Challenges and Possible Solutions for the Power System of the Future

A Research Perspective

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Renewable & Battery Cost Trend: Unlocked Potential by 2025

Universal Solar PV: ~$0.02/kWh in high solar region but still almost half the cost of rooftop solar

Wind LCOE: ~ $0.03/kWh in high wind region

Electric vehicle (~300 miles): ~$7,000 decrease

Commercial building batteries: 2-year payback

Solar/wind + 4-6 hour storage cost = natural gas power plant

No breakthrough technology needed!
Renewables are increasing...

Global Renewable Power Capacity, 2007-2017

World Total
2,195 Gigawatts

- Ocean, CSP and geothermal power
- Bio-power
- Solar PV
- Wind power
- Hydropower

RENEWABLES 2018 GLOBAL STATUS REPORT
Not just wind and solar PV

Electric Vehicles

Batteries

Source: EPRI Program on Electric Transportation

Source: Bloomberg New Energy Finance, illustrated by EPRI
Inverter Based Resources and Low Short Circuit Systems
What is short circuit ratio (SCR)...?

- **SCR** – Ratio of short circuit MVA at a source bus to the MW rating of generator
  - High value of SCR implies that the source is ‘small’ relative to the rest of the network.
    - If source moves around a lot, network is minimally impacted.
  - Lower values of SCR implies that source can be ‘comparable’ size with network.
    - Movement of source will impact network

Source: “Integrating Inverter-Based Resources into Weak Power Power Systems”, Andrew Issacs, Electronix Corporation, EPRI-NERC-NATF-ESIG Webinar Series, 2018
Weak grids…

▪ How does a weak grid arise?
  – There is **limited fault current** available in the system -> resulting in lower voltages
  – There is **large impedance** between the source and rest of the network -> resulting in lower voltages

▪ Why may this be an issue?
  – An inverter uses measured voltage to decide the magnitude and angle of injected current
  – Small variation in current injection can cause large variation in voltages
  – An inverter tries to detect angle and magnitude of phase voltage, and react to this detection in a very fast manner.
  – This can results in an unstable operation.
  – In order to deliver a specific value of P and Q, both magnitude and angle of V should be known in order to decide the value and angle of current

\[
I \angle \phi = \frac{P - jQ}{V \angle - \psi}
\]
Inverters and Weak Grids

- Wind/Solar interconnections in weak systems are becoming more common
  - Connected farther away from transmission
  - Reduction of available short circuit current

- Contingencies or scheduled outages (e.g. lines under maintenance) may reduce system strength below typical levels expected under normal operating conditions.
  - Changes impedance of system

- Additionally, if such a network situation coincides with ramping up of the plant, the location can become even weaker
  - Injection of higher current through an already weak network

- Converter controller instabilities might occur under weak grid conditions
  - Inherent fast controllers may not be stable

PES General Meeting, Chicago, IL, July 2017
Present Industry Practices to Ascertain Inverter Impact in Low Short Circuit

- No clear industry standard on metrics & associated thresholds to identify a weak area of the system

- Low SCR doesn’t necessarily imply converter control instability
  - May re-tune (slowdown) inverter controls

- Other options to deal with low SCR
  - System reinforcement (synchronous condenser, new transmission)
  - Curtail plant output

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Table 2.1: Comparison of SCR Methods

<table>
<thead>
<tr>
<th>Metric</th>
<th>Simple calculation using short circuit program</th>
<th>Accounts for nearby inverter based equipment</th>
<th>Provides common metric across a larger group of VER</th>
<th>Accounts for weak electrical coupling between plants within larger group</th>
<th>Considers non-active power inverter capacity*</th>
<th>Able to consider individual sub-plants within larger group</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCR</td>
<td>★★★</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CSCR</td>
<td>★</td>
<td>★★★</td>
<td>★★</td>
<td>★</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>WSCR-MW</td>
<td>★</td>
<td>★★★</td>
<td>★★</td>
<td>★</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>WSCR-MVA</td>
<td>★</td>
<td>★★★</td>
<td>★★</td>
<td>★</td>
<td>★★</td>
<td>X</td>
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<td>SCRIF</td>
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</tr>
</tbody>
</table>

Source: “Integrating Variable Energy Resources into Weak Power Systems”, NERC, June 2017
But SCR Does Not Provide The Entire Picture…

- For an inverter plant, a low or high value of SCR may not provide the entire picture about control instability

- Controller instability due to extended duration of a fault can be because of:
  - Increased controller effort to maintain respective references during the fault
  - Post contingency system does not provide sufficient damping
  - Saturation of controllers due to large values of gain

- New “Advanced Short-Circuit Strength” metric has been developed
  - For a fault at the POI of an inverter based plant, provides estimate on fault clearing time threshold to prevent controller instability.
Limitations of Present Converter Positive Sequence Dynamic Models

Generic Positive Sequence Models Limitations

- Models not suitable for capturing fast controller dynamics/interactions
- Models not accurate for studying unbalanced conditions near the converters
- Models not suitable for interconnection studies of a wind/solar power plant to a weak transmission system
- Models not suitable for detailed studies related to phenomena such as sub-synchronous resonance and ferro-resonance
Proposed REGC_C (Positive Sequence Model)

- Representation of PLL and inner current control loop
- Small timestep required (1ms)
- Improves numerical stability
- Suggested to be used for weak grid studies before conducting detailed three-phase EMT studies

Update:
- PSS®E model implementation almost complete
- Model testing in collaboration with EPRI members
Inverter Based Resource Impact on Protection Relays
Motivation, Challenges & Needs

- Continuously increasing penetration level of inverter interfaced resources, predominantly renewables (Type III, Type IV WTGs & PVs)
- Complex fault response
- Differs significantly from synchronous short-circuit current contribution (SCC)

Challenge

- Accurate short-circuit models for protection/planning studies
- Performance of legacy protection schemes (distance protection etc)
Inverter Based Resources Fault Response Characteristics

Synchronous Generator

• SCC magnitude close to nominal load current (typically 1.1-1.5 pu)
  • Initial transient (typical duration 0.5 - 1.5 cycles) – uncontrolled response – controller “reaction time”
• Fault current can be capacitive, inductive or resistive
• Typically low negative sequence current contribution
• No zero sequence current

IBR fault response depends on inverter control scheme
IBR Short Circuit Models

Synchronous generator classical short circuit model (voltage source behind an impedance) is not applicable

- Voltage controlled current source
- Iterative solution (nonlinear behavior)
  - considers the impact of controls on the short circuit response
  - respects inverter current limits

<table>
<thead>
<tr>
<th>IEEE PSRC C24 WG</th>
<th>Fault Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time frame 1 (seconds or cycles)</td>
<td>Positive sequence voltage (pu)</td>
</tr>
<tr>
<td>Positive sequence voltage (pu)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

PSS®CAPE

ASPEN OneLiner v14
Protection System Performance Evaluation

- Investigate relays response & identify potential misoperation scenarios
- Provide recommendations and study practices to protection engineers when conducting protection studies to prevent relay misoperation & miscoordination

Related Industry Efforts:
- DOE Project “Inverter Based Resource (IBR) Negative Sequence Current (I2) Injection Study”
Next Generation Tools for Distribution Planning
Distribution System Analysis Tools

Present day tools

- Snap shot simulation
- Extreme values
- Simple and efficient
- Seemed to have everything

Requirements for future tools

- Accelerate advanced analysis
- Varying operational conditions
- Big data processing
- The evolution is happening
The Next Generation of Distribution Analysis Tools

Graphical User Interface OpenDSS-G

Time-based advance analysis for planning

GIS visualization (under development)

Big data analysis (under development)

Advanced Visualization OpenDSS-Viewer

Specialized analysis Add-ons
The Next Generation of Distribution Analysis Tools

- Accelerating simulations

And other techniques that can be used to take advantage of multicore computers when using OpenDSS
The Next Generation of Distribution Analysis Tools

- Simplifying Complex Processes and Data

  High level interface, describes the simulation process and global considerations of the planning study

  Medium level interface, describes customized equipment using pre-existing functions

  Low level interface, describes customized functionalities as new components for the simulation
Conclusions
Distributed Energy Resources (DER) Impact on Bulk Power System
Why should DER be modeled explicitly…?

Block tripping of DERs can be a concern to system stability

How does a transmission planner get this visibility?
A solution for DER to be modeled for bulk power system planning studies...

- Represents pumps, fans, lighting, HVAC systems, residential AC.
- Recently updated to represent behind the meter DER (R-DER)
- Also represents dedicated load serving DER resources not netted with load

Is this representation perfectly accurate?
- No. It is only reasonably accurate

Does it need to be perfectly accurate?
- No.

Focus of this presentation

If the decision to be made from studies does not change whether one uses detailed models or aggregated models, then aggregate models are sufficient.
The modeling challenge still persists though…

Entire load on a substation modeled as a single equivalent

Complete three phase voltage profile represented by single RMS profile

1.05pu

0.95pu
Aggregated model to represent the dynamic behavior of DER...

Reference:

How to find parameter values for the model? Present focus is on voltage thresholds.
Partial trip of DER based on voltage magnitude...

Individual DER $V_{trip} = 0.88\text{pu}$

Individual DER $V_{trip} = 0.5\text{pu}$

Impact on bulk power system…

- Simulation premise
  - System generation is 69 GW, gross load is 81 GW, DER is 14 GW
  - Fault applied in the middle of transmission line, and subsequently line is cleared in 6 cycles
  - Load dynamics are considered along with DER dynamics

Without the parallel trip characteristic, there could be a huge misrepresentation of amount of DER that ride through a single phase fault
Flexibility and Resource Uncertainty
German Hourly Net Load Range – August Workdays, 2019

Data Source: ENTSOe Transparency Platform Data

27 GW RANGE
Carbon Reduction Necessitates Enabling Flexibility

Long-Term Planning Needs – What “Type” of Capacity is Needed?

Traditional "Generic Capacity" Metrics

**LOLE\text{\scriptsize{GENERIC-CAPACITY}}**

*Traditional* metric to capture events that occur due to capacity shortfalls in peak conditions

New "Flexible Capacity" Metrics

**LOLE\text{\scriptsize{MULTI-HOUR}}**

*New metric* to capture events due to system ramping deficiencies of longer than one hour in duration

**LOLE\text{\scriptsize{INTRA-HOUR}}**

*New metric* to capture events due to system ramping deficiencies inside a single hour

New need to ensure flexibility adequacy in long-term planning?

More Information:
Flexibility Will Become More Valuable

- Increasing variability and uncertainty will require flexibility on all time scales and at different spatial scales

- Different resources may contribute
  - DER, storage and inverter based resources may provide some of the needed flexibility services
  - Retrofits and altered operational practices

More Information:
Metrics for Quantifying Flexibility in Power System Planning, 3002004243, 2014 (EPRI)
Short-term Operational Needs – Impact on Operating Reserve

*Terminology not universal

**Instantaneous events**
- **Primary**
  - Stabilize frequency
- **Secondary**
  - Return frequency to nominal and/or ACE to zero
- **Tertiary**
  - Return system to secure state (replace other reserves)

**Longer duration events**
- **Secondary**
  - Return frequency to nominal and/or ACE to zero
- **Tertiary**
  - Return system to secure state (replace other reserves)
- **Correct the anticipated ACE**
  - Manual (Part of Optimal Dispatch)
- **Correct the current ACE**
  - Automatic (Within Optimal Dispatch)
Few industry working groups in relation to these topics...

- CIGRE JWG C2/C4.41 Impact of high penetration of inverter-based generation on system inertia of networks
- CIGRE WG C4.56 on Electromagnetic transient simulation models for large-scale system impact studies in power systems having a high penetration of inverter-based resources
- CIGRE WG B5.65 Enhancing Protection System Performance by Optimizing the Response of Inverter-Based Sources
- IEEE/CIGRE B4.82 Working Group on Use of Real Code in EMT Models for Power System Analysis
- IEEE PSDP Task Force on Modeling and Simulation of Large Power Systems with High Penetration of Inverter-Based Generation
- WECC Modeling and Validation Work Group (MVWG)
  - WECC Load Modeling Task Force (LMTF)
  - WECC Renewable Energy Modeling Task Force (REMTF)
- NERC Inverter Based Resource Performance Task Force (IRPTF)
- NERC Load Modeling Task Force (LMTF)
- NERC System Planning Impacts from Distributed Energy Resources Working Group (SPIDERWG)
Questions, comments, and suggestions..?
Together...Shaping the Future of Electricity