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Planning and Implementation of Bankable Microgrids

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Abstract

Currently, many Microgrid projects remain financially uncertain and not bankable for institutional investors due to major challenges in existing planning and design methods that require multiple, complex steps and software tools.

Existing techniques treat every Microgrid project as a unique system, resulting in expensive, non-standardized approaches and implementations which cannot be compared. That is, it is not possible to correlate the results from different planning methods performed by different project developers and/or engineering companies.

This very expensive individual process cannot guarantee financial revenue streams, cannot be reliably audited, impedes pooling of multiple Microgrid projects into a financial asset class, nor does it allow for wide-spread and attractive Microgrid and Distributed Energy Resource projects deployment.

Thus, a reliable, integrated, and streamlined process is needed that guides the Microgrid developer and engineer through conceptual design, engineering, detailed electrical design, implementation, and operation in a standardized and data driven approach, creating reliable results and financial indicators that can be audited and repeated by investors and financers.

This article describes the steps and methods involved in creating bankable Microgrids by relying on an integrated Microgrid planning software approach that unifies proven technologies and tested planning methods, researched and developed by the United States National Laboratory System as well as the US Department of Energy, to reduce design times.

Growing Markets

By the year 2027 it is expected that the Microgrid market reaches a volume of 31 billion dollars (Wood, 2018). Another Navigant report identified 240 additional Microgrid projects in the second half of 2018 alone. This represents 10% of the total installed and planned Microgrids of 2258 (Navigant, 2018). Two years earlier Navigant only tracked 1586 projects and counted 148 projects added in the second half of 2016 (Lorenz, 2016). There is a clear trend that Microgrids are growing considerably. However, the definition of Microgrids can vary widely (U.S Department of Energy Berkeley Lab, 2017) and depending

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on the objective, Distributed Energy Resource (DER) projects including Photovoltaics, electric storage, or Combined Heat and Power (CHP), which for example cannot seamless island from the utility, constitute a way larger market. This explains the considerable differences in market study results. For example, the DER market is estimated to reach 570 billion dollars in 2027 based on Grand View Research (Grand View Research, 2018). With the changing regulation landscape and increased constraints on the electric distribution system, those DER assets need to be planned and controlled to reduce integration costs and also to mitigate the impact on the electricity system (California Public Utilities Comission, 2017). The coordinated control of multiple on-site DER, storage systems, and flexible loads form a controllable cluster of distributed resources with potential to provide benefits to both the system owner and the stakeholders of the wider distribution system by reducing energy costs, deferring capacity upgrades, and shifting load to periods of excess capacity. (G. Y. Morris, 2012), (Michael Stadler G. C., 2016). Thus, proper DER and Microgrid project solutions that can be planned, developed, and deployed in a fast/cost-effective manner are needed to support this growing market.

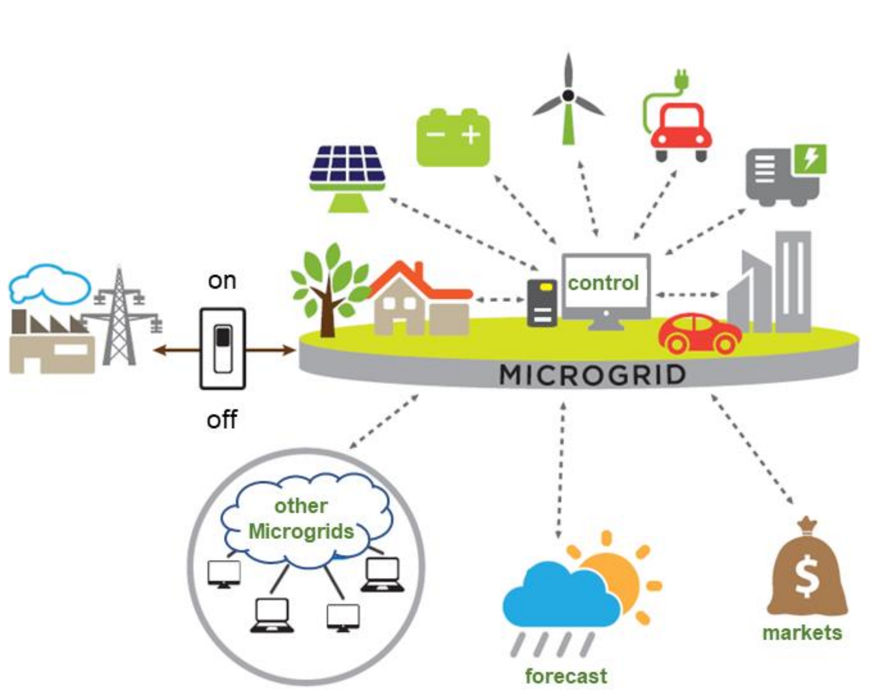

Figure 1: Microgrid Concept. A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode (LBNL, USDOE, 2019).

Planning, Development, and Implementation Costs

The current Microgrid and DER project development costs are very high and the Blue Lake Rancheria Microgrid project for example incurred 20% development and soft costs, resulting to roughly 1.3 million dollars for that specific project (Carter, 2019). Based on (Dan Ton, 2012), up to 30% of the entire Microgrid costs can be attributed to the system integration and engineering, which indicates that for

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wide-spread and fast Microgrid/DER deployment these costs need to come down considerable by creating a standardized modelling and engineering approach.

Steps Needed for a Successful Planning, Deployment, Implementation, and Operation

The following high level steps are needed to deploy and operate a Microgrid or DER project successfully:

a) Conceptual Design

The conceptual design answers the question: What technologies should be considered to maximize savings to improve investment returns, minimize CO_2 emissions, or maximize the survivability of a Microgrid during natural disasters?

Thus, this phase is mostly driven by economic or environmental concerns and should deliver the most optimal combination of DERs and their technology sizes to meet those concerns. Supply and demand will be either simulated or optimized, minimizing cost objectives such as the annual energy costs, Leveled Costs of Electricity (LCOE), and Net Present Value (NPV), or emissions objectives such as total emission volume. Investment costs, operational, maintenance costs, among others are considered in this calculation, but different modelling techniques and approaches exist (Peter Tozzi Jr., 2017), (Zack Pecenak, forthcoming). Some established tools use simulation approaches, where in such approaches the user changes input data (e.g. costs for a certain technology) and checks how this impacts the results (e.g. adopted technologies in a Microgrid) (Henrik Lund, 2017). The relationship between results and input is determined by physical models. In general, such simulation approaches do not have built in mechanisms to find the best or optimal solution (e.g. investment capacity). Thus, it is not easily possible to find the most optimal technology combinations and operational dispatches since there are millions of combinations for technology choices and operational levels. However, such simulation tools are helpful to understand a complex system by running multiple iterations in a manual fashion.

A new generation of conceptual design tools is emerging and such tools use mathematical optimization techniques, which allow finding the true optimal combination of technologies by "built" in "iteration" techniques, so called solvers. Examples for such tools are REOpt (NREL, 2007-2019), designed by the National Renewable Energy Laboratory or the Distributed Energy Resources Customer Adoption Model (DER-CAM), designed by Lawrence Berkeley National Laboratory (Berkeley Lab, 2019). However, such optimization tools are more complex and can be more difficult to use since the results might be hard to interpret, or deliver results which are against common expectations based on historic centralized utility views. However, these more complex tools also optimize the dispatch/operation of the considered technologies, and in this way, mimic a DER or Microgrid controller, thus creating more realistic planning results. Some of them also consider power-flow and energy networks and flows in them (Salman Mashayekh, 2017).

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The basic Microgrid design challenge is shown in Figure 2. Starting with hourly load profiles (or sub-hourly resolutions) on the right hand-side for the whole year, the optimization algorithm needs to identify the best technology combinations and determine how to operate them, based on economic and technical parameters. Economic parameters can include subsidies, prices for electricity, fuel costs, maintenance costs, etc. Technical parameters can include charging efficiencies, electrical efficiencies for generators, or maximum available space for renewable technologies, among others.

As seen in Figure 2 there are more than a dozen possible technologies which can supplement each other, or even compete, like CHP, solar thermal, or PV since they are generating heat and electricity at different price levels and availabilities. Thus, the electrical, thermal, or cooling interactions between these technologies can be complex and require optimization techniques.

The red, blue, and green arrows are the energy flows between the technologies and loads. In every time step (one hour or smaller) the energy flow can change based on environmental constraints or changes in the electricity rates, among other factors. It is easy to imagine that these changes in energy flows will influence the decision making on the selected technologies and their capacities. In other words, the planned operation will also drive the investment decision, and thus, it is absolutely necessary to consider the optimal dispatch of technologies as already mentioned. This of course mimics a real Microgrid controller, underscoring the need to have a Microgrid controller in the operation and maintenance phase that works similar to the dispatch modelling in the conceptual design phase.

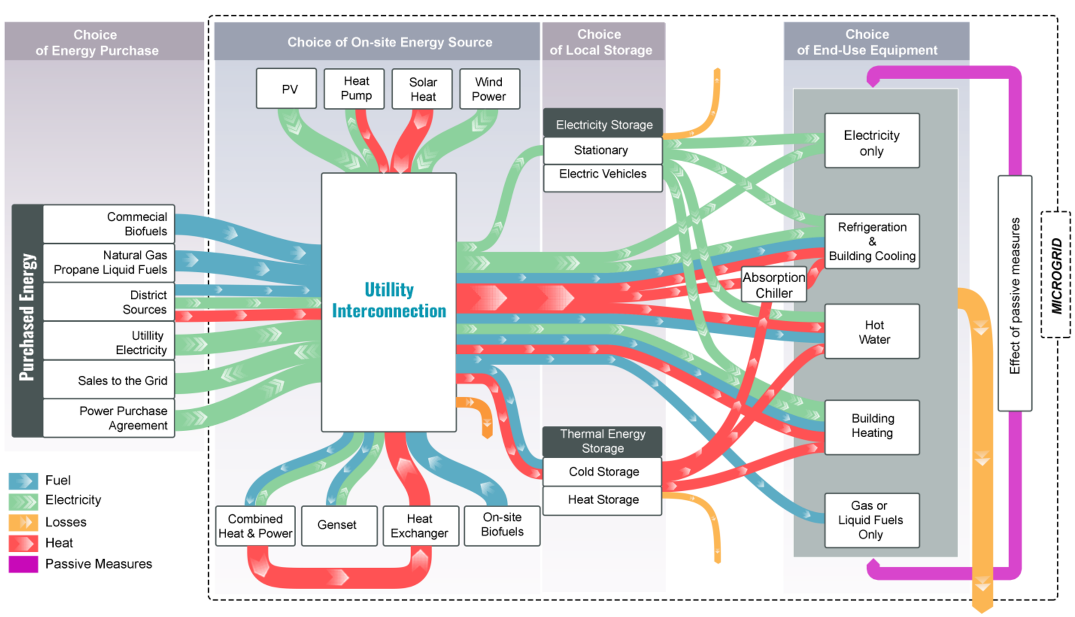

Figure 2: Energy Flows in Microgrid or DER Projects. The complexity of interactions between all the different technology possibilities and also the changing energy flows in every time-step (e.g. because of varying prices or solar insolation), make it difficult to find the best solution and operation of technologies. Spread-sheet tools and simulation tools without mathematic optimization techniques are not able to solve this complex problem in a satisfactory way.

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In the conceptual design phase, only limited technical questions are answered. However, a main challenge in this phase is to collect and find the proper data needed to perform the conceptual design study. Data which is needed, and can create challenges, are detailed hourly load profiles for electricity or cooling for an entire year or future technology parameters and performance data e.g. electric efficiency or costs in $/kW for specific technology vendors, among other data.
These challenges indicate that data driven approaches, which leverage web-services as weather forecasts or built in tools and vendor equipment pricing information, are needed.

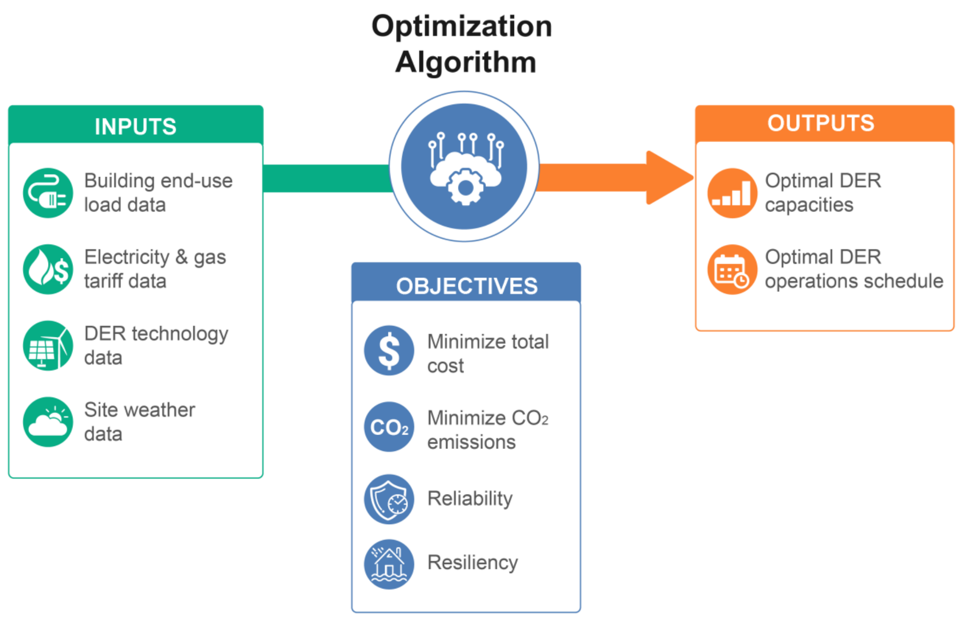

Figure 3: Data flow Conceptual Design via Optimization Techniques. Detailed hourly load to allow assessment of load shifting potentials needs to be combined with utility information, and technology data as well historic weather information. To speed-up the data collection process, databases and links to other services (e.g. weather sites) are needed. Based on the selected objective the optimal DER capacities and optimal operation will change.

b) Technical Design

The technical design phase will answer more detailed engineering questions regarding the distribution system, cabling, transformers, switches, breakers, and the stability of the system, among others.
Depending on the software tool there are no power flow considerations in the conceptual design phase. However, some tools consider basic power flow for strategic placing of DERs in the network, but detailed power flow simulations as a time series power flow (power flow for the whole year and not just snap-shots) or transient analyses need to be done in this technical design phase with different approaches and tools. Transient analyses are typically used to

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determine problems during e.g. start-up phases for electric motors or in fault conditions. If resilience is an objective, then transient stability studies will also need to be performed. Power flow analyses do not consider such dynamic effects as in transient analyses and focus on a quasi-static system for the voltage and current. In this way, the power flow analysis determines if lines and cables are properly sized, but transient analyses determine if a system will be stable or collapses in the event of an unexpected or dynamic event. In this phase, protection design and coordination needs to be done too.

For this sophisticated engineering task tools and models are needed that can include GridLAB-D (GridLab-D, 2017), developed by the Pacific Northwest National Laboratory with support from the US Department of Energy or OpenDSS, designed by the Electric Power Research Institute (EPRI, 1997 - 2018). Some of these analyses introduce considerable complexities and need an engineering background, limiting the usability for certain stakeholders such as bankers, investors, or real estate companies. Furthermore, most of the time the technical design process is completely decoupled from the conceptual design and no integration exists, obstructing any data flow. This is especially problematic when the technical design reveals issues with the underlying conceptual design, leading to unplanned engineering time and costs.

This challenge indicates that the conceptual and technical design should be implemented in one single platform, allowing multiple views, complexity levels, and details depending on the user class, i.e. engineer versus financial person.

c) *Implementation Phase*

In this phase an effective construction, onsite engineering and implementation, testing, as well as commissioning needs to be achieved. Microgrid projects can be complex and involve multiple vendors, engineering and construction companies, as well as consulting firms, making the coordination and timing of all the different technical steps difficult. Delays, due to an ineffective project management, will increase costs, create penalties, or reduce the profit. This challenge even increases when large companies or organizations implement multiple Microgrids and DER projects at the same time. Thus, effective tracking of the challenges, milestones, progress, and costs is absolutely necessary. On top of this, on-the-job training might be needed to complete certain steps in the Microgrid implementation process, in light of the novelty of such projects. This on-the-job training should be supported by online classes and training material, minimizing the human interaction to reduce training time and costs. For this, an effective management software will be needed, otherwise the calculated savings from the conceptual and technical design phase are at risk due to delays and cost-over-runs. Most optimal would be a software platform that can interface with the previous two phases to minimize data handling issues and allow seamless data exchange and adaptions in the different phases.

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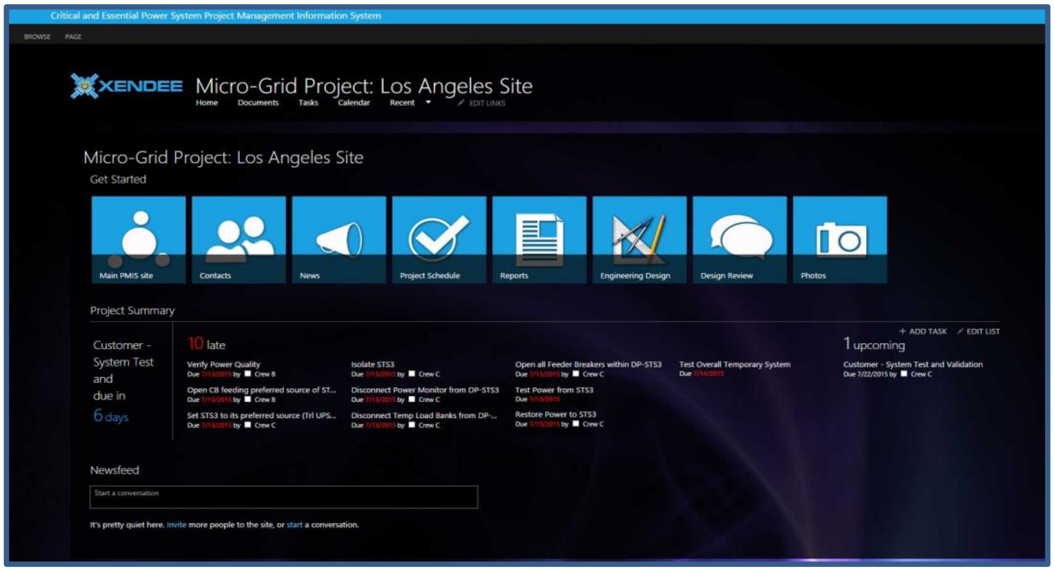

Figure 4: Example Management Platform that Effectively Supports the Implementation of Microgrids. The system will track delays and notify the responsible persons via the Project Schedule feature. The user can comment on and review the conceptual design and technical design (engineering design) and the whole set of project contacts and vendors can be managed.

d) *Operation and Maintenance Phase:*

In this phase the Microgrid or the DER assets are controlled to achieve a certain goal in real-time. That goal (e.g. cost minimization) should be the same as in the conceptual design phase to guarantee the calculated savings and benefits and establish a bankable solution that guarantees economic and financial indicators as LCOE, NPV, Return on Investment (ROI), etc. If the operational goals deviate from the assumed goals in the planning phase, a thorough analysis of the deviations and their impacts need to be done and fed back to the planning module to better understand future projects and the impact of the deviations.

This alludes to the circumstance that the Microgrid controller, used in the operation, has to follow the same mathematical principles and methodologies as in the conceptual design phase (but of course the objective can deviate as described above). Thus, suggesting an integrated approach that uses a single platform.

A very commonly used methodology to dispatch the Microgrid assets in a cost minimizing fashion are Model Predictive Control Methods (MPC) (Michael Stadler S. M., 2015) (Michael Zachar, 2016). These MPC methods collect weather forecasts, actual status of the DER technologies as operational levels or state of the charge, create load forecasts for the next 24 to 48 hours and optimize the operation by sending optimized instructions to the DER assets. This process will be repeated every 5 to 15 minutes with updated data and status information. By doing so, a rolling forecast and dispatch is generated that has, to some extent, forward looking capabilities and can deal with uncertainty. Here physical connections need to be made between

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the software platform and the DERs and data communication systems following the IEEE 2030.7 standard (IEEE, 2018).

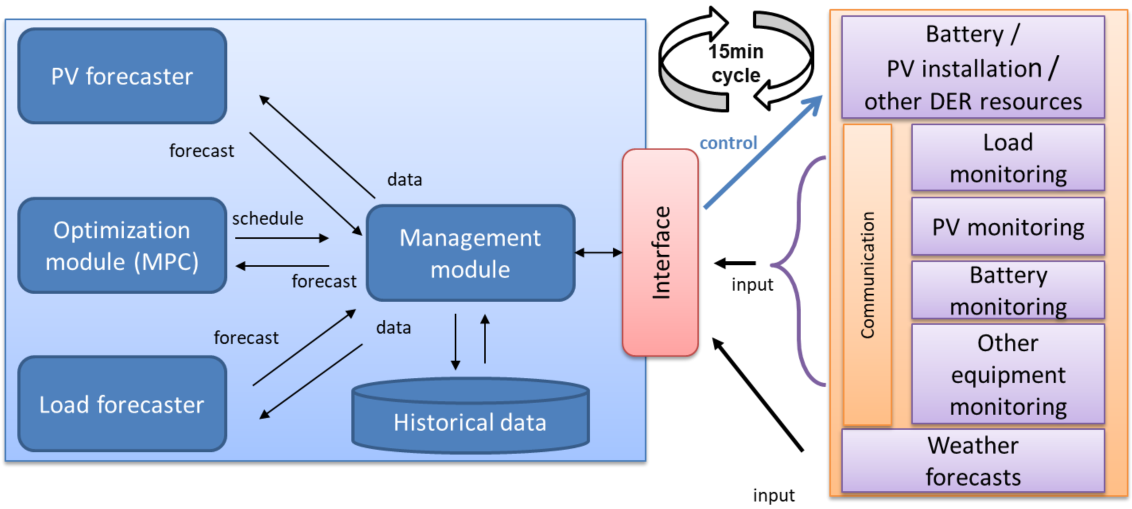

Figure 5: Model Predictive Control for DER and Microgrid Assets: In contrast to rule based approaches that follow some pre-defined strategies, MPC allows to "look into the future" and adapt to changed conditions in a better way. The optimization algorithm used in the MPC is the same algorithm as used in the conceptual phase, but uses real-time information instead of simulated data or assumed data. Open data communication systems are important to support such a software based Microgrid controller.

Simple rule based controller methodologies also exist to reduce the costs considerably, but of course this also reduces the precision since forward looking capabilities are mostly ignored (Stadler, 2018). Finally, the data collected from the operation should inform the operator to enable him/her to reduce unnecessary maintenance.

A major benefit of one single platform is that deviations in the operation and financial indicators (e.g. NPV) can be easily analyzed and fed-back to the conceptual design modules, creating the ultimate planning process, guaranteeing the most precision and accurate financial indicators.

Challenges with existing Financial Indicators

A very commonly used index in the electricity space is the LCOE: Levelized Costs of Electricity. The LCOE is a helpful indicator in the electricity industry that allows comparing multiple power plants and the relative electricity generation costs. A simple definition of the LCOE can be

LCOE = Costs/Generated Electricity ($/kWh).

Different time intervals can be applied and some define the LCOE over the whole lifetime of a power plant, for an individual year, or shorter periods. The costs typically include annualized capital costs, fuel costs, as well as maintenance costs, among others. Thus, the LCOE allows easy comparisons between different power plant investment options. It is obvious that intuition would suggest that a Microgrid LCOE can be compared with the utility electricity prices to determine if a Microgrid project is attractive.

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It turns out that this can become a difficult task for a Microgrid. There are multiple differences between a Microgrid and traditional power plants. A Microgrid

- can have multiple generation resource
- can serve multiple end-uses: electricity, heating, and cooling
- can purchase, generate, and sell electricity, heat, as well as cooling
- is mostly designed to minimize its energy costs and selling energy is not the primary goal.

The implication of this is that the LCOE actually can become Levelized Costs of Energy since it might be hard to link certain investments to the electricity or heating side. Such an example are CHP units for which the heat to power ratio can change over time, and with that, also how much costs should be associated with the electricity or heating side. In other words, the more we have heating or cooling services in a microgrid, the more the LCO-Electricity gets distorted and does not reflect the LCO-Electricity in a traditional sense anymore. Please note that the LCOE definition, as used by the utility industry, does not have any revenue streams in it (e.g. from sales) since the LCOE is an indicator for the minimum price the utility wants to achieve, when selling the electricity. For a Microgrid that generates, purchases, and sells energy this creates further complications. Let's assume that the major goal of a Microgrid is to minimize its energy costs, then we want to consider the sales in our revenue stream to improve the economics of the Microgrid, but this would also imply that we should subtract sales from the costs in the LCOE definition. However, this definition is conflicting with the traditional definition of the LCOE. Thus, the LCOE is not a good indicator to determine the economic attractiveness of a Microgrid project (Martin Mitscher, 2012), (EIA, 2019), (Jacqueline Yujia Tao, 2016). In any case, the usage of a LCOE to calculate the dispatch of multiple Microgrid assets is not accurate and needs to be solved by optimization methodologies.

Thus, the best approach to assess the economics of a DER or Microgrid project is to minimize the total energy costs (over the full lifetime) or NPV, including all investments for the electricity, heating, and cooling side, all fuel costs, operational costs, and of course sales and other revenues that the Microgrid has and compare that to a reference case: The reference case indicates the business as usual case, in which we supply the energy for the end-uses separately and not via a Microgrid. Such a total energy cost minimization naturally determines the unit commitment or dispatch of resources without the need of calculating the LCOE for decision making.

Reference costs could also be interpreted as the amount of money an investor is willing to pay, constituting an upper cost boundary. The goal then becomes to optimize against that boundary and find the cheapest solution, satisfying the energy needs of the Microgrid. When finished with this optimization, different economic indices can be *reported* and they can have different definitions, as discussed for the LCOE. However, then the user can chose which definition and index he or she uses to analyze the results, but the result is always most optimal and does not depend on the definition of the economic index.

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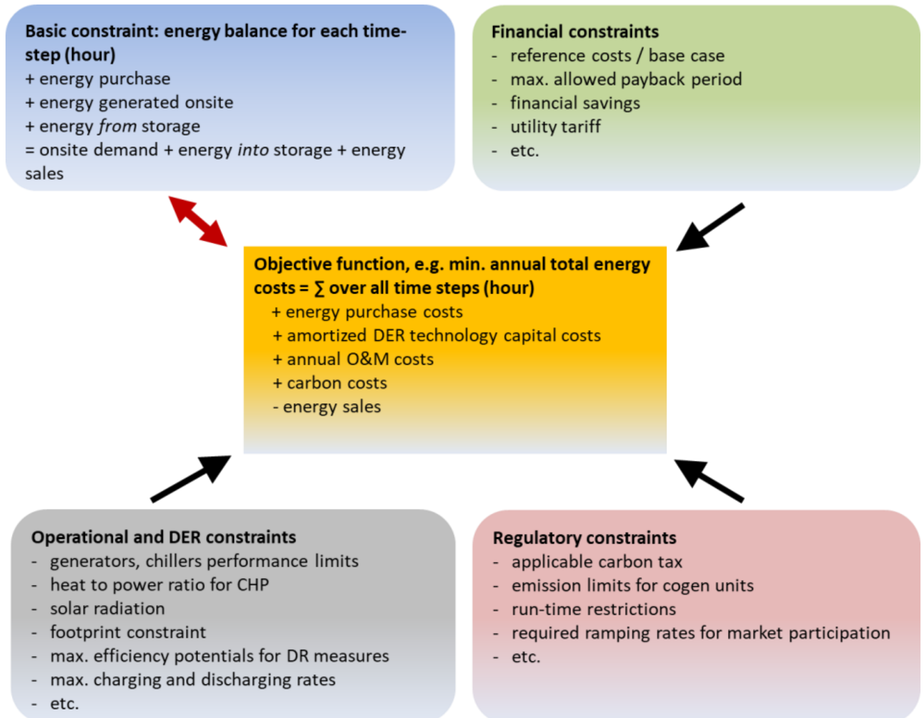

Figure 6: High Level Economic Optimization Model for the Conceptual Design Phase. To minimize the annual energy costs for a Microgrid it is useful to set reference costs (e.g. costs of energy without a Microgrid) and optimize the energy balance subject to other constraints, making sure that every solution for the selected technologies and associated dispatch meets the constraints and reference costs. There is an important relationship between the energy balance and objective function. The optimization algorithm and solver have a lot of flexibility by "playing" around with the millions of combinations of technology choices and dispatch choices (e.g. when to turn on and off the technologies). Thus, this process naturally, delivers the most optimal dispatch in an automated fashion. More details on such optimization techniques can be found a (Salman Mashayekh, 2018)

Overcoming Siloed Tools:

A forthcoming report analyzed 31 different Microgrid/DER, design, power flow, and transient tools showing that there are a lot of tools emerging (Zack Pecenak, forthcoming). Another overview of simulation and optimization tools in the Microgrid space can be found at (Peter Tozzi Jr., 2017). However, most of them are either purposed for academic usage or are black boxes that cannot be easily integrated into one platform and married with power flow capabilities or transient analyses features. Each tool analyzed has been designed for a specific application and has challenges to capture the whole market needs.

As laid out in the previous chapters, one single tool would be very beneficial to enable effective Microgrid/DER design and deployment. BankableEnergy |XENDEE Inc (BankableEnergy, 2018) has been looking into this challenge during the last six years and tested multiple approaches, technologies, and algorithms and after an exhaustive research effort, decided to integrate OpenDSS and DER-CAM, in one platform and added IEEE/ANSI and IEC fault analysis, device evaluation, and

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management/implementation capabilites to support bankable solutions. Currently, transient analysis are being added to the platform.

The structure of DER-CAM allowed for changes and additions of features, which are needed by the Microgrid and DER community. One such needed change is a fast and reliable real multi-year optimization, which allows for changes in technology prices, tariffs, among others over time (Zachary K. Pecenak, forthcoming).

The Ultimate Microgrid Software

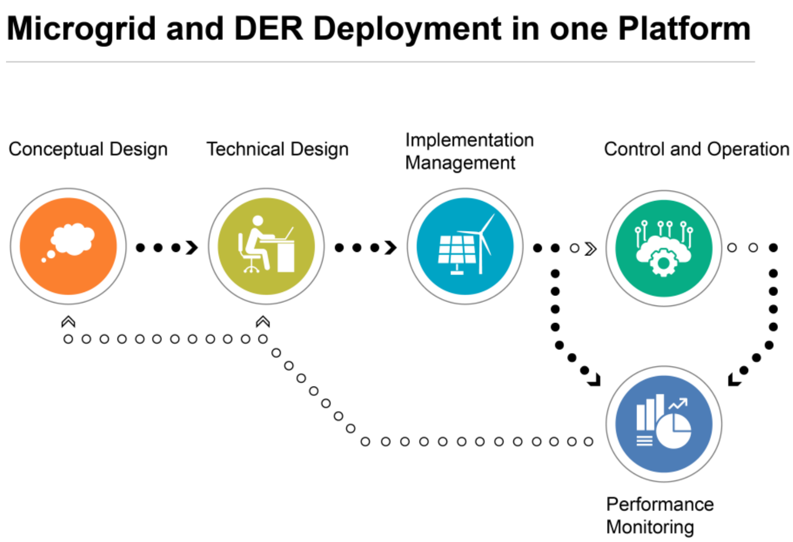

Figure 7: Holistic Microgrid Planning, Implementation, and Operation Process. All steps needed to build and operate a DER or Microgrid project should be integration in one single software platform allowing for informed decisions and easy data sharing.

Based on the considerations in the previous sections the optimal Microgrid software system needs to incorporate the described single steps into one platform, using mathematical optimization techniques for the conceptual design phase, marry it with power flow, transient, management, and operational features and capabilities following similar methodologies as in the conceptual design phase (Figure 7).

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