Grid Integration of Solar Energy Workshop

Important: The bullets below are an attempt to represent the opinions and input shared by workshop attendees. They are not a statement of the opinions of the U.S. Department of Energy.

Breakout Session 1

What grid architectural objectives are required to achieve seamless, real-time integration of hundreds of GW of solar at the $0.06/kWh SunShot goal?

- Need a clear definition of architectural objectives
    - Consider services that architecture needs to provide, e.g. Distribution System Operator (DSO) concept
    - Very much dependent on policy, market, and regulatory framework, e.g. Regulation 2.0 vs. utility 2.0
    - Need to establish a focus for various objectives, e.g. protection, operations, visibility, security, economic
    - Need to establish metrics and run trade-off analysis
    - Need clearer definition of what LCOE includes
- Necessary attributes of grid architecture
    - Need a research-based taxonomy of grid architecture
    - Need a roadmap for what capabilities and when
    - Need to consider energy, market, communication, and data layers
    - Need to allow design flexibility, i.e. central vs distributed
- Need common models and policies for data
    - Coherent view of information on spatial and temporal data of varying granularity
    - Allowing consideration for data ownership, security and privacy
    - Consider what/when/ why data need to be collected, where it resides, and who can have access.
    - Consider data lifecycles including collection, quality assurance, analytics, storage, hosting, and retirement
- Modeling Capability Needs
    - Transmission/Distribution Interface
        - Consolidation of transmission and distribution models/networks
        - Seamless merging of distribution and transmission
    - Distribution/Consumer Interface
        - Customer side needs to be represented on the distribution models
        - Real-time prices for customers
    - Distribution/Generation Interface
    - Time-series analysis
        - Currently no real-time modeling of distribution grid
        - Need tracking of distribution data

    - Time-scale variability
    - Address Uncertainty (of future load profiles, weather, etc. built in)
    - Vertical and horizontal integration
    - Flexibility
    - Model-free data
    - Interoperability
        - Do you need them all to talk to each other?
        - What information needs to be transacted?
    - Speed
        - Fast time response vs. reduction of complexity
        - Cloud, GPUs, Algorithms

What technology breakthroughs are required to achieve seamless, real-time integration of 100s of GW of solar at the $0.06/kWh SunShot goal?

- Smart controller (behind-the-meter)
    - Plug-and-play
    - Flexible load control, storage, generation, forecasting
- Hierarchical modeling that can handle hierarchical control
    - Larger and larger distributed networks
    - With rings of confidence levels
- Model-free data
    - Data that is not particular to any one model, but rather can be used for any model
    - Won't stifle innovation
- Cost-effective routing of power
    - Reduced cost of power electronics
    - Active electricity routing (tech needed)
- Big data
    - Cloud computing
- Transparency in pricing
    - Common, consistent, easily translatable language around pricing structures
    - Economics and pricing info available and easily digestible and transparent
- Algorithms
    - Extended to millions of buses
- Distribution Control
    - Distributed control versus central control
        - Define and integrate
        - Standardization and regulation
    - Democratic vs. proprietary – regulation and incentive
    - Data for predictive analytics are necessary for strategy and planning
    - Secondary data and lack of distribution of data disconnects distributed power
        - Due to 'engineer-and-forget' practice vs. active collection/response practice
    - Smaller timescale = more data = more potential solutions. Perhaps too many?
        - Aggregator handling individual residences – system of being able to access
    - Cloud – leads to sharing/user interface
- Control System/Modeling
    - Distributed control intelligence at every node
    - Need technologies at different levels that can respond autonomously in real time that is coordinated and bottom up (esp. when thinking about rooftop solar)

    - Using EMS, but getting all the data and integrating with system level knowledge is complicated, immature
    - DERMs are out there but need added functionality and interoperability
    - Integration of various Distributed Energy Resource Management Systems (DERMS), Outage Management Systems (OMS), Direct Memory Access (DMA), Building Management Systems (BMS), Supervisory Control and Data Acquisition (SCADA), etc.
        - Interoperability: What information should be moving between them?
    - Once you get beyond 3 phase devices, the DMS is blind to them
    - Work to be done in utility software packages, e.g. lack of good storage models in SS simulations
- Control Interfaces
    - Can battery storage modulate output of solar panel?
    - Not designed for high speed control: Issue with intermittency
- Energy storage
    - Will enable more solar deployment should costs decrease
    - Battery systems need local economic analysis
- Cost
    - Life-cycle cost: measurement based, condition based modeling and maintenance
- Communication requirements and challenges
    - Latency for wireless communications, not designed for this application
    - Communication standards and management for batteries and inverters
    - Large-scale management system across large geographical areas
    - Requirements for reliability and availability – utility grade as compared to consumer internet grade. Must quantify what we need.
- Sensing
    - Multimode – tying measurement into the inverter that can be accessed remotely
    - Sensing on the fly versus continuous.
    - Informatics: collecting, deciding what to collect, and sufficiently sharing data effectively.
- Use energy in DC form rather than converting to AC from conversion efficiency
    - Challenge of communication through DC-DC: prevent loss through inverter but still get the information
- Communications
    - Integrating different smart inverters, sensors, energy storage related inverters is difficult
    - Can the network bandwidth handle the level of communication needed?
    - Technologies will be a function of the architectures they are a part of, e.g. some technologies may require fiber networks
- Data
    - What data do we have today? What data do we need to have? What ultimately will we need at different hierarchies?
    - AMI data going to billing at utility, not operations
    - Data processing and display
- Reliability is a factor that needs to be considered throughout

What lessons learned from other industries can be leveraged towards achieving the breakthroughs in question #2? What other industries that historically haven't been involved in grid integration challenges need to be involved to achieve these goals?

- Telecommunications/cable providers: packaged services, reliability
- Cellular industry: plug-and-play, reliability, commissioning, technology providers
- Transportation and logistics
- Electronics design and automation industry: PSpice
- Airport traffic control towers: good at scheduling, handling weather
- Aerospace: Model based systems engineering – like with CAD to save time and money, plan ahead of time. But it's not just CAD, also includes synthesizing, life-cycle management, very complex system with many steps. System intelligence
- Automotive/Flight control: international standards, interoperability, PLM concepts
- Finance/banking/credit card industry: processing millions of transactions real time
- Amazon/Uber/Walmart: model of "hosting" items/service, scheduling, ops research, competitive commodity business
- Cyber security lessons across all: oil & gas distribution
- Other Nations: centralized systems, time of use rates in E. Europe – policies in general use
- Data Sciences: predictive marketing, controls, machine learning, social media
- Behavioral Sciences: nudge people to make choices in automated future, requires perception shift
- Internet philosophy
    - Intelligence for management and control of the network at many levels, not just at the edge
    - Layer architecture: moving active power
    - Demand response analogies to communications network
- Existing utilities: experience in deploying these technologies. May need to do this in an incremental way. Need to have several views of management – high level down to smaller geographical areas
- Apples/Facebooks/Googles
    - Make electricity attractive, lesson to be learned somewhere, customer-utility relationship, this conversation touches on public policy
    - Taking aggregated data and making it accessible
- ERCOT: Large scale integration of wind supported by improved forecasting, analytics
- Military: some things related to energy have already been done, but information is inaccessible
- Weather forecasting industry: analytics, predictions
- Industrial automation: control of many "nodes"
- Biology field: bottom up modeling
- Mathematics
    - Simplifying complex concepts, e.g. fractal grids, scaling micro-grids, DC nanogrids
    - Distributed approach to self-healing, data correction
- USB: plug-and-play nature

How can existing standards be leveraged and what new standards should be implemented to achieve seamless, real-time integration of solar energy?

- Fewer/streamlined standards drives innovation
    - In some cases, regulation limits what is technologically possible

- Integration vs. Federation:
  - Federation, putting disparate things together, they can work independently
- Standards
  - See standards coming from digital, rather than analog. Richer languages for standards.
  - Have both too many and not enough standards, perhaps they are just not the right ones
  - Standards have to escape from proprietary solutions, a historical issue within utility industry
  - Need to understand where the gaps are in current standards
- Standards Process
  - Should not rush too fast into standards, need to allow more room for research
  - Standards process is as important as the standards themselves
  - Community needs to simplify the standardization landscape
  - Inefficiencies in standard formation (e.g., 1547, a DG standard, took 6-7 years to get an idea though)
  - Streamlining standard development process, difficult and time consuming process
  - Quickly changing standards with new technology has risks for stranded assets
  - IETF – document set out for request for comments
  - State by state approach is nonsensical
  - Include academic participation
  - Manufacturers cannot provide the solution: they do not have the final say
  - Need the ability to develop products as the standards are developed
- Relevant Standards:
  - IEC 61850 – implementing microgrid controllers
  - Electricity Rule 21 in California: smart inverter, applied 61850, IEE2030.5
  - Leverage existing SGIP and NIST platform
  - Open FMB
  - Use DR – open ADR 2.0a and 2.0b – established standards
  - IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems
  - UL 1741 Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources
  - Data interchange standards – DNP3, IEC 61850, MultiSpeak, ICCP
- NERC transmission standards
  - Unsustainable in distributed systems; doesn't have the regulation structure in place
- Areas of Interest
  - DC-DC: need to be developed further, especially for open standard SAE Combo
  - Building system integrated with whole PV system. Standards mismatch.
  - Standards for behind the 1547 interconnection: Battery/storage/emergency bus systems regulation
  - Standards regarding resiliency and reliability
  - Inverter communication standardization is important

Are there other major concerns that need to be addressed to effectively achieve 100s GWs of solar energy on the electric grid?

- Use cases for solar introduction
  - Availability of use-case analysis of historical solar systems
- Not underestimating the challenges it will take, even for "progressive utilities"
  - SCADA is new to some utilities
  - A utility handbook or program that facilitates the transition could be something of interest
  - Benefits and impacts of DER need better understanding

- Customer side: education, inspiration, understanding
- Taxonomy issues

Breakout Session 2

How can the solutions from the individual focus areas in Breakout Session 1 be combined as a system-level approach to achieve seamless, real-time integration of 100s of GW of solar energy into the electric grid at SunShot cost targets?

- Interoperability
    - Linking data and models in real-time
    - Functional Mockup Interfaces (FMI) could be used as glue to link models together
    - Flexibility of data used within similar models: design, planning, operations
    - Improved interface of behind meter and secondary side and substation.
        - Although similar modeling capabilities for the transmission system are well known, few do secondary system mapping.
    - Model-free data
    - Open source/commercial models exist and are being combined with others. Limited use.
    - National Labs have many different tools that do similar things
        - look into consolidation/integration/cooperation
- Modeling
    - Understanding temporal and spatial scale will characterize the requirements for the models, the data supports/validates the models
        - Real time integration, need to solve power analysis problems very quickly, must be integrated into utility tools (currently can't handle QSTS analysis)
        - State estimation programs – weather forecasting is separate from power systems analysis
        - Abstraction at different granularities can drive model formation for system integration
    - Integrated economic, technical, and regulatory aware modeling
    - Sequencing of modernizing the grid to handle high penetration solar
    - Different models for: before meter, distribution, transmission, generation
        - Roadmaps for what capabilities and when; maturity models
    - Mismatch between models of project assessment and interconnection approval
    - Interconnection should proactively look to use new services
    - Co-simulation tools for holistic analysis
    - Timescale is necessary for operations and controls.
- System level approach for distribution management that will lead to system-wide intelligence
    - Need for architectural guidelines, not to be confused with reference design
    - Holistic vs. silos – multidisciplinary aspects crucial
        - Transition from serial mode to parallel mode, need for systems approach that enables distribution design and engineering, development community, policymakers
        - Research community is fragmented in priority and focus

        - Utility/distribution design and planning engineers/development community/policy makers/regulators need to be involved in the early stage system planning and design
        - Create a construct where planning, security, communications are all a part of design from the beginning
        - Cross-talk/handoff at early stage of development
    - Partnerships
        - Between industry and university to utilize research technology sitting in academia
        - Between generator/provider (traditionally utility) and consumer in decision-making process
        - Should be required in the solicitation to groups asking them to make solutions
    - Education gap, professional development, teach utility folks on system level approaches
    - Convergence of operations and planning systems
        - Standardized models for PV systems
        - Create a better data interaction
        - Push toward real-time operation
        - Planning supports operation role, e.g. sensors to provide visibility
        - Converting instead of converging
- Need for objectives (economic, resilience, reliability, carbon reduction), then bring use cases into the picture, and afterward find solutions
    - Use-cases: different utilities have varying resources, wide range of capabilities, this has implications for *sequencing* or O&M upgrade schedules
        - Are there commonalities to all utilities?
    - Model approaches, different locations and market structures (over 4000 utilities), providing a common path forward that is driven by the industry
- What do we want to control, why do we want to control it, and is it controllable?
    - With 100 GW of solar producing power at the same time, would the system use this real-time? Would it require storage?
    - Narrow the challenges: is there any minimum scope where solar could be absorbed by current architecture without completely overhauling what we have?
    - What capacity of spinning reserve is necessary to support a certain percentage of solar deployed?
    - We do not have tools to judge capacity of feeders. 15%+ on feeders requires further analysis.
- Cost/benefit framework
    - Who is going to pay for it? (technological costs)
    - What does the benefit look like? (Immediate vs. avoided cost, environmental, etc.)
    - What is the future cost to the customer if we do nothing?

How would you construct a scalable demonstration for testing of solutions?

- Picking a demonstration site/representative feeder
    - Representative sample of feeder is infeasible: test areas are vastly different
    - Diversity of utilities across a broad regional area might give a good demonstration test case
    - What is the right demonstration scale?
    - A regional grid test-bed? (DOE, National lab, private?)
- Utility
    - Smaller utilities: can take more risks, flexibility, very little regulation

  - Larger IOUs: more capability, lab resources
  - Share knowledge with Municipals and co-ops
  - Difference between an exploratory project and a utility specific technical problem
    - Touch base with utilities on their specific challenges
    - Value propositions for the participants must be clearly defined, especially for real world scenarios
  - How do you procure resources in an urban area? Especially for larger scale projects.
  - Cost is the most important factor most times. Regulation is often not technologically based. Technical solutions may be effective but also more expensive.
- Design of Experiments
  - Should be involved for selection of best experiments to proceed
  - Could be used to evaluate previous demo projects
- Bridging the gap between simulation → demonstration → deployment
  - Begin with software simulations, augment software to interact with hardware (small scale), and continue to have hardware in the loop with larger software simulation. Continue to have hardware in the model. Is there a space where software simulations can interact with both small demo and real world implementations?
  - How is a controllable hardware test done in a distributed way?
    - How do you simulate distribution feeders?
    - Especially with in-the-loop hardware capability?
- Scalable demonstration requires:
  - Realistic, cost-effective demonstrations need established local infrastructure/investment
  - Repeatable and interconnected standards for scalability
  - Define scalability requirements, goals, and performance metrics
  - Plan for persistence of the demonstration, what are the requirements
  - Explicit risk management strategy with mitigation practices defined
  - Technical requirements based on required capabilities that will scale
  - Sustained management buy in, leadership
  - Data based decision-making
  - Business model independence to apply to any and all utility business models
    - There are similarities between utilities of the same sub-type (IOU, co-op, municipal)
  - Demos may need to be model based to accommodate
- Test beds already exist
  - Rather than build another site, learn from existing sites and make that information available to all
  - PG&E test bed: 12 kV, can plug in any feeder model into software modeling.
  - ESIF test bed: publicly available user facility
  - Maui: small island test systems
  - PJM
- Tools necessary for modeling, analysis, and simulation
  - Currently not sufficient, having to make a lot of assumptions
  - Tool should be able to convert existing models from vendors (standardization) for different types of distributed generation (wind, solar, etc.)
  - Then, verify simulation models with test bed, use feedback to improve, finally use in field testing. Iterative approach for improving tools. At what level are you confident enough for widespread deployment?
  - Lessons to learn from high voltage testing environments: build a facility that is flexible to test for different conditions – feeder and solar related test bed
  - How do you test a system with large amounts of distributed resources?
    - currently don't have the detailed information

        - include flexibility aspect to build features you want
    - Test customer interaction
    - Access is a concern, remote experiments, web connectivity
    - Integrated Modeling environments
        - Build out a computer system/model to test out in steps to expose potential problems
        - Test bed (simulation environment) should consist of representation of grid, control system, generation units, iterations should also include security
        - Use available data to build starting model, and for validation of model
        - Scale: usable for predicting based upon certain conditions
    - "Virtual Machine"
    - Does Simulation hardware software exist that is scalable?
        - 10,000 buses (100k single phase nodes) T&D system – min number. 10x better at transient time scales
        - Currently cannot model transient stability – can this barrier be broken in power engineering. Need to know which time-scale to simulate
- Academic viewpoint
    - Hard part is finding the partners
    - Communication interfaces and metering fairly standardized
    - Pick a sliver of an application to demonstrate scalability, not a complete solution
- Funding aspect
    - Value proposition: e.g. vendors/utilities split cost to fix "worst 50 circuits"
    - License sharing
    - Local economic development funds
- IP issues with partnerships
    - Some utilities offer vendor pilots, but IP issues can arise (the IP could potentially be taken from the vendor)
        - Also, a vendor could come in and pony up half the cash, the outcome is that they are out if it doesn't work, but if it does work there has to be a flow towards further value, explicitly stated (not just moving to the next pilot)
- A database of where the existing solar is installed across the nation would assist in future integration to identify where future challenges will exist, for example state by state.
    - Visualization of where solar is located in a service area would be useful for utilities as a long term planning tool

What regulatory challenges will need to be addressed to achieve the goal of seamless, real-time integration of 100s of GW of solar energy into the electric grid at SunShot cost targets?

- R&D Environment
    - Utility willingness to innovate restricted by commissioners and regulators
    - No flexibility/very structured
    - Standards need to be flexible so that utilities have room to innovate
    - Investment vs. innovation with risk
    - Utilities are typically denied cost recovery for new research endeavors
    - If utilities run pilots/demos regulators should be open to failures ease of approvals
- Partnerships
    - Collaboration

        - Smart inverter working group was successful, used use cases and technical requirements, vendors were involved (not always thrilled)
        - Get all utilities in the room and make big decisions about interconnection
- Rate structure regulation should be more dynamic.
    - Primary driver for stakeholder engagement on both production and end-use
- Third-party development to utility. Streamlined process/ease of communications.
    - Utility needs communication beyond EPRI.
    - Utilities are directed away from research and subsequent funding.
    - Help utilities with research identifying benefits of high penetration of solar. Previous research has been on impacts, specifically negative impacts. Put together a value proposition to assist utilities rather than mandating them to reach certain levels of solar. Show them the benefits.
    - Think about additional assets that utilities can control for their own benefits
- Data privacy
    - Customers may be willing to share data for the greater good if the process was made easy and provided feedback
    - Challenge about sharing and what to share in terms of data – who do you share with, what data are you allowed to collect
- Legislators
    - Politicians get involved, concerns about re-electability, dynamic situation, political force vs. regulatory force
    - Remember that regulators apply law, need to address legislative side of things
- Regulators
    - Bringing the regulating bodies with us towards innovation, things seems piecemeal, but this is driven by regulation
    - Regulators: Who do I trust? Looking for unbiased assessments. Perhaps find an unbiased, objective group to provide resources that regulators can trust.
    - Access to data from utilities is currently not possible. Can aspects of this be made available?
    - IEEE is putting together a data repository
    - Uncertainty/risk stem from regulatory changes
    - Regulatory experimentation (FERC, net-metering, etc.)
        - What if FERC got into distribution system regulation?
    - Valuation methodologies for assets or integrated assets
        - Currently done by the states "favorite consultant"
    - Regulatory mandate, gives certainty to all stakeholders (more important to be certain than good)
        - Multiple markets can play on the same principals/rules that regulators set (e.g. PJM)
    - Assume a market interface to bulk power from distribution system, requires matching on time scales and dynamically run markets (like commodity markets)
    - Tie utility performance to future returns
    - High penetration solar challenges the regulatory model; utilities are based on natural monopoly model
- Subsidy
    - All technology and infrastructure has used government subsidy: Why write it off, why does SunShot want to end up in a place with no subsidy?
    - State subsidies are a huge piece of the pie
    - Easy to start a subsidy, hard to wean off; should be part of the subsidy planning process
- All states have unique regulations
    - Knowledge and tools should be shared from solar-success states to states looking to establish new regulations.

    - Tools: create consensus on tool use, commonality and level
- Jurisdictional challenges
    - State, federal, municipal have an impact on penetration rate of solar
    - Policy appropriateness at the fed and state level, mandates may be more impactful
- Tariffs or rates that allocate costs and service

How do you measure progress toward these solutions? What metrics should be used?

- Expanded LCOE with transmission and distribution costs is essential.
    - Difficult to assess broadly. Regional differences.
    - What are the potential values of new services?
    - Is there a 'PUC type' cost benefit analysis available?
    - What is LCOE with storage and demand response?
    - System size vs. cost of interconnection and regulation
- How do you quantify/value:
    - Reliability, currently measured by IEEE.
    - Outage contingency
    - Safety
    - GHG emissions, Decarbonization
    - Currently no metric for resiliency
- Research point-of-view
    - Very complex to set such metrics for overall progress
    - Indirect measurement: e.g. when topics get hot, it is clear by articles, student interest, faculty positions
    - Direct measurement: e.g. number of startups spun out of research
- Metrics will skew to each utility/environment; they should come from ISOs and independent bodies, third party verification
- Metrics (what we should start measuring):
    - The amount of PV deployed versus capacity.
    - PV output vs. GHG reduction
        - RPS doesn't count for rooftop solar in some states
    - Many utilities don't model secondary feeders
    - Scaling
        - 100,000s of buses processed by models
        - 100s of gigabytes per hour
    - Penetration by feeder, by region/district, over time
    - Maintained reserves to support solar
    - Energy security issues
    - Amount of maintenance can you defer due to your solar deployment?
    - Planning metrics
        - Probabilistic hosting capacity
    - Reliability per kWh solar installed
    - Cost of ramping reserves
    - Profitability of solar companies
    - Peak production per feeder, region, ISO jurisdiction, etc.
    - Successful circuit performance at high penetration
        - No breakers tripping due to reverse power flows
        - No damage to equipment

        - No increase in voltage regulator actions and load tap step changes
        - Improves power quality on circuit
        - Capability of sensing and clearing faults, dynamic protection
    - Evolution of load duration curves
    - How much of the solar generation is dispatchable over time?
    - Income status of solar system hosting households
    - Weather affecting energy availability of system
    - Voltages, Power factor, Regulators, Capacitor banks, Equipment loading, Power flows, Loss Profiles
    - Smart inverters – active power injection and reactive power
    - Fault analysis – in some utilities, relays installed have the capability to record this data. Modern relays have this capability. Measuring accuracy of tools to predict reality
    - Consider reliability of the panel itself – modularize the design.
    - Define Critical vs. non-critical loads
    - Flexibility in generation load
- (Update old metrics) Each of GMLC areas
    - Availability: combination of visibility and controllability
    - Visibility
        - How much is necessary? Needs to be studied and analyzed.
        - Two pieces: catalog of all devices out there and real-time awareness
        - Voltage down to the customer transformer/meter
    - Controllability
        - At what scale? In aggregation. Ideally: close to 100% in grid-supportive control mode. Some are autonomous, some in a more directly controlled way
- Low/ Loss of System Inertia, Frequency Stability
    - Start with simulation which observes at necessary resolution to observe inertia in a system
    - Is the inertia in the system changing? Do you want to have synthetic inertia?
- Verification of effectiveness of solutions
    - Thresholds