, different ICT communication

Use Case Element (UCE)	Use Case Element Description and Application Area
UCE_ADMIN	**Administration and Configuration** consolidates UCE options for several management and maintenance activities, such as: *Device, Client and Certificate Management, Firmware Update / Upgrade, Wake-up Configuration, Monitoring (System logs) and Time Synchronization.*
UCE_ALARM	**Alarming and Notification** provides UCE options for: *Event/Error Reports and Alive Notification.*
UCE_CLS	Communication with **Controllable Local System (CLS)** intended for Demand-Side-Management of e.g., EVs, heat pumps or storage heater systems. These entities are either part of a smart home system or belong to small industrial companies.
UCE_LO	**Load Optimization** provides local load optimization capabilities by means of local network station (distribution network level).
UCE_DER	**Distributed Energy Resources (DER)** includes measurement and control related communication with smaller DERs (< 1MW) as part of the distribution grid (such as wind and photovoltaic systems).
UCE_SM	**Smart Metering** incorporates automated Meter Readings and Communication to central systems by means of intelligent metering systems.
UCE_EVSE_MGMT	**Electric Vehicles Supply Equipment Management** provides operations for basic charging process management of EVSEs which are not part of smart home systems, but located at public or semi-public area. This use case element provide following options: *Charge Authentication, Billing, Remote Customer Support, Charge Sport Reservation and Asset Management.*
UCE_EV_CM	**Electric Vehicles Charge Management** includes charge control of EVs, which are not part of a smart home system, but located at public or semi-public Electric Vehicle Supply Equipment (EVSE). Different types of charge management are covered by appropriate UCE options: *Soft / fleet focused charge management based on Time of Use tariffs, Massive charge management based on daily signals and Massive Local Charge Management based on Charge Modulation.*

Table 1: ICT Model Use Case Element Overview

	ICT Requirement	Description
Mandatory	Minimum availability (temporal)	The temporal availability is calculated from the ratio of the average availability of a technology per connection relative to the considered overall period, e.g. 525420 min / 525600 min = 99.9657%. [%]
	Maximum response time	The response time is the delay between sending a message and receiving an acknowledgement (receipt of a confirmation message transmitted by the receiving station), e.g. 0.2 s. [s]
	Bidirectionality	This parameter defines whether a reverse channel is required or not. [y/n]
	IT security	This is an indicator for the fulfilment of security requirements in general. [Low/High]
	Remote maintenance	The remote maintenance parameter describes whether a technology supports remote access in order to resolve errors or to add communication functionality (e.g. in case of the detection of security gaps). [y/n]
Optional	Minimum data rate per unit	The minimum data rate is the data rate required per device to fulfil the requirements of a desired application, e.g. 10 kbit/s in GPRS. [kbit/s]
	Minimum availability	The spatial availability is calculated from the ratio of a technology coverage relative to the considered total area, e.g. 525 km^2 / 560 km^2 = 93.75 %. [%]
	Traffic classes and Quality of Service (QoS)	Traffic classes describe the possibility to define priority classes in communication techniques or processes. [y/n]
	Maximum data rate per unit	This parameter defines the maximum data rate that needs to be supported per device/application. It is an indicator for the sustainability of a system. [kbit/s]
	Technology lifecycle	This is an indicator for a period in years after which it is expected that a technology will be replaced by another. [years]
	Black start capability	This parameter describes the capability of a communication technology to restart safely after a failure without operator interaction. [y/n]

Table 2: ICT Requirements and Performance Indicators

technologies are considered in order to meet the specific area type conditions.
Furthermore, the penetration of EV and DER systems can be supplied as an input for specific planning tool user needs, otherwise this data is estimated.

Scenario Based ICT Pre-Selection

The *Scenario-Based ICT Pre-Selection* considers the above-illustrated external use case element and ICT requirement input. On the one hand, this part is based on a database, which contains several implementations of High-Level (HL) protocols covering all energy network applications, as introduced within Table 1. On the other hand, the above-mentioned database contains a selection of communication technologies, which are applicable for energy network communication approaches, related to parameters defined in Table 2. This database for communication technologies covers wireless technologies, such as mobile cellular networks (e.g., GSM, UMTS or LTE), but also several wired solutions (e.g., PLC; xDSL or fiber).
The use case element input enables reasonable identification of such HL protocols that need to be considered for the realization of the planning tool user demand. The identified sufficient HL protocol specifications provide the message sizes for implementation of necessary use case element functionalities (see Figure 2). The use case element input is extended by a corresponding ICT requirement and boundary definition related to Table 2. The planning tool user can enter ICT requirements for each enabled use case element. If ICT requirements are not defined for every use case element, missing data is derived from [2, 3]. As illustrated in Figure 2, ICT requirements are mapped to evaluated message sizes and used to calculate minimum data rates for each technical unit, which is used in a first step to limit the number of feasible communication technologies.
Concluding, this procedure enables the identification of adequate HL protocols for implementation of desired applications and a first idea of suitable communication technologies, but does not consider any energy network knowledge and corresponding scalability requirements. In order to incorporate this energy network related data, identified ICT communication technologies are supplied as input to the second part of the ICT model, which is described in detail in the next section.

Infrastructure Planning

The *Infrastructure Planning* (II) part of the ICT model applies the obtained data of the Scenario based ICT Pre-Selection part to the energy network data. In this connection, the model part itself proceeds in two steps – a *Control Flow (Communication Effort)* estimation and an *Infrastructure Aggregation Topology* analysis with respect to EV integration. First, depending on the user input, it is possible to identify the number of estimated technical units (e.g. EVs, DER, local network stations). Applying the expected amount of technical units within the given energy network to the data amount per unit, enables the identification of expected communication effort for the given energy network. This traffic forecast is necessary to determine required capacity and bottlenecks for back-end systems.

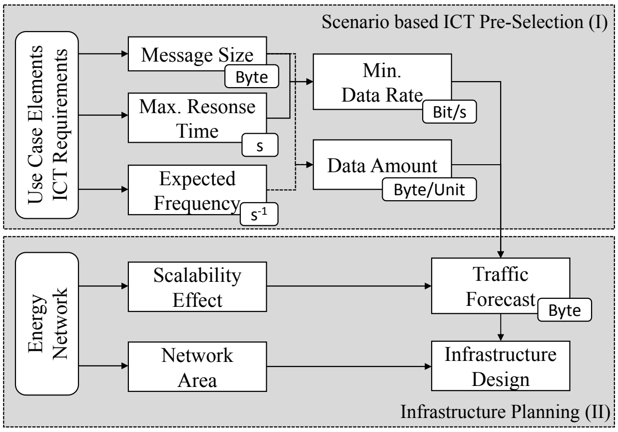

Figure 2: ICT Model Methodology

As depicted in Figure 2, obtained data leads to a direct ICT infrastructure design. On the one hand, the second *Infrastructure Aggregation Topology* step includes a design process for ICT networks, which evaluates promising constellations of communication technologies for the desired network area based on the identified ICT technologies within the Scenario based ICT Pre-Selection. Correspondingly, the design process incorporates several solutions covering a mix of mobile cellular and wired networks.

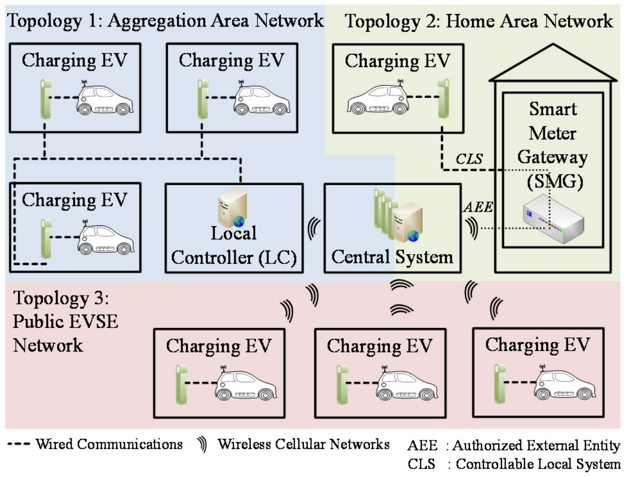

Figure 3: ICT Topology Solutions for EVSE Infrastructure

Furthermore, the design process includes the installation of separate mobile cellular networks, which are exclusively operated for the energy network provider, compared to the use of public networks. In this case it is important to consider characteristics of the area network type, distinguishing between rural, suburban and urban areas. With respect to the integration of EVs, during the design process of ICT networks, several ICT solutions for different charging infrastructure topologies are compared and assessed.

As illustrated in Figure 3, we differentiate between three topology types, depending on the location of an EVSE. If an EVSE is part of a Home Area Network, it is treated as a Controllable Local System (CLS) and controlled by the Smart Meter Gateway (SMG). But EVSEs, which are installed within public or semi-public areas, correspond to two different topology constellations. If EVSEs are located at a reasonable distance of each other, it is possible to establish a wired aggregation network instead of communicating directly to a CS with a cellular network link. Because the aggregation of EVSEs achieves performance gains [7], several aggregation stages are considered during the design process.

Example

The following hypothetical example serves to illustrate the above-described ICT model. For this purpose, we consider a rural energy network with a penetration of 1000 EVs and the use case element '*Electric Vehicles Charge Management'*, to offer control reserve products with a 180 s maximum communication interval. The specific product is the German minute-reserve product. For simplicity, only two mandatory requirements are considered: a minimum availability of 98.5 % and a maximum response time of 0.25 s.

The *Scenario based ICT Pre-Selection (I)* part of the ICT model identifies the *IEC 61850* and the *Open Charge Point Protocol (OCPP)* as reasonable solutions of high level protocols for the implementation of a charge management use case. In accordance with the mentioned ICT requirements *Enhanced Data Rates for GSM Evolution* (EDGE), *High Speed Packet Access* (HSPA) and *Long Term Evolution* (LTE) are identified as possible communication technologies, covering a maximum response time from 0.248 s (EDGE) to 0.024 s (LTE) [7] per EV. The communication requirements for the EV fleet (EDGE: 263.21 s, HSPA: 129.42 s, LTE: 24.94 s) further excludes EDGE as a solution (due to an allowed maximum communication interval of 180 s). Nevertheless, a reduction of communication effort of more than 95 % [7] can be achieved by using enhanced topology mix (see Figure 3) of wired PLC and cellular networks. In this case, EDGE is again a possible solution.

Next, the identified ICT infrastructure solutions are compared and evaluated within a cost-benefit analysis, which is illustrated in the following section.

ICT Recommendation

The ICT recommendation for a given energy network depends on a cost-benefit analysis. In this perspective, all ICT network solutions identified during the Infrastructure Design process are evaluated with respect to the trade-off between communication capabilities and estimated costs. The estimated costs cover investment costs for installation, as well as operational costs. Gained values are summarized within scoring vectors for each ICT solutions, which enable a fair comparison and directly suggest to most promising ICT solutions.

CONCLUSION

This paper presents an ICT planning approach that can be used in combination with distribution network planning processes and tools. The ICT planning model provides ICT solutions which can be used to avoid conventional grid reinforcement. The usage of this model allows the identification of promising ICT technologies for specific cases and provides an accurate estimation of costs. The technologies and their associated costs are a function of the use case and communication requirements defined by the grid planner. Identified ICT networks are evaluated through cost-benefit analysis and directly propose promising ICT solutions for the given distribution network. In future work the current ICT planning tool is expanded to include design considerations for medium and high voltage grids.

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