EVALUATING VALUE PROPOSITION OF MICROGRIDS FOR UTILITIES

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ABSTRACT

At present, the market is seeing utility scale Wind plants, PV Plants and even Battery Storage systems, but not a utility scale Microgrids. There are a number of reasons for this, and as with other technologies at their beginnings, microgrid value proposition for utilities still needs to be proven. This paper presents a methodology for evaluating the value proposition for the microgrids by a comprehensive techno-economic calculation based on economic dispatch optimization of Consumer specific solution in two options: Grid only energy supply vs Microgrid. Only with a detailed study of both options which takes into consideration technical specifications and constraints of all included assets on one side and financial parameters (CAPEX, OPEX) on the other side is it possible to determine a real value of a Microgrid.

INTRODUCTION

Microgrids present electricity market segment which has existed for a long time but only recently gained much deserved focus. There are number of definitions of what a Microgrid exactly presents in the electrical system and this further reflects on market sub-segmentation. If a broader definition is taken where microgrids include integration of decentralized energy resources with own energy management, it is still very challenging to evaluate the microgrid value proposition for the DSOs/utilities. Almost all recent studies and pilot projects of microgrids which are driven from DSO side have been focused on the technical challenges of the grids. New business models evaluated were therefore in the same way focused on the DSO side of the value proposition. Large part of this involves Local Flexibility Markets (LFM).

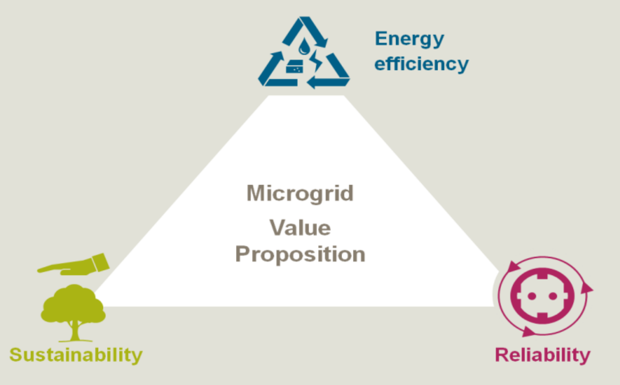

Figure 1 – Microgrid value proposition for end consumers

From the perspective of end consumers, Microgrid market can be sub-segmented into following main categories: *Islands, Campuses, Communities, Critical infrastructures and Commercial and Industrial segments*. Building and managing a microgrid requires a significant effort and investment on the consumer side, hence their motives at the same time also define the microgrid value proposition. We find these in three focus areas (Figure 1): *Reliability, Sustainability and Energy efficiency*. From the very definition of the microgrid it is presumed that all of these are managing their own energy consumption and production in a way which is optimal for them hence reducing the energy import costs. From this perspective microgrids are conflicting with utility business targets. Furthermore, in most countries there is still a weekly developed or even completely missing regulatory framework which treats microgrids. Therefore, there are genuine concerns on utility side how microgrids affect the grid stability, especially on the low voltage levels. While these threats present genuine challenges, they are not to be mistaken with utility microgrid value propositions, and they often are. With a diverse generation mix of all types of DER, microgrids can inherently implement control strategies of all their integrated DER individually and as a optimal mix. Therefore, microgrids inherently also encompass all their business models, or are at least capable of implementing them. In this work we present and evaluate a business case of microgrids from the end consumer perspective which at same time can be fully served by the utilities, hence inventing business models which best serve both sides. We use technical models of distributed energy resources, historical customer load and weather data as well as utility tariff model together with financial parameters and simulate microgrid energy management control over a period of one year to determine the optimal business case for the end consumer, having at the same time a value proposition for the utility. Microgrid energy management system (Figure 2) uses optimal economic dispatch algorithm to calculate the optimal energy mix from all the assets in the microgrid at every single point in time.

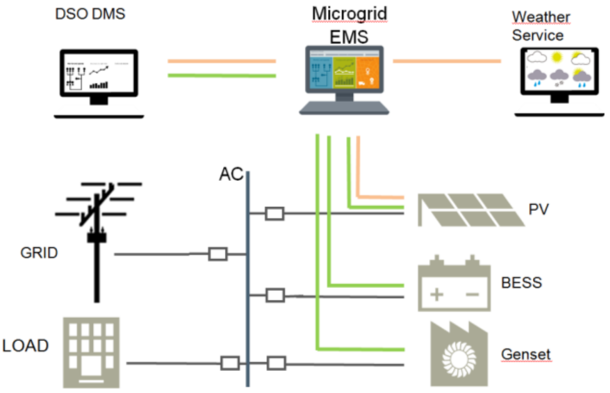

Figure 2 – Microgrid management system

For each business model we define conventional utility grid supply model and a microgrid model, simulate them and compare to show how it fulfils the business case for the end consumer. Finally, we evaluate and show how a utility can provide the needed microgrid functionality and at the same time achieve own technical and business goals.

MICROGRID STANDARDS

Standards which define guidelines and requirements for Microgrids and their integration into the energy system have only recently been finalized. Although technical and generalized as much as possible to accommodate for all grid codes, standards provide a basis for building the business cases as well. Table 1 presents the list of most relevant standards which directly or indirectly define guidelines for microgrid development, testing and control. IEEE Std 1547 only indirectly treats microgrids because it directly regulates DER.

Ref/Standard	Description
[1] IEEE Std 2030.7	Specification of Microgrid Controllers
[2] IEEE Std 2030.8	Testing of Microgrid Controllers
[3] IEEE Std 1547	Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
[4] IEEE P 2030.10	Standard for DC microgrids for rural and remote electricity access applications
[5] IEC/TS 62898-1	Microgrids – Guidelines for microgrid projects planning and specification
[6] IEC/TS 62898-2	Microgrids- Guidelines for Microgrid Operation (and Control)
[7] IEC/TS 62898-3-1 ED1	Microgrids-Technical Requirements - Protection and Dynamic Control

Table 1 – Microgrid standards

While standards define the guidelines and methodology for the whole lifecycle of microgrids, they still do not define the clear values and limits of operations because these depend on grid codes and regulatory frameworks, which can differ from region to region.

Operation mode	Responsibility Authority
Grid connected mode	DSO Grid Code / Local electricity market
Transition mode	DSO Grid Code / Local electricity market
Islanded mode	End customer

Table 2 – Microgrid operation modes

Standards do however define a clear split of responsibility depending on the operation mode of the microgrid, as shown in Table 2.

Power balance, Voltage and Frequency control, Fault levels, Power quality are all to be set by the utility grid code and local electricity market regulation when microgrid is in grid connected mode, but when islanded, the end customer can adjust those independent of it. One exception to this is Pollution/CO2 emissions which may also be externally regulated in Islanded mode. This setup has very significant influence on business model evaluation for each microgrid stakeholder.

REGULATORY FRAMEWORKS

Despite the fact, that the way how microgrids are being deployed and operated has begun to be standardized, corresponding regulatory frameworks and policies for the interconnection of these microgrids with the distribution grid or the standalone operation and the related business models are still missing in a lot of countries. Implementation and operation often depend on long lasting upfront discussions and negotiations with grid operators and/or public authorities. In some countries, especially the ones with already high penetration rates of distributed energy resources (DER), like Germany, rules and regulations do exist. In every case a country by country and in some cases, like the United States of America a state by state evaluation have to be performed in order to figure out which rules and regulations are applicable for the specific microgrid dependent on the type of its generation resources. Different levies and fees might apply for the different sources. Furthermore, in some cases, like in Germany, even the maximum generation capacity of the DERs and/or the capacity of the point of common coupling are influencing critical factors for the business model and the financial viability. A good overview about policies and regulations formulated for the European Union (EU) the United States of America and China, which represents mayor markets for microgrids, are documented in [8].

STAKEHOLDERS

There are a number of different business models with different stakeholders in microgrid projects. A comprehensive layered map of different stakeholders which can be involved in microgrid projects is presented on Figure 3. Depending on the local regulation, utilities can often take the roles of almost all other stakeholders accumulating their potential business value. When evaluating the Microgrid business case as well as Grid operations which can also have multiple entities involved, it is necessary to have a clear split of investment and cost, to obtain a value proposition for each one of those stakeholders

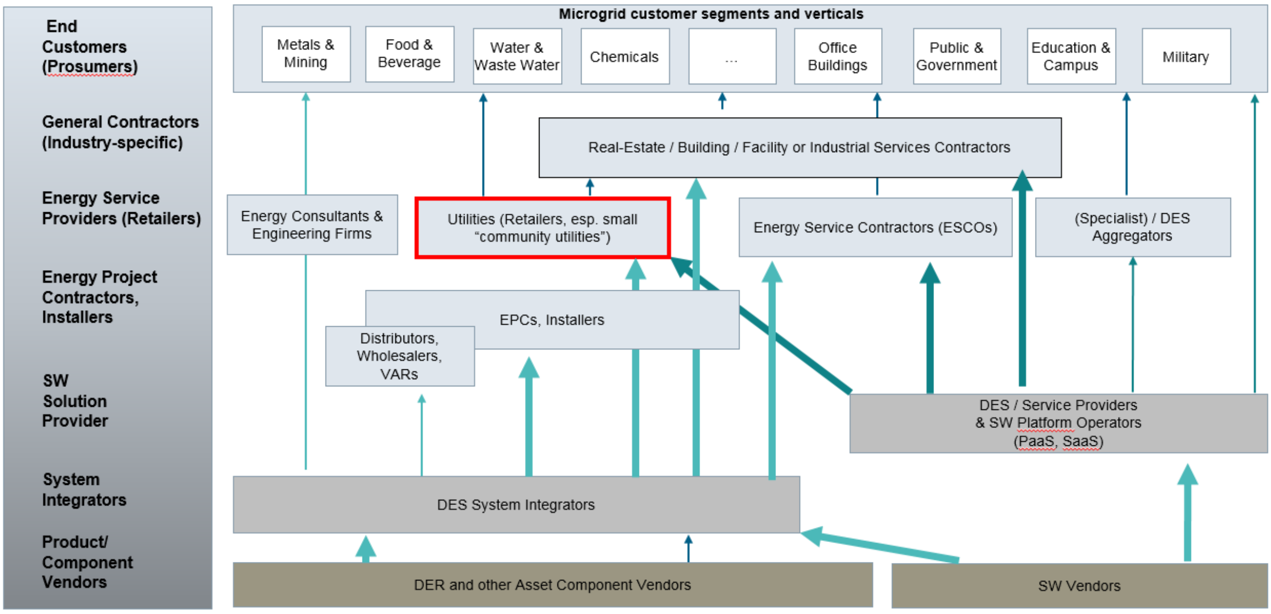

Figure 3 – A comprehensive stakeholder map for microgrid projects

EVALUATING THE VALUE PROPOSITION

Value of the Microid is determined by a techno-economic calculation which takes into account both technical and financial parameters of the two options:

1. Grid supply only

2. Microgrid

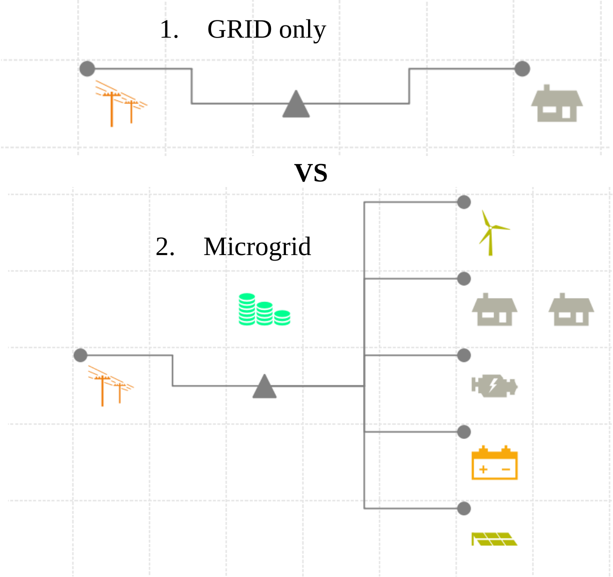

Figure 4 – Topology of a Grid only vs Microgrid solution

The second option named Microgrid does not mean that it is run in Islanded mode at all times, but only when the Microgrid controller or the operator decides to use that operation mode. This can, by all means, be only during blackouts, or when it is more feasible than the grid, or even at all times. **Evaluation Period** is a period over which the business case for both options is compared. This is normally determined by the target ROI and life-time of the most valuable assets. For example, if a utility needs to compare an undersee cable or new transmission feeder investment vs Microgrid, the lifetime of the those would set the Evaluation period, even though there would have to be certain asset replacements of lower value assets such as BESS for Microgrid.

Input data

Evaluating both options requires input data some of which is to be supplied as time-series over a period of time and some as technical values. As the evaluation period normally runs over a number of years, even decades, the data may need to be interpolated to match the evaluation period. Most time series data have dependency on seasons and weather, so it is highly recommended to use data acquired over a period of at least 1 year. Time step size is also important, and the smaller it is the better. At least hourly values are needed. Measurement precision directly affects the quality of results. Following input data is needed:

Consumer Load and Generation data is a historical time series of consumer load over a period of time, preferably at least 1year. Generation data includes a measured time series of existing generation whether it is from renewables or conventional generators. This data provides a very valuable insight in number and duration of outages but also the dynamics of the Load changes.

Weather Data

In order to account for any newly installed DER, especially renewable sources, it is necessary to obtain the weather data for the consumer's location. This includes time series measurement data for temperature, solar radiation (diffuse and direct), wind speed and direction. Example shown on Figure 5.

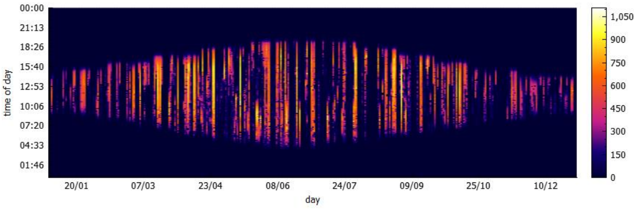

Figure 5 – Solar radiation heat diagram

Tariff Data

To be able to evaluate the cost of energy from the grid at all times, a time series Tariff data is needed for both options. Depending on the utility, the tariff data can be static or dynamic (spot market) and fairly complex in structure. Over the billing period and even within a single day it can significantly change, even to become negative at times. It can include a number of different charges, such as demand charges, transport charges, renewable charges etc. It can also include incentives. However complex tariff may be it is absolutely crucial to properly model it to calculate both options with proper price per kWh.

Technical Data

Technical data includes detailed technical specification of all DER assets in a Microgrid. For example, a single diesel generator would have over 20 technical parameters which include generation capacity as maximum and minimum output power, number of allowed starts and stops per day, efficiency curves, overload and underload capacity and even scheduled maintenance periods.

Financial Data

Financial data include CAPEX and OPEX of the complete solution. Apart from the cost of all assets, CAPEX has to account all development, building and deployment costs in both options with appropriate assignment to all stakeholders involved. Evaluation period must be considered in sense that CAPEX has to account for all asset replacements and OPEX needs to include maintenance costs over the entire period. Financial data also includes cost of fuel for any conventional generation. Additionally, for the Grid only option, outage penalties on the side of the utility as well as outage induced losses on the consumer side have to be taken into account. Finally cost of financing as well as any involved interest and discounts rates which can be calculated into a WACC have to be considered.

Evaluation methodology

Evaluation of both options requires a cost-based calculation through simulation of real-time operation of both cases. This means to calculate at every single point in time over the evaluation period what the cost of energy is for the end consumer as well as the utility, including all of the above mentioned technical and financial input data. Both options are to be considered at their optimal and at the same time realistic operation states. Microgrid option itself first has to be optimally designed and optimally sized. This means that the there is the optimal generation mix of all DER in a microgrid with the optimal size. This evaluation is done with the same method. Since the evaluation period can be very long different scenarios have to be additionally evaluated to account for potential changes in Load, Weather, Tariff, Fuel costs and OPEX. These variations are to be selectively chosen based on the long-term estimations.

The calculation method to be used is a cost-based optimization of economic dispatch. Calculation must be done over a full evaluation period and is a minimization function:

Minimize:

$$C_E = \sum_{t=1}^{t=N} \left[\left(C_{REN}^t P_{REN}^t \right) + C_{ESS}^t \left(|P_{ESS}^{+t}| + |P_{ESS}^{-t}| \right) + \left(C_g^t P_g^t \right) + \left(C_G^t P_G^t \right) \right]$$

$C_{REN}^t, C_{ESS}^t, C_g^t, C_G^t$ – Cost of energy coefficients
P_{REN}^t - power produced by renewables PV or Wind
P_{ESS}^{+t} - power produced by BESS when discharging
P_{ESS}^{-t} - power consumed by BESS when charging
P_g^t - power generated by conventional generators
P_G^t - power imported from the grid
N – Total number of time steps (e.g. 8760h per year)

Subject to following constraints:

- Unit capacity limits: the output of each unit must be within its minimum and maximum limits
- Ramp rates: output of each unit cannot change more than allowed by the ramp rate
- BESS state of charge within the limits
- Equality constraint: The total power output must match the load for each time interval
- Overproduction of renewables is curtailed to avoid the no solution problem

There are several methods for solving the optimization function where Greedy dispatch algorithm or Mixed integer programming are the fastest. Commercial tools which incorporate these are available on the market.

BUSINESS CASE SCENARIOS

Here we present a business case calculation for the utility microgrid vs. distribution grid extension. Very often, under normal conditions, even basic calculation shows that the microgrid business case is infeasible to the grid extension. There are however specific conditions which make the microgrid a better business case or even the only possible solution. Those special conditions are all separate business cases and some of those are following:

Undersea - Marine cable extension for islands

For islands which are connected to the grid via undersea cables replacement always has a high cost. Depending on the number of customers on the island and island's distance from the shore, microgrid may be more feasible.

Old city areas (protected heritage)

Grid extension in old city parts, and especially protected sites is often not possible, so installing DER on the customer side in a managed microgrid can solve the problem.

Remote continental areas

Very remote villages, towns and industries which reach their capacity limit may require whole new feeder, maybe even on transmission level. Installing a microgrid instead ca be more feasible.

Critical industries with high cost of blackouts

Some Industrial and commercial customers have large costs of outages and these are passed onto utilities via penalties. Microgrids may provide the needed resilience under the positive business case.

BUSINESS CASE OF ISLAND MICROGRIDS

We take example of an island in Norway, connected to the grid via undersea cable which needs a replacement. We evaluate the business case of a microgrid vs cable replacement. Utility is obliged by the law to supply all inhabited islands with electricity independent of its population, and at the same price as if they were on shore. The undersea cable has a lifetime of 40 years and must be replaced every 35 years. Microgrid DER are Diesel generator, Wind turbine, PV plant and a Battery under the control of Microgrid controller, as shown on Figure 4. (the microgrid is connected to the grid after the installation until the existing cable breaks). Table 3 shows the replacement periods of all assets in both scenarios.

Year	GRID	Microgrid
1	Cable	DG, WT, CTRL, BATT
11		DG, BATT
21		DG, WT, CTRL
25		BATT
35	Cable	DG
40	Salvage	Salvage

Table 3 – Replacement periods

Using the above-mentioned input data and methodology with standard framework of finance within a proprietary software solution Siemens PSS DE, we model both scenarios and simulate them over the period of 40 years. The results obtained are generalized from the real-life business case evaluation and presented in Table 4.

	1. Cable	2. MG	3. MG+Cable
COE (€/kWh)	0.34	0.31	0.27
NPC (€)	3,600,000	3,500,000	2,900,000
Operating cost (€)	45,000	115,000	85,000
Initial capital (€)	2,900,000	1,900,000	1,500,000
Fuel cost (€)		40,000	32,000
O&M (€)	27,329	19,500	15,000
Elec Prod (kWh/yr)	750,000	1,400,000	1,400,000
Elec Cons (kWh/yr)	750,000	750,000	750,000
Excess energy	0	650,000	650,000

Table 4 – Business Case simulation results

CONCLUSION

As it can be seen in Table 4. the cost of energy is very high in all scenarios and exceeds by far the low cost of energy in 98% renewable Norway. However, this cost is driven by the CAPEX of the Island case, and when scenarios are compared Migrogrid provides a better business case than cable replacement. It requires a much lower initial capital and with the assumption that replacement costs will sink over the next 40 years, DER technology improve, it has a clear advantage. Furthermore, it can be seen that in microgrid case there is a very significant amount of over-production, due to the dimensioning of the Microgrid to provide the stable supply. Scenario 3 is made to account for selling this excessive energy back through the cable for 10 years assuming it continues to live so long additionally improving the microgrid business case.

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