

DISTRIBUTION NETWORK PLANNING FOR COMMERCIAL AND INDUSTRIAL AREAS: THE REALISATION OF FLEXIBLE AND MODULAR SMART MICROGRIDS

F.D. Wattjes
Cofely GDF SUEZ & TU/e
The Netherlands
frits.wattjes@cofely-gdfsuez.nl

R.C. Goes
Liandon (part of Alliander)
the Netherlands
rob.goes@alliander.com

J. Erbrink
Liandon (part of Alliander)
the Netherlands
jur.erbrink@alliander.com

ABSTRACT

The energy transition and increased application of ICT systems can enable a breakdown of regional distribution grids into smaller and smarter, local networks (microgrids). This paper will focus on business sites where microgrids are the key enabler for balancing local generation with local consumption, reducing energy flows over the Point of Connection by means of Demand Side Management at customers premises. The relatively small scale of these microgrids offer Distribution Network Operators (DNO) a new perspective on network planning issues. This paper proposes a pragmatic approach for network planning, taking flexibility of connected customers into consideration. By applying this approach smart microgrids can be modular and flexible realised, leading towards proactive grid investments decisions.

INTRODUCTION

The current electrical infrastructure based on centralized generation and top-down distribution is transforming into a new digitalized grid, based on decentralized generation and new grid architectures. These smart grids are able to meet traditional demands with improved and additional services for system users [1]. ICT systems enable the breakdown of regional distribution grids into smaller, local networks (microgrids), which can operate in parallel with the regional distribution grid. Microgrids play a major role within this new grid architecture, because sustainability can be linked to solving problems locally [2]. Besides providing additional services for end-users, microgrids can also improve overall power system performance by managing intermittency of Distributed Generation based on Renewable Energy Sources (DG-RES) and optimize local systems to flatten out peaks in consumption by Demand Side Management (DSM) at customer premises.

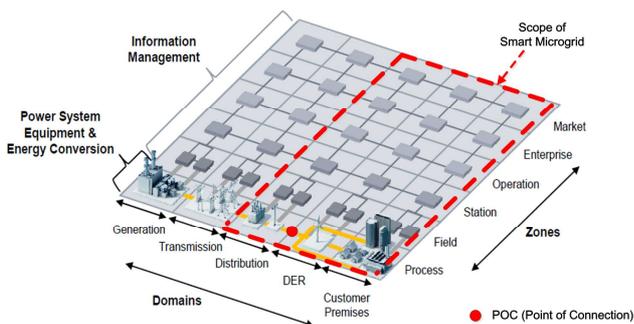


Figure 1 Scope smart microgrid concept (adapted from [3])

The depicted scope of a smart microgrid is also referred to as a *local loop* [4] which accommodates the *local* power exchange between distributed generators, consumers and storage capabilities via a smart distribution grid on and near a business park. This paper is a result of the development of a smart microgrid case study within a consortium of Alliander, Cofely GDF SUEZ, Eindhoven University of Technology and a Dutch municipality. This paper will focus in particular on distribution grid issues for industrial & commercial sites from a Distribution Network Operators (DNO) perspective. The main dilemma for a DNO in a greenfield situation is where and how much to invest in grid capacity when load forecast is unpredictable. Pre-investment in too much grid capacity, because actual load is not in line with forecasts, leads to ineffective investments. Waiting for new connection requests can lead towards planning problems and unnecessary expenses. This theme is not new; in fact many network planning optimization approaches have been developed from a scientific point of view [5]. However, these advanced decision support tools are in practice quite complex and laborious processes, resulting in inconsequent use and subjective decisions based on gut feelings [6]. Other limitations concerning changing load profiles due to present smart grid developments (e.g. DSM and DG-RES) are not taken into consideration [7]. A basic assumption regarding local network planning is that local peak load can be reduced by dispatching flexibility which is offered by local consumers and/or alignment with DG-RES.

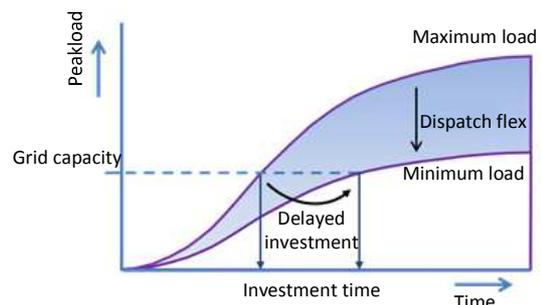


Figure 2 Dispatch of flexible power and associated investments

This paper proposes a pragmatic planning support tool for realizing modular (built with standardized components) and flexible (resistant to future changes) smart microgrids for commercial & industrial areas (business sites) in a greenfield situation. The structure of this paper is as follows. At first the pragmatic network planning methodology is introduced. The proposed approach is applied in a pilot project in which a smart microgrid

concept is analysed for an industrial & commercial area in a Dutch municipality. Secondly, results of a cost calculation for two design variants (a traditional and a smart variant) will be presented, followed by discussing conclusions and next steps.

APPROACH

A traditional design approach with available standards can be applied in projects using existing technologies and concepts. The assumptions of the existing technologies and concepts within smart grids are however put under pressure, and a more conceptual design approach is necessary. Therefore, System Engineering is chosen as the design approach for flexible and modular smart microgrids [2]. *Figure 3* depict the design steps conform Systems Engineering. The main focus of this paper is on distribution network planning, therefore the design steps for problem- and stakeholder analysis are out of scope. This paper will start with scenario analysis.

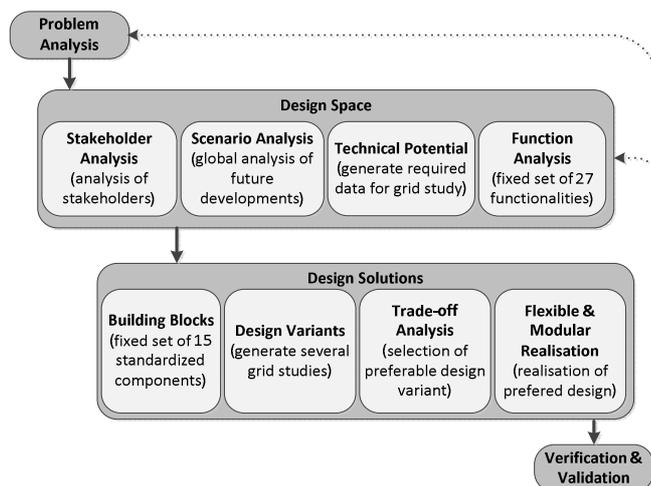


Figure 3 Systems Engineering Approach for smart microgrid design and realisation (adapted from [2])

A large variety of variables influence the development of distribution grids within business sites. Examples of general variables within the context of smart microgrids are technical potential for flexibility at customer premises, the value of flexibility, economic climate, energy prices, etc. A scenario analysis, which analyses different possible futures with unknown variables, has a dual purpose. At first it will prepare stakeholders for uncertain future developments and allows them to anticipate on this by making strategic design choices. Secondly, scenario descriptions will describe system behavior throughout the entire life cycle and give stakeholders a clear understanding of the functioning of a smart microgrid. To perform a grid study for a specific site, additional technical parameters need to be addressed within each defined scenario. For smart microgrids these are: 1) *Start situation*: greenfield, brownfield or brownfield restructuring, 2) *Consumer typology*: small

consumers ($\leq 3 \times 80A$), large consumers ($> 3 \times 80A$) or a mix of small and large consumers, 3) *Electric Vehicles*: (conservative growth, moderate growth or total electrification, 4) *degree of local demand supply match*: no DSM, partly DSM or full DSM employment, 5) *DG-RES*: no DG-RES, moderate degree of DG-RES or a large degree of DG-RES, and 5) *load forecast*: slow, expected or fast growth. The above properties within Smart Grid developments can be depicted in a morphological overview for several scenarios as shown in Table 1.

Start Situation	Consumers typology	Electric Vehicles	Demand Supply match	DG-RES	Load forecast
Green Field	Small	Conservative	No match	No	Slow
Brown field	Large	Moderate	Partly	Moderate	Expected
Brown Field restruct.	Mix	Total Electrification	Full	Large	Fast

Table 1 Morphological overview several scenario's examples (red=scenario 1, green = scenario 2, purple = scenario 3)

Future contextual developments are mapped, based on the variables from the scenario analysis. A load forecast (Figure 4) can be prepared based on these scenario's using specified data from a municipality or project developer for a specific business site. This will include generation forecasts for the deployment of DG-RES, load forecasts based on the settlement of (types of) companies, assumptions for potential flexible power, etc.

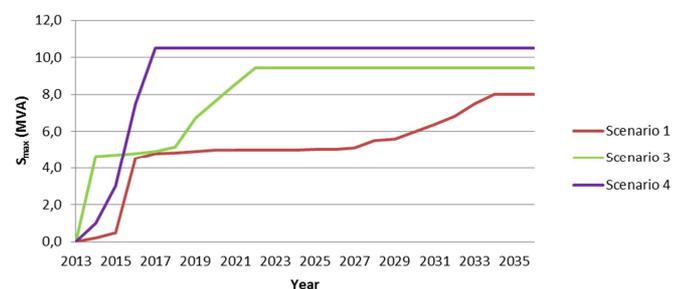


Figure 4 Example Load forecast scenarios

The next step in the systems engineering approach is the function analysis, which addresses what functionalities smart microgrids need to have. For smart microgrids a selection of 27 functions are predetermined. Examples of possible functionalities are depicted in Table 2. Designing specific business sites require an allocation of conditional functionalities, which are a selection of the fixed set of 27 functions.

Function level 1	Function level2	Function level 3
Metering	Energy Power Switchgear Temperature	Active, reactive Active, reactive Events Transformer
Control	Assets	Remote switching Control active assets
Protection	Conventional Advanced	Fuse Relays/differential
Communication	LAN WAN	Wireless Optic fibre

Table 2 Examples of Smart Microgrid functions

Different network variants can be designed by allocating smart microgrid functionalities towards function fulfillers. These function fulfillers are designed as building blocks which meet the concerning DNO's policy and standards. Multiple functions are merged into one building block. By doing this, a lot of functions can be allocated to a relatively small number of building blocks. For smart microgrids a selection of 15 building blocks are predetermined. Building block descriptions contain at least a description of functionalities, properties and costs. Table 3 show the fixed set of 15 building blocks for smart microgrids. Table 4 show a selection of functions which are allocated to building blocks.

Group	Building Block	General Description
RS/SS	iRS, iSS, iSS+	Intelligent Control- & Switching Stations, costs 200k€ - 1.700k€
DR	iDR	Intelligent Distribution Stations costs 300k€
Cable	MV630, MV240, MV16, LV150	Medium & low voltage cables with different diameters, protection and communication options costs 50€ - 145€ per meter
MSR	cMSR, iMSR, bMSR, mMSR	Medium Voltage Substations (conventional, intelligent, budget, measured) costs 10k€ - 60k€
Customers Connection	iKR, iKA, LSA	Intelligent Customer Connection (160-2000 kVA) and (<160kVA) costs 1k€ - 35k€

Table 3 Building Blocks Smart Microgrids

Function	iRS	iSS	iSS+	cMSR	iMSR	bMSR	mMSR
Power metering	√	√	√	x	√	x	√
Remote switching	√	√	√	x	√	x	x
Protection relays/differential	x	√	√	x	√	x	x
Protection fuse	√	x	x	√	x	√	√
Transformer temperature	√	x	x	x	√	x	x
Optic fibre communication	√	√	√	x	√	x	x

Table 4 Examples of allocated functionalities towards building blocks

At this point in the design approach a number of parameters are available to design several variants of a distribution grid. These parameters comprise:

- insight in contextual surroundings and possible future developments;
- load forecasts based on these insights;
- a fixed set of functionalities to allocate to a specific business site;
- a fixed set of building blocks to fulfill the required functions.

Two design variants are presented in this paper, based on several assumptions as stated in the mentioned pilot project. In reality much more alternative variants should be considered. At first there is a reference scenario 0 (Figure 5), a traditional design for a passive grid, using conventional assets and based on current regulatory requirements. Flexibility within the business site is not taken into consideration, grid design is based on a fixed load forecast for year 30, there is no additional metering and DG-RES is connected at substation level (regulatory requirement). For smart microgrids it is essential that there is a local loop, in such a way that DG must be connected within this local loop to balance local demand and local generation, and not at the nearest substation outside the local loop. In scenario x (Figure 6), this local loop is taken into consideration, besides additional metering (e.g. applying measurements in the grid) and the use of the offered flexibility by stakeholders within the local loop. Costs for unlocking flexibility (e.g. systems, cloud services) are not taken into consideration. These costs fall into the scope of energy service suppliers such as aggregators, etc.



Figure 5 Design variant scenario 0



Figure 6 Design variant scenario x

Based on the generated design variants, a choice for the optimal design solution needs to be made. This could be done by verifying the design solutions to key criteria which are gradually stated in several previous system engineering steps, for instance by means of a trade-off analysis. Examples of important key criteria are costs, reliability, maintainability, connection speed, postponed investments, needed surface area, grid losses, nuisance, etc. For this paper only costs are taken into consideration. For each variant the associated costs are determined, based on cost indications of the building blocks. Cost savings by postponed investments and preventing divestments are main drivers for a DNO. Core of the proposed approach is choosing grid capacity by following load growth on a business site, and if possible, taking flexibility into account. Even if there is no flexibility available, following load growth and not build a grid at full strength based on uncertain assumptions over 30 years, is valuable. The dispatch of future flexibility can be used to postpone large investments (see also Figure 2). During the operation of the smart microgrid, the chosen scenario needs to be verified regularly, based on realised grid capacity, new load forecasts and actual potential flexible power. Differences between the original demand, actual measured load and dispatched flexibility, offers possibilities to postpone grid investments (Figure 7). The required data must be made available by different stakeholders of the microgrid: capacity data is supplied by DNO's Asset Management department, load forecasts by municipalities or energy service suppliers, flexibility by aggregators or by means of energy scans for potential flexibility at customer premises.

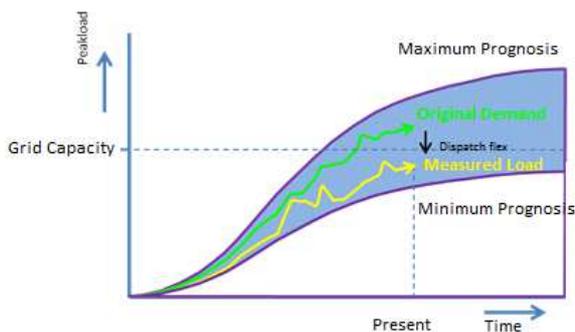


Figure 7 Verification of load forecasts based on measured load and dispatched flexibility

RESULTS

The development of the yearly costs for scenario 0 and x are depicted in Figure 8. The cumulative costs for both scenarios will not differ a lot at the end of 30 years. The main difference is during the start-up of the business site. Both scenarios will start with large investments, mainly to connect large wind turbines. In scenario 0 (business as usual) most investments during start-up are necessary because grid design is based on year 30. In scenario x investments will follow the load forecasts more closely.

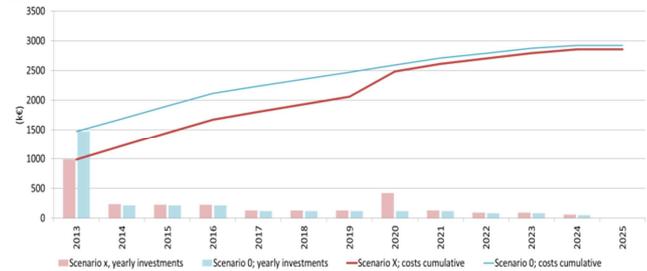


Figure 8 Yearly Costs Scenario 0 & Scenario x

The costs allocation is depicted in Figure 9. The total costs are quite similar, the allocation of the costs is however different. In scenario 0 there are more associated costs related to the electrical infrastructure (cables) while in scenario x more costs for metering are necessary.

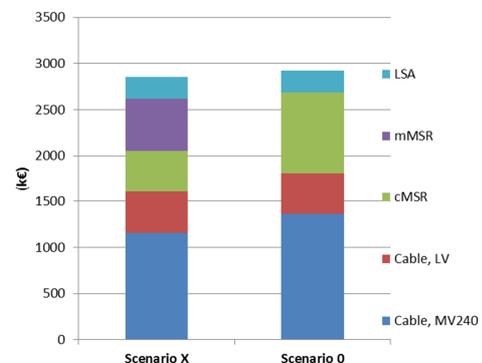


Figure 9 Costs Allocation

CONCLUSIONS AND NEXT STEPS

The proposed approach for modular and flexible realisation of smart distribution grids on a business site, have strong similarity with Alliander's (DNO) existing policy with respect to grid design, and the defined functionalities and selected building blocks have strong similarity with Alliander's existing standards. The proposed approach however differs on two items with respect to the design of smart microgrids: the dispatch of flexibility and not to jump into solutions. Applying flexibility in design and using scenario's for flexible power is currently not taken into consideration. This should be implemented in design teams regarding smart microgrids. Modular and flexible realisation supports the objectives of a DNO to postpone investments. The previous section shows that the total investment may remain the same by applying the proposed approach, but it is much more interesting that the timing of these investments will change and can be controlled. Asset management becomes proactive instead of reactive, because load forecasts will be repeatedly verified to a chosen scenario instead of realising a grid based on one (static) scenario for load forecasts (Figure 10). During everyday practice, it is possible that the specified final situation can be achieved in different ways during the whole period of operation (dynamic planning).

In addition, the specified end situation may change as well (dynamic planning under uncertainty). The proposed approach will overcome these uncertainties on a very pragmatic manner, appropriate for small scale business sites.

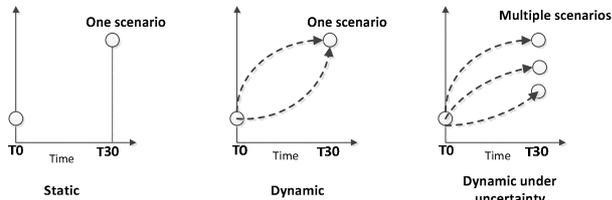


Figure 10 Graphical impressions of planning problems (adapted from [6])

The used design framework of Systems Engineering proved to be applicable within smart microgrid development. Systems Engineering is system user centered, the actual need of customers is centralised. Technology is not in the lead, but the system as-a-whole (also for non-technological issues) is taken into consideration. Within the proposed approach, thinking in functions is key, instead of thinking in solutions. The proposed concept also requires that a DNO becomes involved at a very early stage in project development. The sustainable transition of the energy system should be seen from the complete value chain of generation, distribution and consumption. Early involvement of a DNO will improve sustainable development of business sites. All of these issues are taken into consideration with the proposed approach. Based on these conclusions, Figure 11 depicts the focus or learning areas (red dotted box) of DNO's.

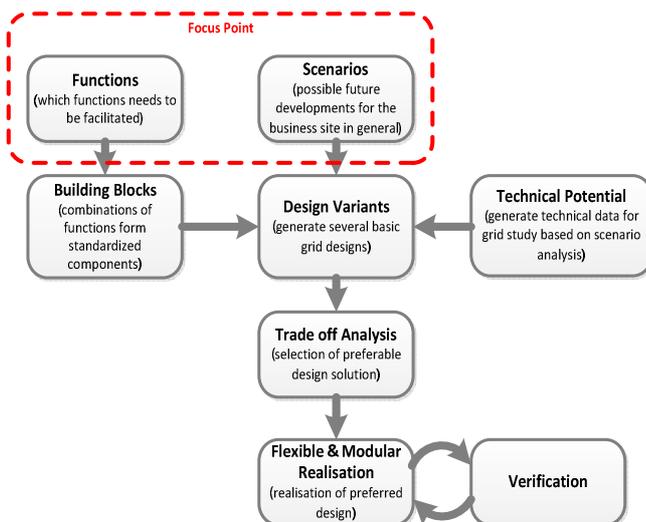


Figure 11 Flow chart of the generic design steps as taken in the Systems Engineering Approach

The proposed approach is an abstract and high level concept and it should be validated in (multiple) pilot projects and the defined functionalities and building

blocks may be optimised. This way, the concept of modular and flexible design and realisation becomes more and more robust and applicable. The concept is until now only focusing on greenfields, applying this way of thinking within brownfields could be very supportive in the revision, restructuring or expansion of existing business sites to meet new sustainable demands. The concept is also exclusively focusing on electricity networks. Enriching the concept for multiple energy carriers (e.g. heat/cold, gas) could be valuable for the optimisation of the overall energy system. All of these items are still work in progress. The first step will be the application of the proposed approach into detailed design solutions for the smart microgrid casus in a Dutch Municipality.

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REFERENCES

- [1] EU Commissie Taskforce for Smart Grids; "Expert Group 1: Functionalities of Smart Grids & Smart Meters," 2010.
- [2] F. Wattjes and J. Slootweg, "Design Considerations for Smart Microgrids," in *UPEC*, Dublin, 2013.
- [3] Smart Grids Coordination Group, "Technical report "Reference Architecture for the Smart Grid"," CEN-CENELEC-ETSI, 2012.
- [4] R. Hakvoort and A. Huygen, "Sturen op het gebruik van lokale energienetten," D-Cision & TNO, 2012.
- [5] K. El Bakari, C. Carter-Brown, S. Jupe, A. Baitch, C. Abbey, A. Rasi Aoki, M. Fan, C. Nakazawa and F. Pilo, "Survey on methods and tools for planning of active distribution networks," in *CIRED - Workshop Paper 158*, Lisbon, 2012.
- [6] M. Grond, J. Morren and J. Slootweg, "Requirements for advanced decision support tools in future distribution network planning," in *CIRED - 22nd International Conference on Electricity Distribution*, Stockholm, 2013.
- [7] F. Pilo, S. Jupe, F. Silvestro, K. El Bakari, C. Abbey, G. Celli, J. Taylor, A. Baitch and C. Carter Brown, "Planning and optimisation of active distribution systems - an overview of cigre working group C6.19 activities," in *CIRED - workshop paper 135*, Lisbon, 2012.