DESIGN OF DECENTRAL ENERGY SYSTEMS – OPTIMIZED ENERGY SUPPLY ON BASIS OF PSS®DE

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ABSTRACT

The idea of decentral energy systems is not new. Already in the very beginning of electrification, several decentral structures were installed. The current trend of integrating more and more distributed generation in the electric power supply systems initiates new supply assignments. The core of this paper introduces a five-step approach to evaluate energy systems and support customers on their pathway towards an efficient and sustainable supply system.

INTRODUCTION

Energy and power systems are in a transition phase worldwide. With an increasing share of distributed and renewable generation, driven by environmental awareness of today's consumers, they are changing from the one-way supply to more diverse, dynamic, and complex systems. The changes introduce not only multilayered energy, information, and money flows but also multiple actors into the so-called decentral energy systems. In parallel, the existing principles of an efficient, economic and sustainable energy supply remain as important as ever. Therefore, innovative and integrated infrastructure planning becomes more and more important.

DESIGN PROCESS

Decentral energy systems offer a variety of new business opportunities. With comprehensive expertise in energy and power systems, Siemens supports its customers in designing their specific decentral energy systems – from consulting and planning to software and services [1-3]. Figure 1 shows the core of the design methodology, to evaluate energy systems and support customers on their pathway towards more efficient and sustainable decentral energy systems.

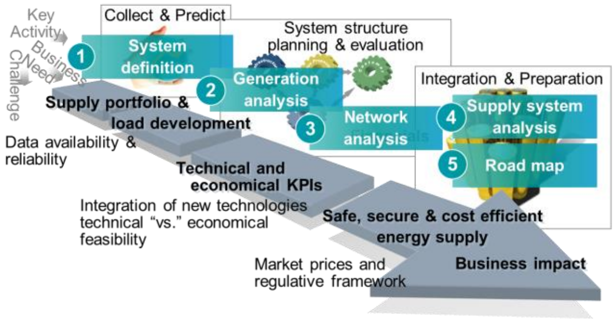
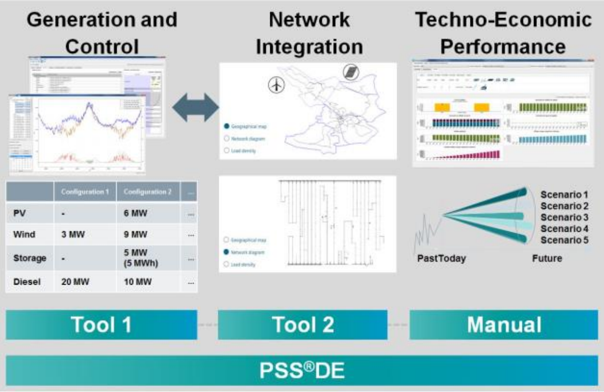


Figure 1 Methodology to design decentral energy systems

This methodology can be used for different applications, such as residential communities, rural electrification, institutions and industrial plants. Each decentral energy system is different from another and therefore is individually customized and optimized by Siemens to match the customer's requirement. The system design methodology comprises a five-step approach:

- **System Definition**: The design of decentral energy systems starts with data collections and predictions for supply options and load development. Different variants are defined (e.g. on basis of load increases or renewable energy potentials) and reflect the boundary conditions of the stakeholders involved.
- **Generation Analysis**: Based on the above variants and the collected data (load, installed capacities of thermal units, potential of renewable energy sources like hydro, wind, etc.) the generation portfolio is simulated and evaluated. The operational optimization takes into account the fuel consumption, the use of renewable energy, available storage flexibility and additional constraints like reserve margins or limits of components.
- **Network Development Analysis**: After the generation analysis the development and analysis of different network concepts is the core task of the necessary strategic network analysis. This process starts with the compilation of a basic system model. This network model has to consider at least the topological and electrical data of the equipment, and will be extended to several other data items as required for the technical analyses (e.g. load flow, short circuit, or reliability analysis).
- **Scenario Comparison and Decision Making**: In order to assure the feasibility and sustainability of the proposed system design, a techno-economical comparison of different scenarios is conducted. The technical planning criteria and planning approach is being used as the basis for an economical analysis of the different system scenarios.
- **Roadmap**: After the selection of the preferred scenario, another iteration of technical and economical analyses takes place. Decision makers select the target network based on the technical and economical evaluations of developed supply scenarios including sensitivity analysis. Once the individual optimum between technical and economical feasibility is identified, the chosen solution is described in a detailed roadmap and prioritized recommendations to prepare the implementation.

With this five-step approach, Siemens has successfully designed decentral energy systems and has gained the necessary expertise and experience to realize CO_2 and cost savings potentials. Detailed system analyses are executed with Power System Simulator®Distributed Energy (PSS®DE), which is a proprietary tool that Siemens has specifically developed to design decentral energy systems. As shown in Figure 2, PSS®DE is the first software environment for the integrated analysis and design of decentral energy systems.



	Configuration 1	Configuration 2	...
PV	-	6 MW	...
Wind	3 MW	9 MW	...
Storage	-	5 MW (5 MWh)	...
Diesel	20 MW	10 MW	...

Figure 2 PSS®DE for decentral energy systems

In the past, the generation analysis and network analysis were run in different tools. One tool was used for the sizing of decentral energy systems (Tool 1 in Figure 2). Subsequently a second tool analyzed the network, using the results of the generation analysis. Finally, the techno-economic performance of different scenarios was compared manually. PSS®DE provides the functionality of Tool 1 and Tool 2 as well as sophisticated financial engineering tools in place of the manual analysis. It provides detailed system analysis including the dimensioning of generation and storage units and analysis of network structures to assure network resilience and achieve optimal Levelized Cost of Energy (LCoE) and network tariffs.

MICROGRID

"Decentral energy system" is a term which encompasses a diverse array of generation, storage, energy monitoring and control solutions. "Microgrids" are one of the most important parts of decentral energy systems. Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network, or while islanded [4]. Microgrids contain all elements of complex energy systems and "smart" utilization of these energy resources to maintain the balance between generation and consumption. The most important feature of a microgrid is the "islanding" ability to separate and isolate itself from the utility's distribution system during power system disturbances and blackouts.

With respect to user applications or market segments, microgrids can be categorized into six groups:

- **Campus / Institution**: This microgrid type consists of a certain number of buildings in a limited geographical area. In case of "normal" government or college buildings, moderate power supply reliability will be adequate, while research institutes may require higher levels of power quality.
- **Industry / Commerce**: this type will be established in an existing or a completely new industrial / commercial area. Considering sensitive manufacturing processes and high demand on electrical and thermal energy, more and more industrial / commercial operators are using microgrids to provide electricity cost-effectively, sustainably, and reliably.
- **Military**: There are measurable benefits by changing power supply of military bases from diesel backup generators to more efficient microgrids based on renewables.
- **Utility / Community**: These microgrids can provide power to urban or rural communities that are connected to the larger utility grid. This type will mainly include residential, but sometimes also commercial and industrial customers in a geographical region. They may include city areas, neighbourhoods, and rural feeders.
- **Island**: Island microgrids in most cases have no connection to the utility grid. In very few cases there may be a cable connection to the utility grid of the mainland, if the distance of the island to the mainland is in an acceptable range.
- **Rural Electrification**: Such "off-grid" microgrids are ideal for geographically remote regions with no connection to a public network. Other remote microgrids are built to remain autonomous and to realize energy independence.

MICROGRID DESIGN EXAMPLE

In this paper, one concrete project for an industry customer is anonymized to present the whole design process. The goal of the industry customer is to demonstrate feasibility of a zero-emission building concept and a carbon-neutral and self-sustaining energy supply using renewable energy sources only. At present, the heat demand is met through gas boilers that utilize a gas pipe line from the local utility. The customer is considering the possibility of installing Combined Heat and Power (CHP) units to co-supply its electricity and heat demands, after witnessing the financial success story of converting a nearby industry to CHP technology.

System Definition

The first step of design process is to define the energy supply system based on available data from customer. This project considers the main office building of a factory. The peak electric and thermal demand in load and energy is about 167 kW and 700 MWh respectively. The load profiles of both electricity and heating demand are available for the generation analysis. As shown in Figure 3, presently, electricity is supplied via one 10 / 0.4 kV transformer connecting the main low voltage distribution station to the public grid. The loads are fed from the main station. The heat demand is supplied by gas boilers. The current energy supply system is set as the reference "Business As Usual" (BAU) scenario. Considering local renewable potentials and geographical conditions, Photovoltaic (PV) is the only economically available renewable option. The maximum possible area is formed by roof and southern facade of the building. In order to balance the PV generation profile and improve overall system sustainability, it is also necessary to install a storage system. In this project, an Energy Storage System (ESS) with lithium-ion battery is considered. A CHP plant using gas is an option to cover electricity as well as heat demand.

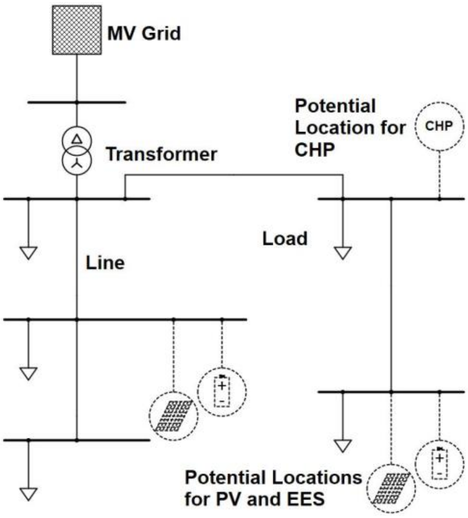


Figure 3 Industrial network

Following, four scenarios will be investigated:

- **BAU**: Electricity supply from network; heat supply from boiler
- **Scenario 1**: Electricity supply from network, on-site PV; heat supply from boiler
- **Scenario 2**: Electricity supply from network, on-site PV and ESS; heat supply from boiler
- **Scenario 3**: Electricity supply from network, on-site PV, ESS and CHP; heat supply from boiler and CHP; Energy management system to ensure stable and secure operation

Generation Analysis

In the generation analysis, the potential capacities for PV, battery storage and CHP are identified with reference data from customer. The maximum possible capacities for PV and CHP is 200 kW each, and 92 kWh for the EES. As shown in Table I, two sizes are considered for PV, EES and CHP each, resulting in 15 different configurations for the decentral energy system. On this basis, different generation portfolios are simulated and evaluated with PSS®DE.

TABLE I: CONFIGURATIONS FOR DIFFERENT SCENARIOS

Scenario	Configuration					
	PV [kW]		EES [kWh]		CHP [kW]	
BAU	-					
1	100	200	-		-	
2	100	200	46	92	-	
3	100	200	46	92	100	200

All generation portfolios are required to meet the energy demands according to both electric and heating load profiles. Figure 4 shows the electric load profile for one year. Time of the day is shown on the y-axis, while the days in a year are shown on the x-axis. Different colors represent different load values.

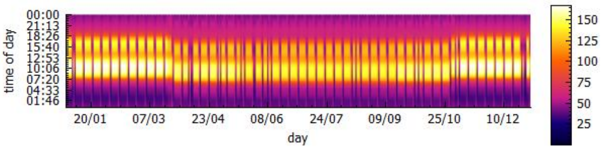


Figure 4 PSS®DE electric load profile

The simulations provide detailed information on the operation of the available generation resources, like PV generation, charging and discharging of battery storage units. Figure 5 shows an exemplary supply profile.

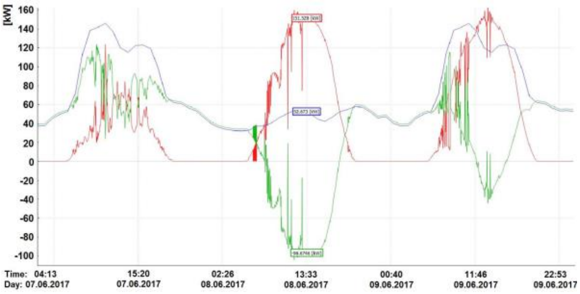


Figure 5 PSS®DE electric power supply by sources
(red: PV generation, green: grid feed-in, blue: load profile)

The simulation also delivers financial results considering both capital expenditure and operational expenditure of the selected generation structure on basis of the specific composition and interaction of the different generation resources. The financial key performance indicators, such as Net Present Value (NPV) and LCoE can be derived for the evaluated scenarios. Figure 6 shows the results of NPV for different configurations.

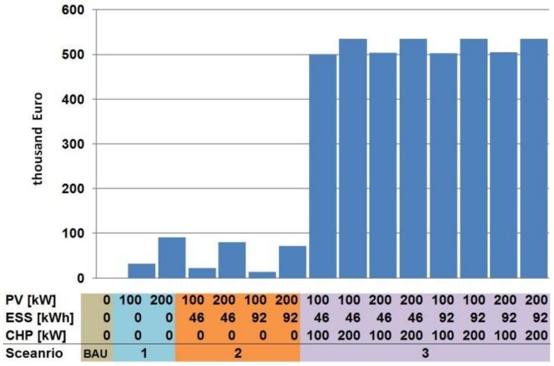


Figure 6 PSS®DE NPV results for different configurations

Network Development Analysis

After the generation analysis, the analysis of different network development concepts for the industrial network is the core task of the necessary strategic network analysis. Based on the network model for the precisely defined base scenario, the task of developing new variants is executed for each scenario. Subsequently and in order to prepare a comparison of different scenarios, a detailed technical analysis of these different system scenario is required. Here, various technical network calculations can be performed, such as load flow, short circuit, or reliability analysis. The selection of analyses depends on both available data and requirement of customer.

In this project only load flows in networks are investigated. For each configuration, four network states are simulated:

- **State 1**: Theoretical operating state with minimum load and maximum PV
- **State 2**: Theoretical operating state with maximum load and no PV
- **State 3**: Simulated operating state with maximum load and relevant PV feed-in
- **State 4**: Simulated operating state with maximum PV feed-in and relevant load

Based on the system model, the busbar voltages and the loading of branch elements such as transformers, lines and cables, are calculated with load flow calculation. The thermal limits of components and the voltage profile are checked throughout the system.

In Figure 7 the simulation results of the integrated network analysis functionality in PSS®DE are shown for different configurations. The results matrix from the integrated network analysis identifies critical network issues (in red) in some of these scenarios. Considering the critical situation in different configurations, traditional network extension measures are applied to solve the problem and the costs for these measures are calculated.

1. State	🟩	🟨	🟥	🟩	🟥	🟩	🟨	🟩	🟩	🟥	🟥	🟩	🟩	🟨	🟨
2. State	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
3. State	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩
4. State	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PV [kW]	0	100	200	100	200	100	200	100	100	200	200	100	100	200	200
ESS [kWh]	0	0	0	46	46	92	92	46	46	46	46	92	92	92	92
CHP [kW]	0	0	0	0	0	0	0	100	200	100	200	100	200	100	200
Sceanrio	BAU	1		2				3							

Figure 7 PSS®DE network simulation results
(green: within limit, yellow: close to limit, red: exceeds limit)

Scenario Comparison

Based on the simulation results from both generation and network analyses a techno-economical comparison is conducted. The cost-benefit analysis of each scenario calculates key economic figures using NPV.

In this project, the configurations in Scenario 3 have better results than other scenarios. The configuration with 46 kWh ESS is better than the one with 92 kWh in generation analysis. However, it requires higher grid investment. In total, considering all results from generation and network analyses, the configuration with maximum PV and battery storage capacities shows the best performance.

Decision Making

Final decision making also has to consider key risks. In this project, especially changes in gas price pose an economic risk. The current gas price is low and there is risk of higher prices in future. Risk assessment considerations thus derive Scenario 3 with maximum PV, maximum ESS and 100 kW CHP as final recommendation.

CONCLUSION

Decentral energy systems and respectively microgrids are increasingly recognized as a complementing concept for future energy supply systems. They can serve as building blocks towards smarter, more resilient and more sustainable systems with increased integration of distributed energy sources. Integrated planning methodologies and tools are key to realize these benefits in concrete projects. Siemens offers detailed system analysis with PSS®DE and develops a roadmap towards a cleaner ecosystem with improved efficiency. The individual concepts for design create major benefits for grid owner, operator, customer and generator.

REFERENCES

[1] Tao, L.; Schwaegerl, C.; Narayanan, S., Zhang, J. H., 2011, “From laboratory Microgrid to real markets – Challenges and opportunities”, *Power Electronics and ECCE Asia*, Jeju, South Korea.

[2] Tao, L.; Mueller, H.; Natti, S., Lovelady, D. M., 2012, “A novel microgrid simulation and demonstration tool”, *CIRED Workshop*, Lisbon, Portugal.

[3] Schwaegerl, C.; Tao, L., 2013, Chapter 1: The Microgrids Concept, Microgrids: Architectures and Control, Wiley, New Jersey, USA.

[4] Cigre Working Group C6.22, 2009, *Microgrids 1 Engineering, Economics, & Experience*, Cigre, Paris, France.