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A Direct Calculation of Locational Marginal Value of Distributed Energy Resources

CIGRE - Grid Of The Future
30th October, 2018

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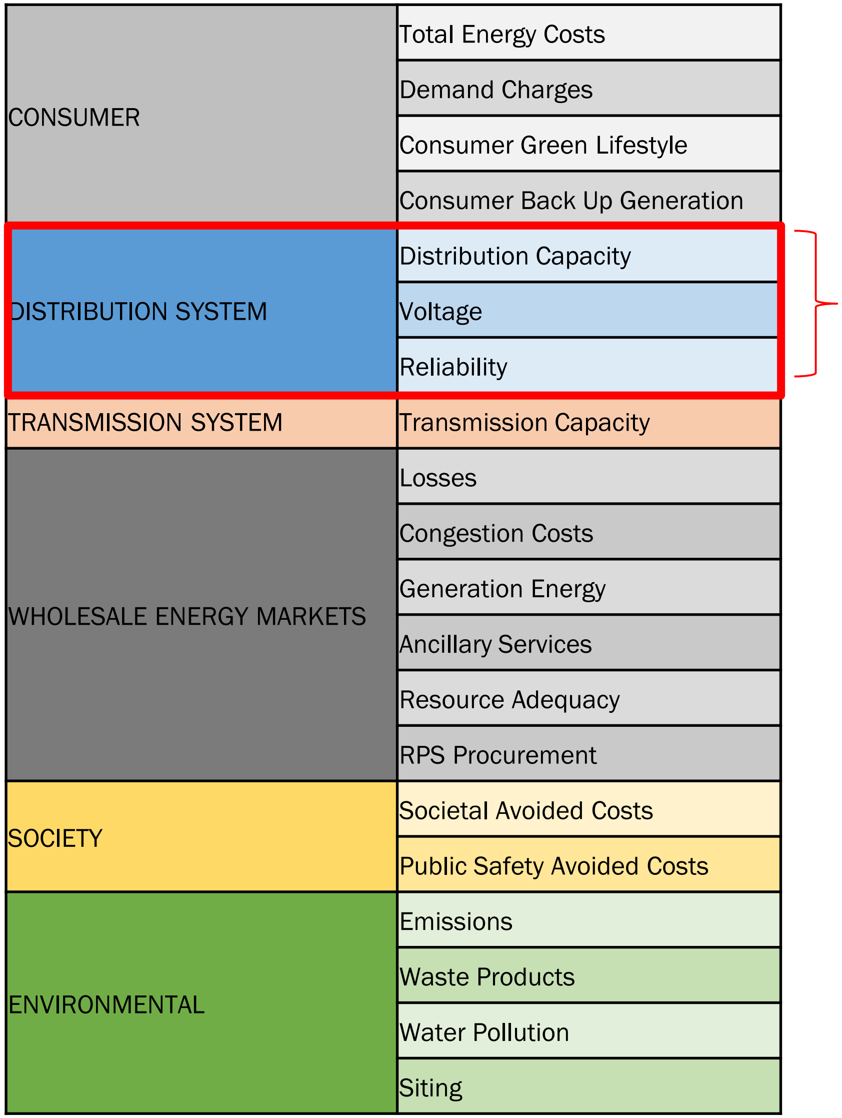
Potential Value Created by a DER



CONSUMER	Total Energy Costs
	Demand Charges
	Consumer Green Lifestyle
	Consumer Back Up Generation
DISTRIBUTION SYSTEM	Distribution Capacity
	Voltage
	Reliability
TRANSMISSION SYSTEM	Transmission Capacity
WHOLESALE ENERGY MARKETS	Losses
	Congestion Costs
	Generation Energy
	Ancillary Services
	Resource Adequacy
	RPS Procurement
SOCIETY	Societal Avoided Costs
	Public Safety Avoided Costs
ENVIRONMENTAL	Emissions
	Waste Products
	Water Pollution
	Siting

Value to Distribution Grid

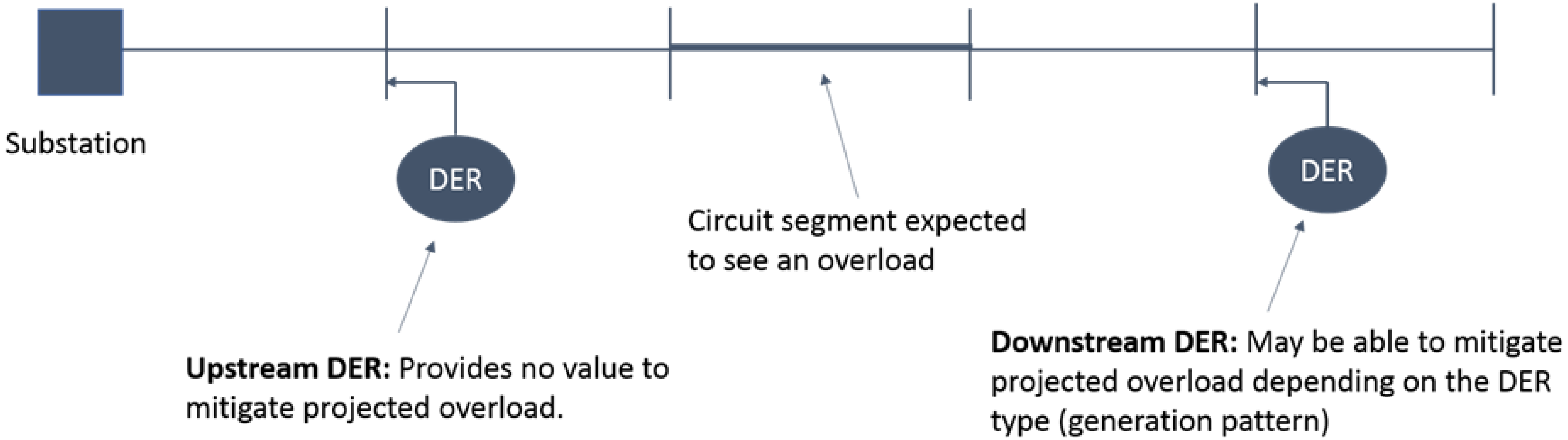
- DER value is realized by various parties.

- Several categories of value are potentially realized from DER
- Few value streams are associated with value to distribution grid
- Value streams realized are dependent on DER location and type

Focus

- ✓ Considering avoided costs of traditional investments to evaluate the benefits of DERs to the grid
- ✓ Focus on Feeders with Planned Investments
  - Can DER help with violations so we avoid the investment?
    - – Interpret total cost into marginal cost
    - – Defined as the Marginal Cost of Capacity (MCC)
  - Calculate contribution of each DER to avoided investment
    - – Defined as the Locational Marginal Value (LMV)
- ✓ Key Contribution:
  - Generic algorithm for direct calculation of the value of DER
  - Technology agnostic design based on AC power flow formulation

Value of DER: Fundamentals



Circuit segment expected to see an overload

Upstream DER: Provides no value to mitigate projected overload.

Downstream DER: May be able to mitigate projected overload depending on the DER type (generation pattern)

- ✓ Value of DER is **locational and temporal** in nature.
- ✓ The value of DER to the grid cannot be determined by system, or even necessarily feeder averages.
- ✓ If there are no constraints on the feeder (e.g. segment that is expected to see an overload), DER will have no value in deferring a distribution investment.

Value of DER : Fundamentals contd.

- ✓ Elements for Valuing DER
  - Avoided cost of circuit upgrades
  - How this cost is apportioned among affected parts of the circuit
  - Effectiveness of active and reactive power in reducing or avoiding this cost
  - Alignment of different DER technologies with the temporal value of DER
  - How much of the generic DER value a given technology can realize
- ✓ The value of DER is affected by the sensitivity of the circuit condition requiring capacity or voltage investments to the real and reactive power from that DER

Value of DER : Fundamentals contd.

- ✓ Accuracy and Efficiency of DER valuation methodology would:
    - Compensate DERs for services they provide to the distribution grid
    - Address different characteristics/capabilities of DER technologies
    - Consider locational and temporal value
- ✓ Need for fair and equitable methodology avoiding under and over compensation
- ✓ Value provided to the DER based on when and where it is functional

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Mathematical Formulation

- ✓ *Marginal Cost of Capacity (MCC):* Marginal cost of grid upgrades required to mitigate overloads and voltage violations in the network
- ✓ *Locational Marginal Value (LMV):* Sum of the marginal value of real power, reactive power and reserve provided by the DER at any point in time
- ✓ *Relationship between LMV and MCC:*

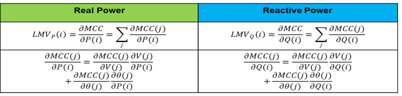
$$LMV_P(i) = \frac{\partial MCCT}{\partial P(i)} = \frac{\partial \sum_j MCC(j)}{\partial P(i)}$$

- *MCCT: total penalty function for all branches*
- *MCC(j): penalty for branch j*
- i: *bus at which LMV is calculated*
- j: *location of violation*
  - Under/over-voltage bus
  - Current magnitude> amp limit

How it works: the math

Direct LMV calculations

Real Power	Reactive Power
$LMV_P(i) = \frac{\partial MCC}{\partial P(i)} = \sum_j \frac{\partial MCC(j)}{\partial P(i)}$	$LMV_Q(i) = \frac{\partial MCC}{\partial Q(i)} = \sum_j \frac{\partial MCC(j)}{\partial Q(i)}$
$\frac{\partial MCC(j)}{\partial P(i)} = \frac{\partial MCC(j)}{\partial V(j)}\frac{\partial V(j)}{\partial P(i)} + \frac{\partial MCC(j)}{\partial \theta(j)}\frac{\partial \theta(j)}{\partial P(i)}$	$\frac{\partial MCC(j)}{\partial Q(i)} = \frac{\partial MCC(j)}{\partial V(j)}\frac{\partial V(j)}{\partial Q(i)} + \frac{\partial MCC(j)}{\partial \theta(j)}\frac{\partial \theta(j)}{\partial Q(i)}$



How it works: the math

Direct LMV calculations

Real Power	Reactive Power
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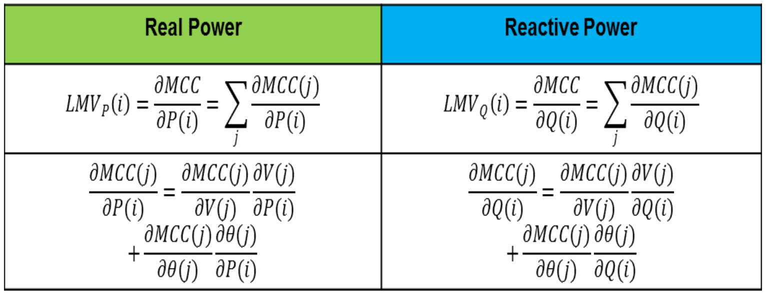

Real Power	Reactive Power
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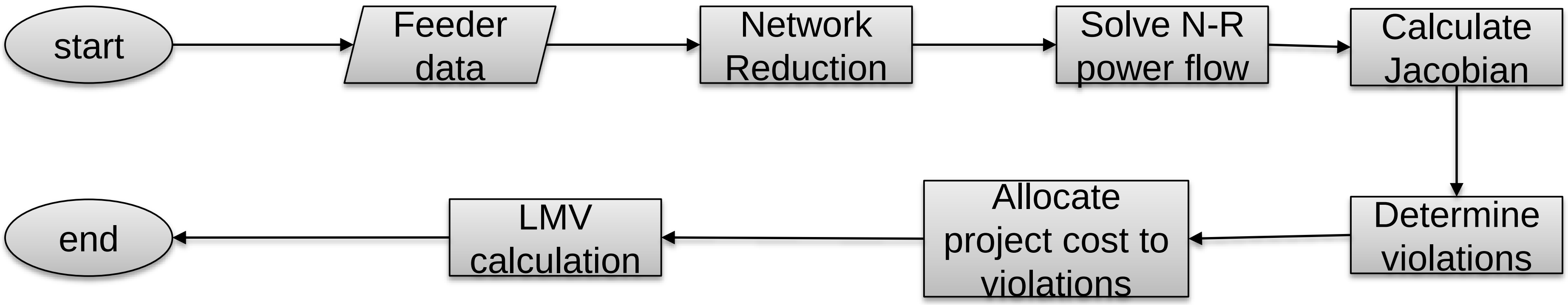
$$\boxed{J^{-1} = \begin{bmatrix} \frac{\partial \theta}{\partial P} & \frac{\partial \theta}{\partial Q} \\ \frac{\partial V}{\partial P} & \frac{\partial V}{\partial Q} \end{bmatrix}}$$

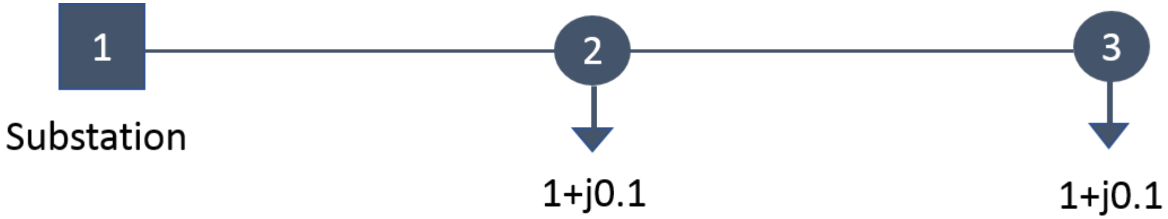
Process Description



- ✓ Preparation Step: Reducing the network to a balanced, single-phase system to deal with computational complexity of large-scale distribution feeder topologies and power flow
- ✓ Violation Determination Step: Unconstrained power flow to identify number, location and magnitude of violations
- ✓ LMV Determination Step: Calculation of real and reactive LMV using the computed MCC value
- ✓ The above steps may be repeated for each hour in the planning horizon

Test Case Results

- ✓ Test Case: 3-bus network with thermal overloads



- ✓ Power flow results and LMV values for an overload on branch 1-2

Node	Voltage magnitude (p.u.)	Voltage angle (deg)	Branch	Current Magnitude (p.u.)	Current limit (p.u.)	LMV-P ($/kW)	LMV-Q ($/kVAr)
1	1	0	1-2	2.0729	1.1	-	-
2	0.9757	-0.0287	2-3	1.0429	1.1	644.1	88.3
3	0.9636	-0.0436				661.0	90.2

Test Case Results contd.

✓ Observations for the overload on branch 1-2

- LMV for real power is much higher than that for reactive power - mainly due to load power factor
- Overload can be relieved by injecting real or reactive power downstream the location of violation
- LMV for real and reactive power increases at the electrical distance from violation increases

Node	Voltage magnitude (p.u.)	Voltage angle (deg)	Branch	Current Magnitude (p.u.)	Current limit (p.u.)	LMV-P ($/kW)	LMV-Q ($/kVAr)
1	1	0	1-2	2.0729	1.1	-	-
2	0.9757	-0.0287	2-3	1.0429	1.1	644.1	88.3
3	0.9636	-0.0436				661.0	90.2

Test Case contd.

- ✓ Power flow results and LMV values for an overload on branch 2-3

Node	Voltage magnitude (p.u.)	Voltage angle (deg)	Branch	Current Magnitude (p.u.)	Current limit (p.u.)	LMV-P ($/kW)	LMV-Q ($/kVAr)
1	1	0	1-2	2.0729	2.5	-	-
2	0.9757	-0.0287	2-3	1.0429	0.9	7.4	10.5
3	0.9636	-0.0436				653.0	84.8

- ✓ Observations:
  - LMV for real and reactive power at node 2 dropped significantly
  - LMV not exactly zero – accounting for network losses
  - LMV for real and reactive power significantly higher at node 3 – proximity to the violation

Future work

Future work

- ✓ Compensation issues
  - Differential value of first vs intermediate vs last DER
    - Update LMV to create “LMV curve” or simply use base case LMV
    - Can vary greatly based on topology of overloads
  - LMV stepping stone to structure
    - Tariff-based payment to DERs
    - Capacity auction for DERs

- ✓ Policy issues
  - Location and time granularity of LMV
  - Relate traditional project to NWA
    - Lumpiness of wired project
    - Cost allocation
  - How much DER available and ready to respond to price signals
    - Too much DER vs too little DER

- ✓ Valuation of specific DER technologies
  - Constrained by DER capabilities

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