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MSG Micro Smart Grid EUREF

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MODEL-BASED QUANTIFICATION OF A MICROGRID VIA KEY PERFORMANCE INDICATORS

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Microgrids

Microgrids (MGs) are aggregations of distributed generators (DGs), such as photovoltaic (PV) power plants, small wind turbines (SWTs) and combined heat-and-power (CHP) units, electric energy storages (ESS), electric vehicles (EVs), electric demands e.g. from buildings, and further energy dimensions, for instance thermal energy or natural gas.

For a further MG deployment, economical, technical and ecological key figures, named key performance indicators (KPI), have to be quantified in order to assess the value of a microgrid in comparison with other upcoming energy technologies.

Energy System Model

For examining the economic and ecologic values of the microgrid, a microgrid energy system model has been developed using Matlab/Simulink and named Simulation Model for Optimized Operation and Topology of Electric and Thermal Energy Systems (SMOOTH).

Key characteristics of SMOOTH are:

- Time step model: Resolution of data is variable (used here: hourly), analysis horizon is one year
- Weather data for irradiance and wind speed is used (Data of 2013 is used here)
- Different energy flows are regarded, especially electric and thermal energy, (e.g. in CHP plants)
- Economic dispatch algorithm for commitment of dispatchable microgrid components, such as stationary ESS or CHP plants, is used

Economic Dispatch Algorithm

Each operating point of each dispatchable component is attached with operating costs. By linearizing the component behavior, a linear equation system for each time step is built and solved, choosing the operating point for each component which is cost-optimal for the whole microgrid system.

This approach combines decentral and central MG control elements, as individual component behavior as well as cost optimality of the entire microgrid in each time step is regarded.

Energy constraints for electric and thermal energy have to be fulfilled in every time step for every component k with a total of n microgrid components in the setup:

$$\sum_{k=1}^{n} E_{el,k} = 0 \qquad \sum_{k=1}^{n} E_{th,k} = 0$$

Economic KPIs

Levelized cost of electricity (LCOE) is a wide-spread key figure to assess the economic value of a microgrid. By taking capital expenditures and operation expenditures into account, the annuity method is applied and annuities are and divided by the annual energy consumption of the microgrid:

$$LCOE = \frac{\text{Capex} \times \text{CRF(WACC, N)} + \text{Opex} + Costs_{fuel} \times Fuel}{E_{demand}}$$

$$CRF(WACC, N) = \frac{\text{WACC} * (1 + WACC)^N}{(1 + WACC)^N - 1}$$

$$WACC = \frac{\text{E}}{\text{E + D}} \times k_E + \frac{\text{D}}{\text{E + D}} \times k_D$$

LCOM is a figure which is designed to assess the economic value of implementing and operating an electric vehicle fleet. This value comprises the investment in EVs as well as in the necessary electric vehicle supply equipment (EVSE) and takes energy prices as variable operating expenditures into account.

$$LCOM = \frac{\text{Capex}_{EV} \times \text{CRF(WACC, N}_{EV})_{EV} + \text{Opex}_{\text{EV,fix}} + \text{Opex}_{\text{EV,var}} + \text{Capex}_{EVSE} \times \text{CRF(WACC, N}_{EVSE})_{EVSE} + \text{Opex}_{EVSE,fix}}{\text{FD}}$$

Ecologic & Autonomy KPIs

To assess the ecologic impact of energy generation, specific CO_2 emissions on supplied microgrid energy are a reasonable figure to compare microgrid energy generation with bulk generation and further energy technologies.

$$Spec\_Emission_{CO_2,Energy} = \frac{\sum_{c=1}^{n} \text{CO}_2 factor_C \times E_c}{E_{MG,total}}$$

$$Spec\_Emission_{CO_2,EV} = \frac{Spec\_Emission_{CO_2,Energy} \times E_{Consumption,EV}}{\text{FD}} = Spec\_Emission_{CO_2,Energy} \times C_{EV}$$

Several degrees of autonomy have been defined to assess the value of microgrid autonomy. To capture the microgrid energy autonomy, three autonomy KPIs have been developed:

$$AE = 1 - \frac{E_{MV,Supply} + E_{MV,Feedin}}{E_{MG,Generation} + E_{MG,Demand}}$$

$$EAE = \frac{AE}{LCOE}$$

$$AT = \frac{\sum_{t=1}^{n} (P_{PCC} = 0)}{\sum t}$$

Microgrid Components

Type	Qty.	Characteristics and Parameters
PV	4	Installed power capacities: 19.9, 22.62, 23.4, 60 kWp, Mono CSI technology Life time: 20 years, Capex: 1,500 to 7,000 €/kWp, Opex: 25 €/(kWp x a) Specific CO_2 emissions: 52 g/kWh
SWT	4	Installed power capacities: 4 x 1.2 kW, Hub height: 75 m (2x), 28 m (2x), Specific CO_2 emissions: 8 g/kWh Lifetime: 20 years, Capex: 13,500 €/kW (2x), 11,500 €/kW (2x), Opex: 225 €/(kW x a)
CHP	1	Installed power capacity: 22 kW_{el} Operated by biomethane, Heat-driven operation (Constraint in dispatch) Specific CO_2 emissions: 78.3 g/kWh with biomethane, 500 kW_{el} CHP and degree of efficiency of 36.5 %
ESS	3	Technologies: Li-Ion, Pb, Supercap Capacities: 78 kWh (Li-Ion), 90 kWh (Pb), 3 kWh (Supercap) Capex: 2,500 €/kWh (Li-Ion), 500 €/kWh(Pb), 30,000 €/kWh(Supercap) Opex:25 €/kW (Pb), 30 €/kW (Li-Ion & Supercap) Roundtrip efficiencies: 69 % (Pb), 90% (Li-Ion), 96% (Supercap)
IH (P2H)	1	Installed power capacity: 10 kW_{el}
Buil-dings	5	Mainly standard load profiles (SLP); Total energy demand: ca. 400 MWh/a
EV	10	Fleet Distance (FD): 100,000 km/a, Specific vehicle consumption: 15 kWh/100km Capex fleet: 10 x 40,000 €, Opex fleet: 10 x 2,000 €/a Interest rates: 3% on equity, 8% on debt, Equity ratio on capex: 40% Life time vehicle: 8 years
EVSE	21	21 (Charging stations), Capex: 21 x 5,000 €, Opex: 21 x 250 €/a Interest rates: 3% on equity, 8% on debt, Equity ratio on capex: 40% , Life time: 20 years
Sys-tem	-	Location: 52.5N, 13.4E Specific CO_2 emissions MV grid supply: 576 g/kWh (Germany 2012) Interest rates: 3% on equity, 8% on debt, Equity ratio on capex: 40% MG life time: 20 years Grid and energy distribution expenditures: Capex: 100,000 € , Opex: 10,000 €/a Information and communication technology (ICT) exp., Capex: 18,000 €, Opex: 180 €/a

Table 1: Considered MG component types, quantities and component parameters

Setups & Results

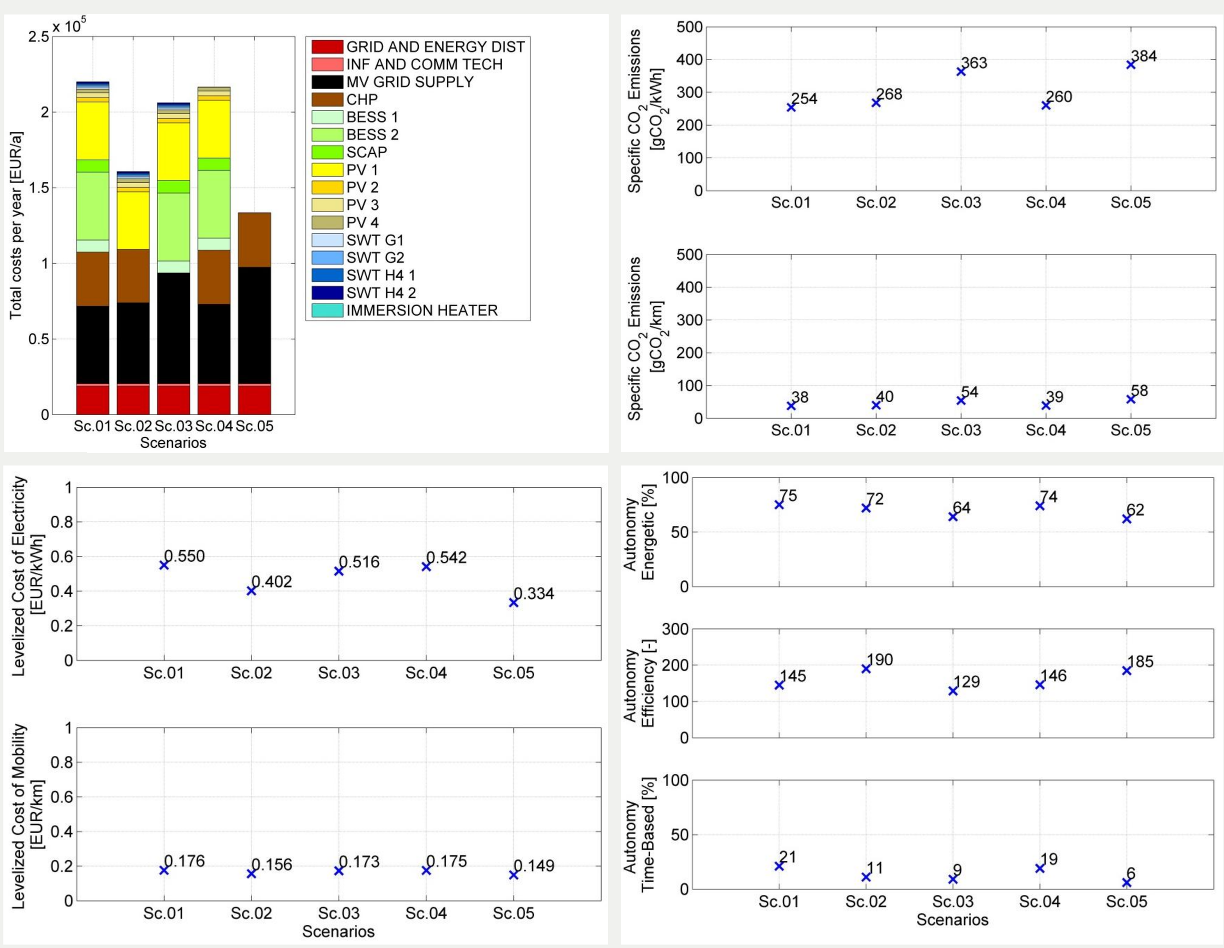
Table 2: Analyzed Microgrid setups.

Description	MG Current Status	MG without ESS	MG without CHP	MG without SWT	MG CHP only
Abbreviation	Scen 01	Scen 02	Scen 03	Scen 04	Scen 05

From figures 1-4, it is obvious that the considered MG components are not adequate for a complete self-sufficiency of the MG, given the high amount of the utility grid supply in total costs. This is mainly due to consumptions of the MG buildings which are higher than DG generation in the considered MG setups.

However, all MG setups reach substantially lower specific CO_2 emissions than the German electric energy mix in 2013. Specific vehicle CO_2 emissions of EVs are as well substantially below comparable Diesel- and gas-fueled ICE vehicle technologies from recent years.

Energetic autonomy values are between 62 (CHP-only) and 75 % (PV, SWT, CHP and ESS) in the regarded setups, emphasizing the key role of the CHP plant.



Figures 1-4: Economic, ecologic and autonomy results for five microgrid setups

Conclusion & Acknowledgement

The developed KPI system has been applied on five different setups of Berlin-based microgrids within a microgrid energy system model containing a short-term economic dispatch algorithm. The KPI system has been proven as an evaluation system for microgrids in terms of economy, ecology and autonomy. However, technical issues, e.g. power and energy generation ratios, e.g. load/generation ratio, line losses or power flow, could be quantified by other key figures. Further research in the economic area are will include fixed feedin tariffs and market participation of microgrids in order to lower LCOE values and enable a higher competitiveness of microgrids in comparison to other energy technologies.

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