Solar Power Integration Challenges: Intermittency and Voltage Regulation Issues

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● CHALLENGES FOR HIGH SOLAR PENETRATION
● FACTORS AFFECTING VOLTAGE PERFORMANCE
● PLANNING AND SYSTEM STUDIES
● REGULATORY REQUIREMENTS AND INCENTIVES
● BRINGING INTELLIGENCE TO THE GRID
● CONCLUSION
INTRUCTION
The Need for Solar PV Generation

• Quick and relatively low-cost alternative to traditional solutions.
• Local power source close to end-users. ... No T&D Costs.
• A valuable asset in heavily-congested areas, where siting and emission concerns may limit other generation options.
• Output conveniently coincides with peak levels of most residential and commercial loads.
  • This also means that it can displace costly peaking plants.
  • Best location for solar farms is not only governed by insolated areas with unobstructed high intensity of sunlight, but also by proximity to local grids to draw on as backup when the sun goes off, among other factors.
• However, most solar projects are not driven by the need for local peaking support, but rather by the desire for “greener” energy supply.
### Grid Penetration Scenarios and Impacts

<table>
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<th>Penetration Level</th>
<th>Impacts on Power Systems and Standards Defining Role and Operating Rules for Distributed PV</th>
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| **Low**           | • No impact on normal feeder or grid operation.  
|                   |   • Current interconnection standards are sufficient.                                        |
| **Medium**        | • Distributed PV affects feeder voltage, may need to widen voltage trip limit, adjust circuit voltage regulation, and adapt circuit-protection settings.  
|                   |   • Under-frequency tripping needs to be widened to coordinate with load-shedding schemes.  
|                   |   • Evolve interconnection standards to consider feeder-level interactions.                  |
| **High**          | • PV systems affect utility feeder and grid balancing (transmission system) and will need to be integrated with both planning and operations.  
|                   |   • Ramp rates may be controlled at the PV system level.                                     
|                   |   • Update interconnection standards to integrate PV for voltage and energy support, allowing voltage regulation, low-voltage ride-through, and enhanced anti-islanding schemes. |

Source: The DOE SunShot Initiative High Penetration Solar Portal
INTRODUCTION

Time Scales for Power Systems Operation

Source: Renewable Electricity Futures Study [1]
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Challenges for High Solar Penetration

• Unpredictable Dispatchability / Intermittency.
• Creates a Substantial Ramping Constraint on Standby Generation.
  • Ramping constraints are more evident on the load-following and regulation time scales than on the scheduling or unit commitment time scale.
• Such limitation forces operators to allocate additional resources to balance generation and demand and maintain reliability in real time.
  • Synchronous generators driven by turbines supplied from solar energy are also considered intermittent generation, except when supplemented by sophisticated storage resources.
  • However, Solar-backed storage technology is still in its early stages of being commercially and economically viable.
Challenges for High Solar Penetration

Utility-Scale Solar Generation

• Transmission lines need to keep pace with forecasted solar farms to ensure that remote solar generation can be transported long distance to load centers.

• Delays in transmission projects can affect the economic feasibility of planned solar developments and may delay or stop the solar project altogether.

• Furthermore, adding more transmission capacity provides utilities with the benefit of accessing more renewable energy resources in a cost effective manner.
Challenges for High Solar Penetration

- Solar PV systems have no effective inertia.
- Solar panel output can plunge by 50% or more in a few minutes [3].
- Rising & setting of the sun $\Rightarrow$ 10-13% changes in PV output over a 15 minutes period [3].
- Time for passing cloud to shade an entire PV system depends on the PV system size, cloud speed, cloud height, and other factors.
- To smooth out the dispatchability limitation, a balancing area must have access to:
  - Solar installations in different regions with different & complementary weather patterns
  - Adequate transmission lines connecting those regions
- Else, peaking units have to be waiting on standby to prevent grid collapse.
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Factors Affecting Voltage Performance

- **Voltage Magnitude & Power Flow Direction** Depend on **Demand** and **Injected Generation**.

- Typically, to regulate voltage:
  - LTC Transformers at Substation
  - Stepped Voltage Regulators on Longer Feeders
  - Switched Capacitors

- However, with imbedded distribution level Solar PV, power may flow from point to point within the distribution network.
Factors Affecting Voltage Performance

• Systems may have Voltage control problems if available SC capability of the renewable source is significant relative to that of the distribution feeder at the PCC.

• Some reports cite Voltage or System Instability if Solar PV penetration exceeds 20%; however, true maximum depends on other factors, such as solar plant location within the network and the type of PV inverter used.

• IEEE 1547-2003 Standard which applies to small PV installations ≤ 10MVA:
  • Does not permit PV inverters to regulate voltage on distribution system.
  • However, feeder voltage deviations are minimal and can be handled by traditional utility regulation means with no harm to the solar installation.
High Solar PV penetration levels may cause significant voltage changes.

Three key “Steady-State” Voltage-Regulation Issues to Watch for:

- Higher than Desired Voltage Rise.
- Reverse-Power Tap Changer Runaway Conditions.
- Undesirable Interactions with Line Drop Compensators.
Factors Affecting Voltage Performance

Higher than Desired Voltage Rise

• High Penetration Levels → Lower Line Currents → Smaller Voltage Drop

• Increase in Solar Intensity in Local Area → Overvoltages are Likely to Occur

• Solar and wind customers are now required to provide VAR regulation much the same as conventional synchronous generators.

• Advancement in Inverter Technology allows for the ability to regulate voltage, as well as other network parameters, at the local level.

• Proper coordination with existing voltage-regulation schemes is necessary.
  • Lack of coordination may lead to added costs associated with wear & tear on transformer tap changers and power-factor management devices.
Factors Affecting Voltage Performance
Reverse-Power Tap Changer Runaway Conditions

- If the output of the solar plant exceeds the local load, surplus power is pushed up through the distribution transformer, feeding into the higher voltage system.
- The tap changer “runs away” (moves to the limit of its highest or lowest allowed position) as a result of the power reversal through a regulator with a controller set to change its “regulating side” if reverse power is detected.
- Some regulators in an auto-loop configuration have a controller that detects reverse power flow and shifts from regulating the “normal output side” to regulating the “normal input side.”
- However, in this case, the source is still on the “normal input side”, and in this condition, the voltage on the PV side of the regulator could rise to a high or low level outside ANSI limits.
- In this case, special advanced controls have to be used to alleviate the problem.
Factors Affecting Voltage Performance

Undervoltages Associated with Line Drop Compensators (LDC)

SUBSTATION

FEEDER

Injected Power

End of Feeder

Factors Affecting Voltage Performance

Undesirable Interactions with Line Drop Compensators (LDC)

Voltage profile for different PV sizes installed at 1 mi from substation during peak load

Large PV can cause more undervoltage problems if connected close to the substation

Factors Affecting Voltage Performance

Constant Substation Voltage - LTC is not Equipped with LDC

Large PV Installed Mid-Way Along the Feeder

Voltage profile for different PV sizes installed at 2 mi from substation during peak load

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Planning and System Studies

Studies to Ensure:

- Voltage Levels Stay within Statutory Limits.
- Thermal Ratings of Equipment are Not Exceeded.
- Existing Switchgear and Cables are Not Underrated for Available Fault Levels.
- Transformers are Not Subjected to Reverse Power Flows.
- Disturbances: Voltage Step Changes, Flicker & Harmonics within Limits.
- Proposed Generation does Not Alter Existing Protection Schemes.
- Feeder Grounding Transformers are Appropriately Sized for Possible Transient Over-Voltages (TOV) Upon Feeder Ground Faults.
- Surge Arrester Rating is Adequate for Lightning and TOV.
- Stability Studies Indicate No Disturbance Effects Related to Solar Installation.
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Regulatory Requirements

- The North American Electric Reliability Corporation (NERC) in the US safeguards the reliability and security of the bulk power system. It establishes and enforces minimum performance standards; however it does not dictate how to meet many of the requirements.

- The IEEE 1547 Standards Apply to all PV sources ≤ 10 MVA Capacity at PCC.
  - Distribution Level PV installations should be designed and tested to the IEEE 1547 standard
  - IEEE 1547 Std prevents PV and other DGs from controlling the voltage.
  - PV and Distributed resources must disconnect from the utility grid if network voltage or frequency go outside a narrow operating range.
  - Certified inverters do this by employing an active anti-islanding scheme.
FERC Order No. 661: Require Plants to (*) :

- Have Ride-through Capability.
- Maintain PF within 0.95 Leading to 0.95 Lagging.
- Have Sufficient Reactive Power Capability.

- However, FERC does not mandate any specific solution to provide the necessary reactive capability, and does not stipulate that this reactive power capability be dynamic unless the System Impact Study shows that it is needed.

(*) Transmission Provider has to show through System Impact Study that above requirements are needed to Ensure Reliability and Safety
Regulatory Incentives  
State Level (US)

- RPS - The State Renewable Portfolio Standards (US).
- RPS Requirements & Goals in 30 States plus District of Columbia (2009)

- Considerable Diversity Among States with respect to:
  - Minimum Requirements of Renewable Energy
  - Implementation Timing
  - Eligible Technologies

- RPS Primarily Mandatory → 15% to 30% Penetration Level Targets by 2020.

- Penalties for Noncompliance, either in the form of Fines or an Alternative Compliance Payment (ACP).
  - An ACP Requires Suppliers to Pay a Predetermined Amount (per kilowatt-hour) if they Fall Short in Meeting the RPS.
90% (626MW) of the 2011 Utility-Sector Installations were in States with RPS Requirements

FERC Initiated Several Market reforms to allow all resources, including Renewables, to Compete in their Respective Markets.

FERC proposed amendments to Market Rules, to Ancillary Services Guidelines, and other related policies, in order to achieve Reliable Integration of Renewables.

FERC actions are expected to increase the amount of electricity produced from renewable energy resources.

FERC Order No. 764: Schedule transmission service on a 15 minute basis.
  - Generator imbalance: Deviation band of +/- 10 percent (min. of 2 MW)
  - Net hourly intermittent generator imbalances within the deviation band to be settled at the system incremental cost at the time of the imbalance.
Regulatory Incentives
The European Council

Climate & Energy Package:

- Aims to ensure that the European Union meets its ambitious Climate and Energy Targets for 2020.
- The "20-20-20" targets, set the following three key objectives for Safe, Competitive and Sustainable Energy in Europe:
  - Reduce Greenhouse Gas Emissions by 20%;
  - To Improve Energy Efficiency by 20%;
  - To Boost the Share of Renewables in the Total Energy Consumption to 20% (compared to 10% in 2007).
Worldwide Solar PV Production

World PV Cell/Module Production from 1990 to 2008

Source: PV Status Report 2009, Renewable Energy Unit, European Commission
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‘Smart Grids’ will be needed to maximize contribution from solar systems while preserving the integrity of the network.
• When generation and load patterns change, traditional Voltage Control methods may not be sufficient to maintain statutory voltages at customers’ substations.

• Voltage signals from key customers’ substations can be sent to primary substations where appropriate voltage control actions can be initiated to improve voltage profiles across a network.

• Minimize feeder losses by managing reactive power flows and other network parameters.

• Smart grids can also help in finding the optimal mix of generation and load by matching generation costs and locations with the various loading schedules across the network with the objective of maximizing reliability and minimizing cost.
**Demand Response:** End users ability to reduce their electric load in response to price signals or other incentives and regulations.

- 8% of energy consumers in the United States are participating in some form of DR program (FERC 2008).
- Potential DR resource contribution from all U.S. programs is close to 41 GW, or about 5.8% of U.S. peak demand (FERC 2008).
- Demand response has increased in popularity due to advances in communication & control technologies, which can allow the use of DR to be expanded farther, which can allow DR to be used as a capacity and energy resource.
- Demand response provides much-needed flexibility to the power system.
- Provides an automated dispatchable load resource capable of responding within seconds and can be used for regulation service and contingency reserves.
CONCLUSION

• Solar has many benefits over conventional power, but none more obvious than being driven by a “fuel” delivered by nature, free of charge.

• Higher penetration levels of intermittent resources create new challenges for integration into existing electrical networks.

• Solar resources can boost system voltage and dynamic stability.

• Adding Transmission line capacity and building ultra-high voltage super grids are needed to carry output of solar generation long distance to major load pockets.

• Global standards & Grid Codes lay the groundwork for interoperability, innovation, and economies of scale to help integrate renewable generation and associated power electronics equipment into power systems.
CONCLUSION

• Progression in storage technologies with commercial viability can fill the gap during intermittency, or until standby generation can ramp up.
• Smart management of the grid can play a pivotal role in managing power flows, minimizing standby capacity from fossil fuels and nuclear, and regulating intermittent generation.
• Interoperability between smart grid devices and systems requires advanced monitoring, adaptive controls, intelligent two-way communication with distribution & substation automation equipment, and state of the art communication architecture.
• Solar is “energy independence” but needs proper mix of new technologies, modern transmission infrastructure, good planning, and proper regulation.
• Attractive incentives have to be in place to carry the momentum quantum leap......
Thank You
The Principle of Statistical Independence

Electric power systems comprise a very large number of components. A typical utility service territory (or market area) includes many thousands of individual customers. The behavior of these customers exhibits some statistical correlation over some time periods, but has little correlation over other periods. During the morning load pickup, customers are generally increasing their usage of electrical devices, leading to an overall increase in electric demand. However, during very short periods of time, on the order of seconds to minutes, some loads are increasing at the same time that other loads are decreasing. There is no correlation between these random events; one customer turns on the lights at the same time as another customer turns off the lights. These events, when they occur simultaneously, have no net impact on electrical demand. This case is perfect negative correlation. More generally, there may be a lack of correlation: sometimes there is coincidence, and sometimes not.

Solar PV panels or PV plants that are spread over a broad geographic area have a similar statistical property. During the short time periods of seconds or possibly minutes, one plant may be experiencing an increase in insolation, resulting in more electrical output from the PV plant. At the same moment, another PV plant (or panel) may experience a decline in insolation and power output. The random nature of these events can be captured statistically and formally described as uncorrelated events. It is important to note that if PV location A always runs counter to PV location B, then they are perfectly negatively correlated (correlation coefficient is -1). But if sometimes they move together, and other times move in opposite directions, this lack of correlation has important implications for balancing requirements.

The principle of statistical independence is the reason why each increase in customer demand (resulting from a switched on light, for example) does not need to be matched by a corresponding increase in generation. Because some customers are switching off their lights at the same time when others are turning theirs on, statistical methods can be used to calculate the amount of generation required to match the aggregate change in load. The principle of statistical independence over short time frames applies to loads; solar energy; wind turbines; and to load, solar, and wind combined. The DOE document illustrates this concept in several different contexts: load, solar, wind, and all three combined. Forecasts for all three are subject to the principle of statistical independence.