An Optimization-based Method in Determining the Capability Curve of a Microgrid

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Introduction

The **microgrid**, as defined by the U.S. Department of Energy, is "a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode"

Microgrids → Viable **ancillary service providers** to the utility grids.

How?

Microgrid DERs can produce reactive power

↓

Microgrids can potentially provide reactive power support to utility grid by injecting or withdrawing reactive power.

Capability Curve for Reactive Power Management

- The reactive power management and voltage stability are strongly related to each other to keep voltage in its proper operational limits.
- Reactive power dispatch is an integral part of power system operation to ensure system load balance and to further manage voltage stability.
- Reactive power requirements usually change over time as loads change.
- To provide ancillary services to the utility grid via reactive power production, the amount of exchanged real and reactive power between microgrid and the utility grid should be managed.

The **capability curve** of a microgrid

=

Microgrid capability in delivering real and reactive powers

Capability Curve of Synchronous generator

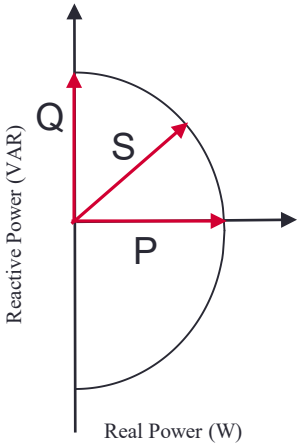
Synchronous generator:

The capability curve of DERs could be defined as a boundary within which the generator operates safely.

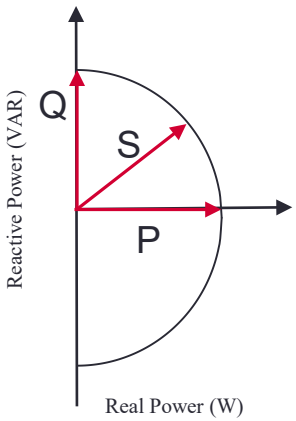
Capability curve: A semicircle with radius S as apparent power

Power limitations:

- Real power → Positive
- Reactive power → Positive or negative
- Apparent power → Positive



Capability Curve of Solar PV



Solar PV System: Contains three elements:

- PV panels
- Inverters
- Transformers

The PV generator → Controlled to operate at MPPT (Maximum Power Point Tracking),
The PV array → Modeled as a current source connected in parallel with a capacitor,
The inverter → Modeled as a voltage source.

Output power: Depends on weather conditions and solar radiation during the day. Maximum delivered real power by PV unit occurs at maximum solar radiation and minimum temperature.

Capability curve: A semicircle with radius S; Similar to the synchronous generator

Capability Curve of Battery energy storage

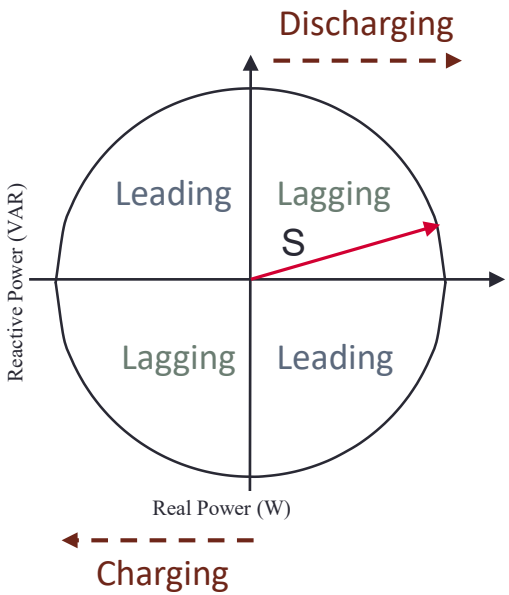
Battery energy storage:

Used to seamlessly supply power to loads during peak hours and to capture power fluctuations of variable DERs.

Two operating modes:

- Charging → Negative real power
- Discharging → Positive real power

Capability curve: A circle with radius S (apparent power)



Microgrid Capability Curve Model

Min/Max:

Reactive power (produced by microgrid based on net real power)

Subject to:

- **Load balance:** Summation of power output of solar PV, battery, and the synchronous generator equals to a hypothetical net load.
- **DERs' capability curves:** Real, reactive, and apparent powers limitations.

Optimization Process:

- Initialize hypothetical net load = The maximum charging power of the battery (a negative value),
- In each iteration, calculate minimum and maximum amount of reactive power and then increase the net load by the selected step,
- Continue this process until net load reaches the generation capacity of the microgrid.

Numerical Analyses

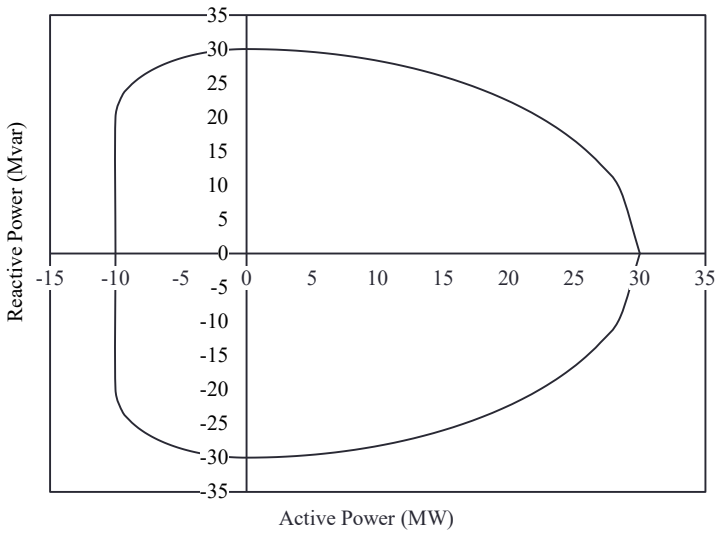
- Case of a microgrid consisting of:
  - ✓Synchronous generator
  - ✓Solar PV
  - ✓Energy storage

- **Case 1**: All three DERs have the same capacity.
- **Case 2**: Two DERs (PV and energy storage) have the same capacity while the synchronous generator is larger.
- **Case 3**: The DERs have different capacities.

Case Number	Synchronous generator (MVA)	Solar Photovoltaic (MVA)	Energy Storage (MVA)
Case 1	10	10	10
Case 2	20	10	10
Case 3	15	5	10

Case 1: All Three DERs Have the Same Capacity

- Negative part resulted from battery charging



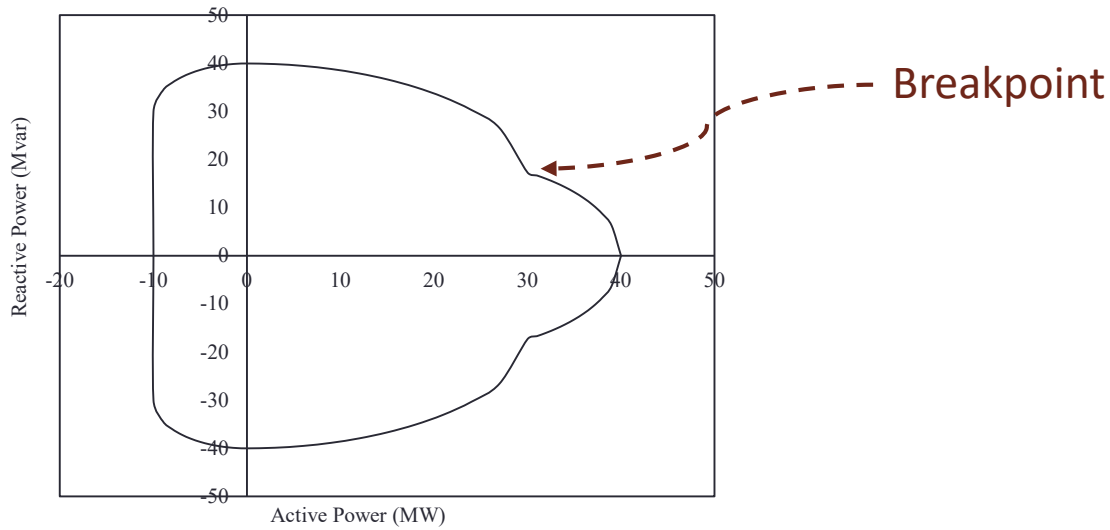
Same capacities

The closest curve to capability curve of each DER

No breakpoint

Case 2: Synchronous Generator Has Larger Capacity

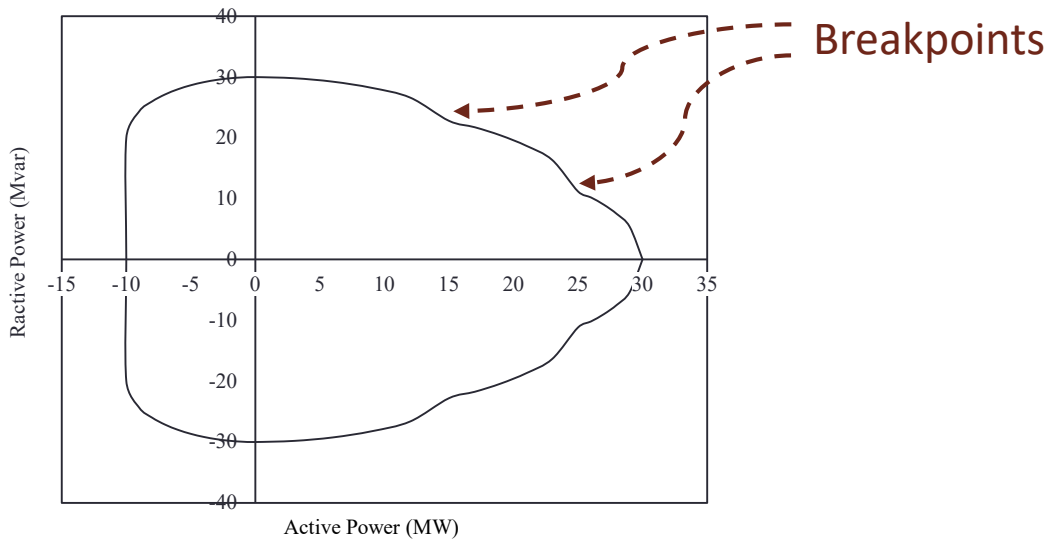
- Not a circle or half circle
- Depends on the capacity of its DERs



Difference in synchronous generator capacity → One breakpoint

Case 3: The DERs Have Different Capacities

- Significantly changed when the DERs have different capacities



Difference in capacities

The most non-symmetrical curve

Two breakpoints

Conclusion

- This paper developed an optimization-based model to find the capability curve of microgrid as a single unit. The numerical analyses were carried out in various cases and the obtained results showed that the microgrid capability curve:
  - is much different from individual DERs; not a circle or half circle,
  - is non-symmetrical,
  - depends on the capacity of its DERs,
  - has a negative part which is resulted from battery charging,
  - its shape would be significantly changed when the DERs have different capacities.
- Similar to individual DERs' capability curves, once microgrid capability curve is obtained, a closed form mathematical model can be fitted into the curve to be used for ancillary service studies.

Thank you

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