Optimal Design of Hybrid AC/DC Microgrids

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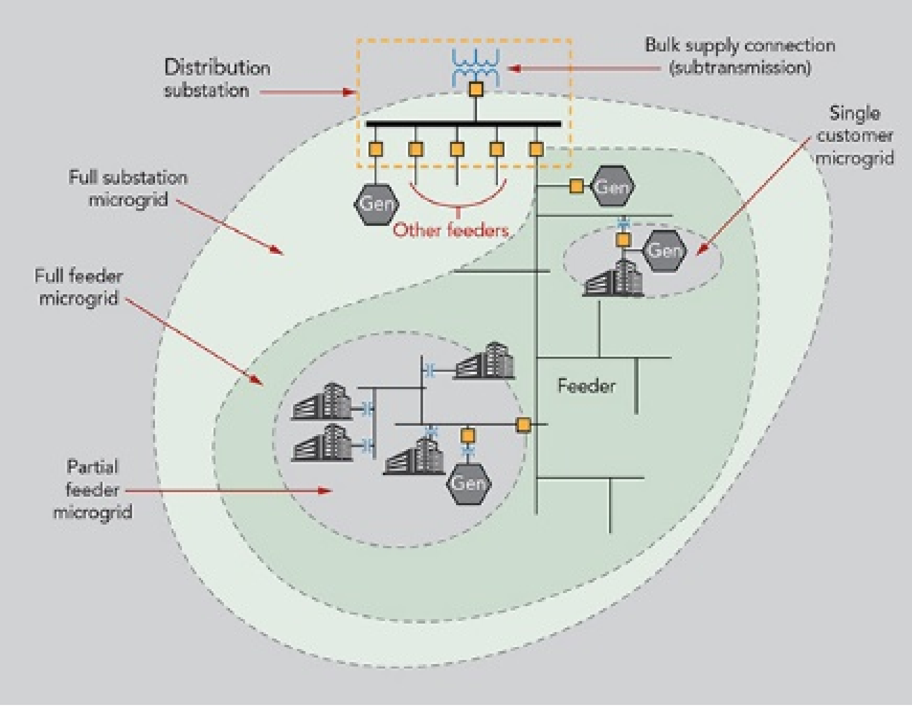
Microgrid definition

- By US DOE: A group of interconnected loads and Distributed Energy Resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid, and can operate in grid-connected and island-mode

Characteristics:

- The electrical boundaries must be clearly defined
- There must be a controller to dispatch DERs and maintain voltage and frequency within acceptable limits
- The aggregated installed capacity must be adequate to supply critical demand (islanding)



Source: Sandia National Laboratory

Significance of Planning Models

- Microgrids offer unprecedented economic and reliability benefits to electricity operators and consumers.
- These benefits must be scrutinized and compared with the microgrid investment cost for ensuring a complete return on investment and further justify microgrid deployments.
- An accurate assessment of microgrid economic benefits is a challenging:
  - Significant uncertain data involved in the assessment
  - Some factors are not easy to comprehend for consumers, such as reliability

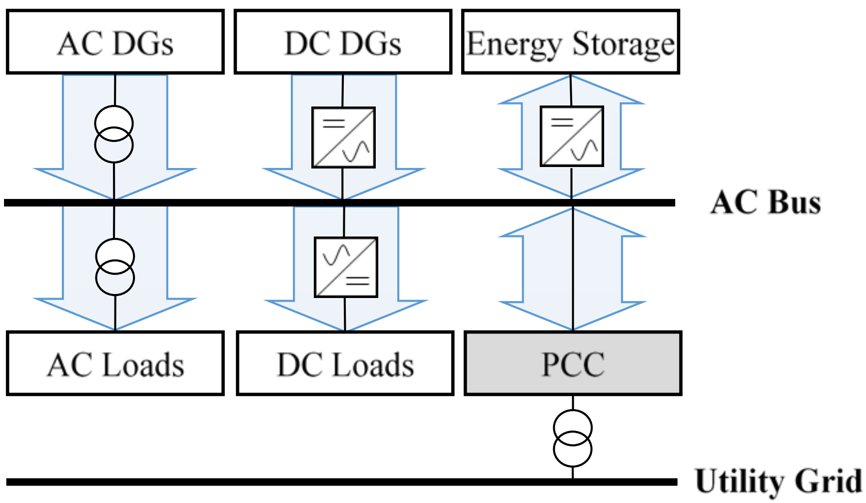
→ Efficient planning models are required for ensuring the economic viability of microgrid deployments and further justifying investments based on cost-worth analyses in uncertain conditions.

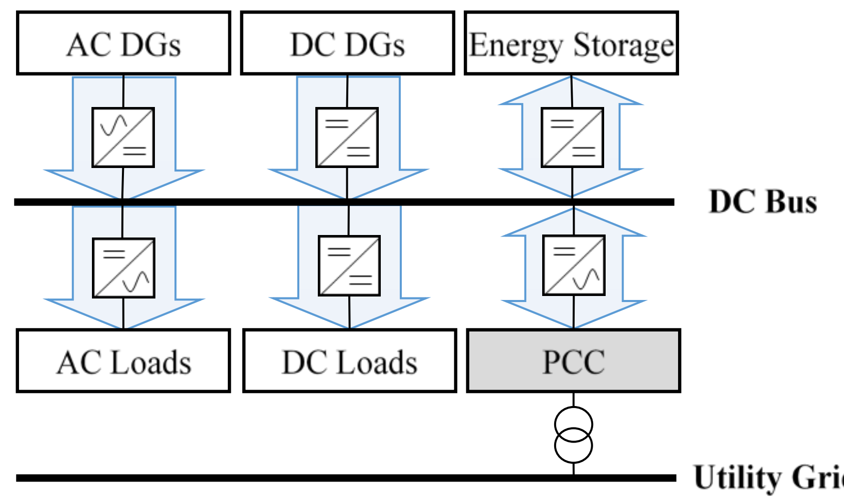
Different categories of Microgrids

- Microgrids can be categorized into different groups based on the
  - type (such as campus, military, residential, commercial, and industrial),
  - size (such as small, medium, and large microgrids),
  - application (such as premium power, resilience-oriented, loss reduction, etc.),
  - connectivity (remote and grid-connected), and
  - voltages and currents adopted in a microgrid **(AC, DC, and hybrid)**.

AC and DC Microgrids

- In AC microgrids, all DERs and loads are connected to a common AC bus.
- In DC microgrids, however, the common bus is DC, where AC-to-DC rectifiers are used for connecting AC generating units, and DC-to-AC inverters are used for supplying AC loads.





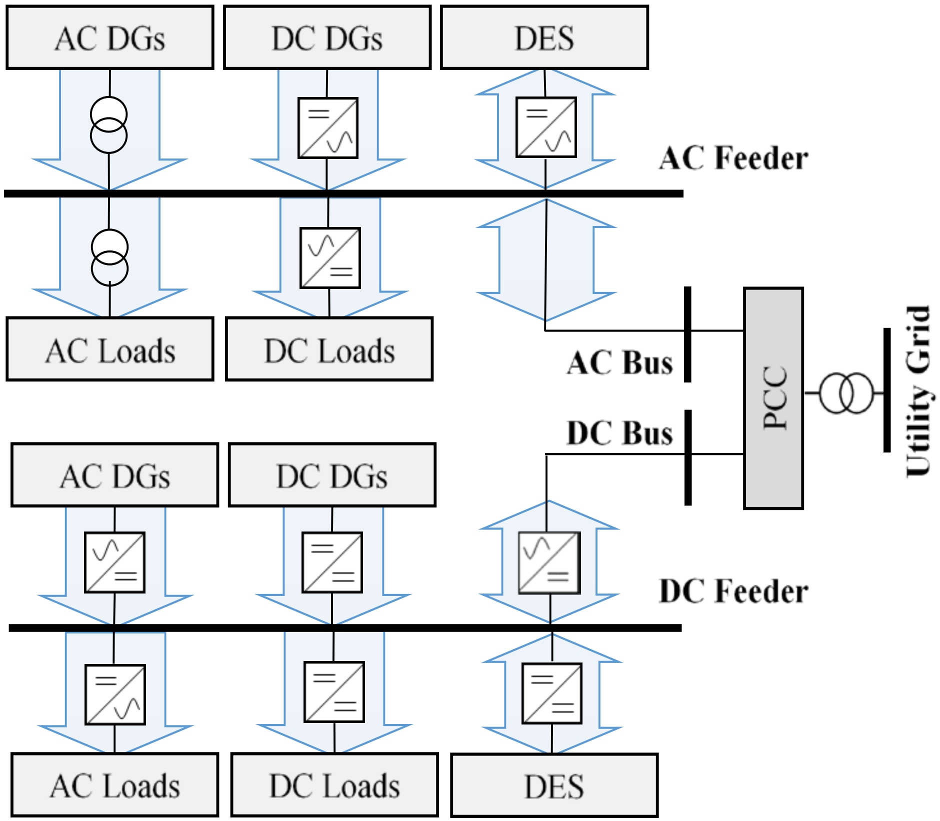
Hybrid Microgrids

- Similar to the traditional approach in expanding power systems, most microgrids are designed to be AC.
- DC microgrids, however, could potentially be more economical and efficient.
  - Most notably, facilitate the integration of DC DERs and eliminate the need for synchronizing generators.

- Hybrid microgrids are introduced to take advantage of both AC and DC microgrids by eliminating multiple converters that further leads to efficient use of DERs, reduction in power conversion losses, and a more efficient supply of loads.
- In hybrid microgrids, both AC and DC buses exist

Hybrid Microgrids

- AC and DC feeders are respectively connected to a main AC and DC bus.
- Loads and DERs should be connected to feeders using appropriate converters.
- Similarly, the connection between similar type of components and feeders necessitates a transformer or converter to provide the desired voltage level.



Problem Statement and Objective

- A static microgrid planning model is proposed while extending the previous work of authors from **AC or DC microgrid planning** to the **Hybrid microgrid planning**.
- The static planning model finds the optimal investments in only one (or limited) snapshot(s) of the planning horizon. That is, the time of the installations is overlooked in static models, and the problem is solved for limited snapshots.

- The proposed planning model determines:
  - the optimal DER size and generation mix,
  - the optimal type of each feeder, i.e., AC or DC,
  - and the point of connection of each DER to feeders based on the type of connection.

Planning Model – Formulation

- The objective is to minimize the microgrid total planning cost:
- Min (IC+OC+RC)

    - IC: the investment cost of DGs and converters
    - OC: the operation cost of dispatchable DGs and the energy exchange with the utility grid
    - RC: the cost of unserved energy

Planning Model

- The investment cost can be represented as:

$$IC = \sum_t \sum_k \sum_{i \in G} C_{1,ikt} x_{ik} + \sum_t \sum_k \sum_{i \in G_{ac}} C_{2,ikt} x_{ik} z_k +$$
$$\sum_t \sum_k \sum_{i \in G_{dc}} C_{3,ikt} x_{ik} (1 - z_k) + \sum_t \sum_k C_{4,kt} z_k + \sum_t \sum_k C_{5,kt} (1 - z_k)$$

Where

- C_1: The investment cost of DERs,
- C_2: The cost of rectifiers required for connecting ac DERs to dc feeders,
- C_3: The cost of inverters required for connecting dc DERs to ac feeders,
- C_4: The cost of inverters for connecting ac loads to dc feeders, and
- C_5: The cost of rectifiers for connecting dc loads to ac feeders.

- z: Binary type variable (dc or ac)
- x: Binary investment variable (installed or ignored)

Planning Model

- The other constraint that needs to be revised in the microgrid planning problem is the load balance, as proposed here:

$$\sum_{i \in \mathrm{G}_{ac}} (P_{it} + P_{M,kt})\left(\eta_{rec} z_k + (1 - z_k)\right) + \sum_{i \in \mathrm{G}_{dc}} P_{it}\left(z_k + \eta_{inv}(1 - z_k)\right) = D_t \qquad \forall k, \forall t$$

- The load balance constraint ensures that the sum of power from all DERs and the exchanged power with the utility grid is equal to the total load in the microgrid.
  - The efficiency of rectifiers and inverters, as shown by η_{rec} and η_{inv}, respectively, is considered in modelling this constraint as there will be losses due to the application of converters.
  - The power generated by ac DERs located in dc feeders is reduced by the coefficient η_{rec}, and the power generated by dc DGs located in ac feeders is reduced by the coefficient η_{inv}.

Planning Model

- The microgrid planning problem is further subject to additional constraints, such as:
  - the charging and discharging constraints of DES
  - maximum power exchange with the utility grid
  - the technical constraints of dispatchable DGs
  - the load adjustment and curtailment

Numerical simulation

- Test microgrid with six DGs and one DES.
  - The peak load is 8.5 MW.
  - The ratio of dc loads: 0.4
  - The ratio of critical loads: 0.5
  - The ratio of dc/ac loads in three feeders: 0.39/0.28, 0.33/0.33, 0.28/0.39

Unit No.	Type	Annualized Investment Cost ($/MW)	Allowable Installation Capacity (MW)	Cost Coefficient ($/MWh)
1,2	Gas	50,000	2	85
			1.5	95
			1.5	105
3,4	Gas	70,000	1	65
			1	70
			1	75
5	Wind	132,000	2	0
6	Solar	133,000	2	0

Numerical simulation - cont'd

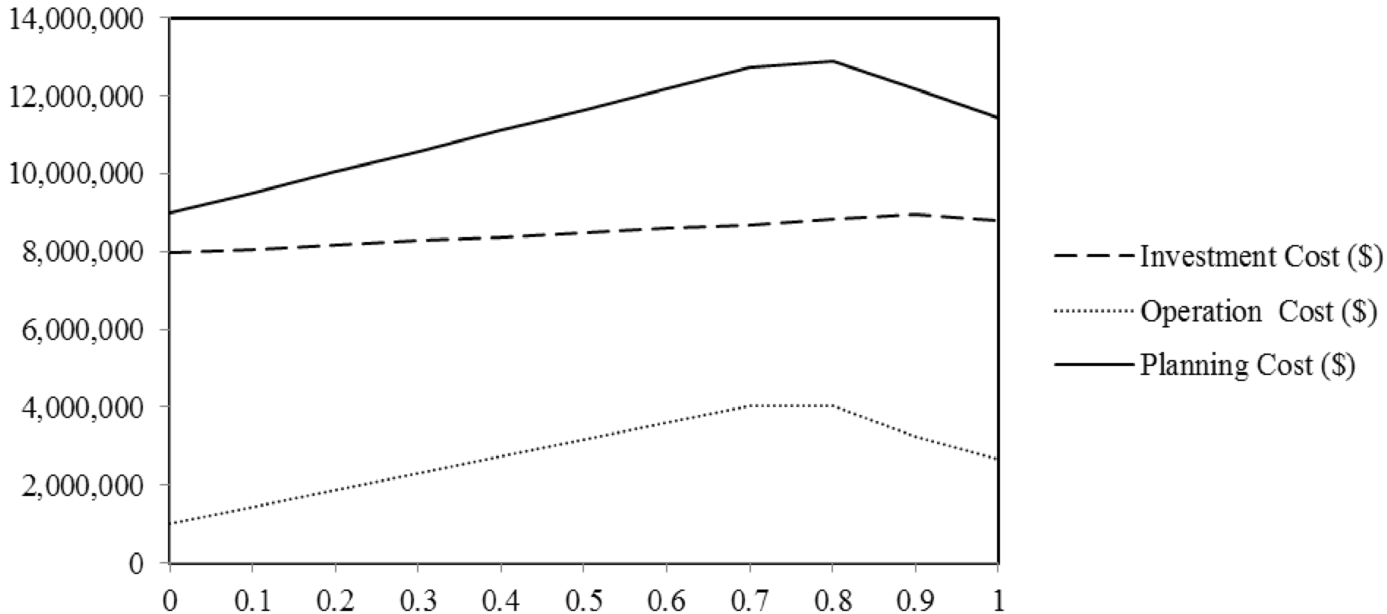
- The hybrid microgrid planning solution would install all DGs with capacity of 0.049 MW for units 1 and 2, 2.376 MW for units 3 and 4, as well as 2 MW for wind and solar PV units. All feeders would be ac.

- The microgrid planning cost ($11,117,190) is less than the cost of supplying loads witout microgrid deployment ($14,548,920), which justifies the microgrid installation

Numerical simulation - cont'd

Sensitivity analysis with respect to the ratio of dc loads

- Increasing this ratio up to 0.6, all feeders are ac
- Increase from 0.6 to 0.8 would result in feeders 1 and 2 to be dc
- Increasing from 0.8 to 0.9 would result in all feeders to be dc



Numerical simulation - cont'd

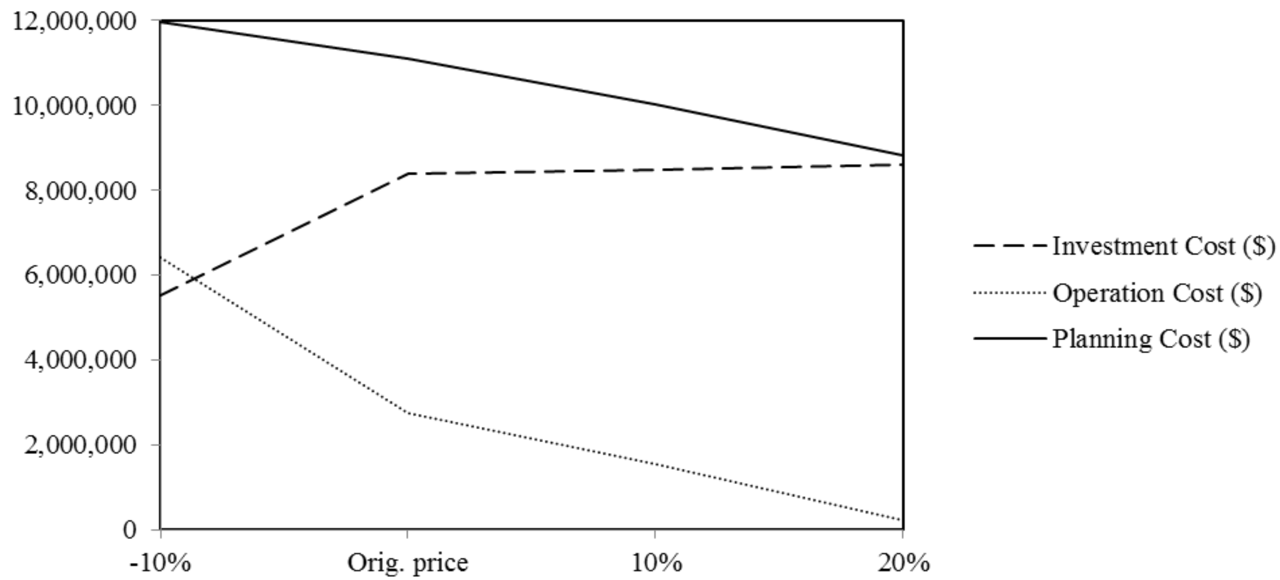
Sensitivity analysis with respect to the ratio of critical loads

- By increasing the ratio of critical loads, the capacity of dispatchable DGs would increase, which causes the microgrid investment and planning costs to increase as well.

Numerical simulation - cont'd

Sensitivity analysis with respect to the market price

- Changing the electricity market prices from -10% to +20% increases the total capacity of dispatchable units as the microgrid would sell more energy to the utility grid (an increase in the revenue)
- As a result, the investment cost increases while the operation cost decreases



Conclusion

- It was verified that the only factor in determining the type of feeders, i.e., either ac or dc, would be **the ratio of dc loads**.
- Increasing the ratio of critical loads would install a larger capacity of dispatchable units in order to seamlessly supply critical loads, which increases the investment, and hence, the planning costs.
- By increasing market prices, it would be more desirable for the microgrid to sell as much power as possible to the utility grid which requires installing more DG capacities, thus increasing the investment cost but decreasing the operation cost.
- The planning results showed that solar and wind units are installed with their maximum capacity in all cases, conceivably due to their zero operation cost.
- ac DERs are mainly installed in ac feeders and dc DERs in dc feeders in order to avoid the conversion costs.

Thank you

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