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Occam's Multi Tool: Five Principles for Comparing Grid Modernization Alternatives

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1.0 The Issue

As grid modernization evolves, regulators, utility executives and engineers, product developers, integrators, energy services organizations, and prosumers are faced with many competing options for grid architectures, industry structures, and functional and role assignments, and technical implementations. Reams of complex and sometimes contradictory reports, studies, analyses, and simulations exist to inform decisions, many of which involve large scale investments. Here we introduce Occam's Multi-Tool, a set of decision heuristics that support differential analysis of competing alternatives for grid options. This multi-tool can and should be applied at the earliest stages of grid decision making at the regulatory, architecture, planning, design, and procurement processes.

Occam's Multi-Tool consists of five principles that, much like Occam's razor,[1] help provide clarity when comparing grid alternatives. To use this multi-tool, we make the following stipulations:

- We are comparing two or more alternatives that, to within 20%, provide the same outcome.
- We ignore the issue of whether a particular technology, existing or developing, works or can work. We presume here that they do or will.
- We set aside cost issues for the most part, as these are moving targets and we seek decision support concepts that do not require or depend on cost estimates or projections.

One of the alternatives under comparative analysis can always be what presently exists in the grid, so we may compare the Business as Usual option to a proposed change. In addition, while the Multi-Tool was conceived as a means to perform differential analysis, in fact it can be applied to analysis of individual grid elements, architectures, designs, etc. since the alternative is always Business as Usual.
The tool definitions are based on a collection of issues that matter well before getting to any considerations of cost and technical performance. They are:

1. Customers/Consumers/Prosumers – The grid exists to serve the public good as a regulated monopoly. As such, the requirements and wishes of these stakeholders must figure into grid modernization decisions.
2. Starting Points – The grid represents an enormous amount of legacy infrastructure, equipment, regulations, and processes. This means that consideration of changes cannot be zero-based.
3. Assumptions – Because of the starting point issue, assumptions can exist that are not explicitly recognized; clarity of assumptions facilitates clarity of decisions.
4. Objectives – Given the diversity of parties involved in electricity delivery, multiple objectives are always present, and they may compete, or even be in conflict. Formulation of objectives must account for the points listed above and lead to control/coordination federation and disaggregation as well as support for local selfish optimization within a global (whole system) coordination framework.
5. Context – Any change to the grid exists within the context of the whole grid, and changes in one part can have impact throughout the grid. Understanding context means understanding the multi-layered set of relationships that define the grid.
6. Structure – In large measure, structure is the context for the grid: circuit structure, industry structure, control and coordination structure, ICT structure, market, and regulatory structure, etc. At a most

[1] P Gibbs and S Hiroshi, *What is Occam's Razor?,* 1997, available online: http://math.ucr.edu/home/baez/physics/General/occam.html

basic level, circuit topology and connectivity are the context for interpreting sensor data and control actions, but the principle of structure as context is general and universal.

7. Models – These are systematic descriptions of objects, systems, or processes that share important characteristics with the thing being modeled. Models can be verbal (text), graphical, mathematical, or computational (simulations). Models aid in reasoning about complex systems or problems. It is of course crucial to use appropriate and accurate models.

In the following section, we define and describe the five implements of Occam’s Multi-Tool and provide short case studies of their application.

2.0 Five Tools for Comparing Grid Options

The tools are presented in the form of questions that are intended to be posed for each of the alternatives, resulting in a differential analysis of the options. To apply a tool, ask and answer the question for each alternative, and then compare the results.

2.1 Tool 1: Do Objectives or Outcomes Align with Public Good and Consumer Wishes?

There are two issues here, and while they both relate to customers/consumers (i.e. grid users), one is a global/systemic view, and one is a more direct consumer view. These views emanate from different stakeholder perspectives can often be in tension with each other. In fact, grid user viewpoints can also be many and diverse, especially in a prosumer/ESO/community energy network environment.

2.1.1 Case Study 1A: Load Following vs. Generation Following

The traditional grid was developed using the model that generation follows load and extensive and sophisticated controls and, in some regions, real time market mechanisms exist to implement that model. This model presumes that the grid exists to serve the customers and that sufficient capacity will be provided to ensure that customers can use as much energy as they want when they want it. The cost of providing this capacity is spread over the ratepayers.

The alternate model is for load to follow generation. This approach, which has arisen partly in response to the increasing use of VER and partly in response to the desire to avoid capital expenditures for capacity, changes the fundamental assumption about users to one in which users are expected to adjust their usage patterns to fit the needs of the grid.

Analysis: The alternate model loses sight of the basic reason the grid exists – to provide electric service. Instead of doing so, the generation-following model expects the users to serve the grid in order to enable VER. Some users may be willing to do this for various reasons, but no user actually wants to do this. Since VER adoption can be driven by public policy, this is an example of the tension between the global view (VER is good for society) and the user view (using the amount of electricity I want when I want it). The generation-following model represents a shift of grid constraints onto the consumer, rather than meeting the customers' needs by applying innovation to ensure abundant energy.

Conclusion: Generation following misaligns with customer wishes but may align with a concept of public good. Consequently, this would have to be weighed with the same consideration for an alternative and since it is likely that judgments will be made based on stakeholder perspectives, it may be necessary to employ additional tools to decide.

2.1.2 Case Study 1B: ToU Rates vs. Flat Rates

A related case is the application of Time-of-Use rates for electricity use by residential consumers. As opposed to the standard approach of applying flat usage rates common in the US. The idea is that Time of Use rates relate actual production costs to prices and incentive users to adjust usage to fit the utility's supply constraints, by making demand curves less peaky.

Analysis: Clearly consumers do not want to have such rates as various experiences have shown for both communications,[1] and electric power.[2] In fact, there is a clear lesson from the telecommunication industry, which in the early days of cell phones had day rates and night rates. This was due to capacity limits, but customers hated it. When flat rates were made available, users flocked to them. As capacity increased, the time-of-use cell phone rates disappeared. Clearly, the time-of- use rates were another example of pushing system constraints onto the users, in conflict with the users' wishes.

Conclusion: Pushing system constraints onto the users is a losing approach in the long term. The customers' interest is in having systems whose constraints *are handled internally* and not by forcing them out onto the users.

2.2 Tool 2: How Many Things Must Change?

Given two or more alterations to the grid with nearly equal outcomes, benefits, or results, there may be significant differences in the number of things that must change for the proposed alternatives to become used and useful. Given near equality in outcomes, the one with the least number of required changes to the present grid is the alternative most likely to happen, especially in the near term. We view it as reasonable that this indicates relative likelihood of success as well. Factors that might override this are legislative or regulatory imperatives (see Tool 1) or public recognition of such high value that the change is accepted (see smart phones for an example of this effect). Note that this tool **does not** refer to the complexity of the resulting new system; in fact, the new system might be of the same order of complexity as the starting point or alternative or may even result in some simplification. It is the "**magnitude" of the transition** that is of importance here, not the complexity of the solution, and we measure that simply by counting the number of elements that must change.

2.2.1 Case Study 2: DR/IoT vs. Storage

This case is a concrete example of two alternatives to dealing with system constraints. Alternative 1 is the transactive grid approach, wherein loads are intelligent and are able to react to signals from the grid to modify their behavior in order to benefit the grid. In this approach, load devices are IoT[3] devices, containing programmable processors and communication links, usually to the internet. Individual devices like refrigerators, lights, hand appliances washers and dryers, HVAC thermostat/controllers, and motors for pumps, fans, etc. are all able to respond to grid signals. They interact with grid control by negotiating with the grid and bidding against each other to provide grid services (in this case Demand Response for purposes such as demand curve modification, and frequency regulation). They may operate through aggregators, who act as intermediaries in the negotiation and dispatch processes. Measurement and verification systems and software are needed to compute the compensation for DR owners and provide settlements. Some form of incentive is needed to get users to participate, and they must acquire and install the DR/IoT devices themselves.

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[1] H Mitomo and T Mitsuka, *Consumers' Preference for Flat Rates: A Case of Media Access Fees*, August 2015, available online: https://www.researchgate.net/publication/228463908_Consumers%27_Preference_for_Flat_Rates_A_Case_of_Media_Access_Fees

[2] E Petrill, et. al., *Characterizing Customer Preferences: How the Doritos Nachos Method Works for Electricity Service Plans*, EPRI, Behavior, Energy and Climate Conference, October 2015, available online: http://escholarship.org/uc/item/5pc2v48v#page-1

[3] Internet of Things

The second alternative is to put grid scale battery storage in distribution substations. Storage is used to provide the same set of capabilities as the DR/IoT option, but storage units are controlled directly and can be connected to utility communication networks and control systems. Third party merchant storage units can be integrated in the same manner, with capacity contracts for compensation to the merchants.

For the IoT approach to work, massive numbers of home devices must be replaced with IoT-enabled versions, meaning a major turnover or modification of tens of millions of devices. Next, utilities must have new control/coordination systems that can work with these devices. Then, utilities must have communication interfaces and protocols that align with protocols in the IoT devices, and must have interconnection agreements ("grid codes") that specify how IoT devices can interact with the grid.[4] Device developers and system integrators must develop the means to comply with these grid codes.

For the storage alternative, utilities must be able to install large equipment in substations and to integrate it with existing utility control and communication systems. New control algorithms are needed to control the storage units.

The IoT alternative requires massive changes in millions of devices, including all manner of consumer devices and equipment. It also requires extensive changes to utility control and communications, new interfaces to non-utility equipment, new business models, new regulatory rules, new compensation schemes for prosumers, and interactions with customers, aggregators, or merchant vendors.

The storage option requires that utilities place equipment in existing substations and make small changes to control systems. No changes are needed to business models, regulatory rules, or customer interfaces.

Conclusion: The storage alternative involves far fewer changes than the IoT alternative and is therefore much more achievable and likely option for the grid than the DR/IoT approach.

2.3 Tool 3: Are Systemic Weakness Introduced or Amplified?

The existing grid has systemic strengths and weaknesses, and these vary from region to region and utility to utility, as well as by tier (bulk energy system, distribution, or consumer). Changes to the grid may or may not introduce new weaknesses or cause existing ones to become more pronounced. As a corollary question, we may ask on the positive side, does a change reduce an existing grid systemic weakness?

Weaknesses to consider include but are not limited to:

- Cyber Security Vulnerability – Expansion of threat surfaces or creating/enabling new potential attack vectors; creation of new single points of failure.
- Physical Security Vulnerability – Exposing existing or new physical assets to natural to human-caused disruption; creation of new single points of failure.

[4] J Taft, *Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes*, June 2016, available online: http://gridarchitecture.pnnl.gov/media/advanced/Architectural%20Basis%20for%20Highly%20Distributed%20Transactive%20Power%20Grids_final.pdf

- Reliability and Resilience Fragility – Introduction or expansion of inherently unreliable components, systems, or configurations; creation of dependencies upon lower reliability elements by existing high reliability elements.[5]
- Gaps in coordination framework;[6] over-granularity of market or coordination.
- Operational Brittleness – creating or increasing dependence on inherently weak methods, tools, or systems; over-reliance on optimization with sensitive dependence on models, information, or conditions that are inaccurate, misaligned with the actual grid or are subject to rapid change that invalidates the optimization solution.
- Increasing economic competition via markets to yield economic benefits but then decreasing system reliability.[7]
- Scalability Limitations – This applies specially to control, coordination, and communication networks, but can also apply to markets and optimization tools that do not properly handle increases in the number of endpoints involved or in capacity of DER or bulk system VER.[8]

2.3.1 Case Study 3: Converting Passive Loads into IoT Devices

The traditional load is passive with respect to the grid, meaning that it operates according to the needs of the owner, and does not have a means of communicating with or reacting to signals from the grid. Ordinary HVAC and lighting are examples of this.

The alternative is to convert a load to being an IoT device. This means that it will have local digital processing, software and/or firmware, and communication capability – typically to the internet. It can be remotely controlled via a cell phone app and may be able to receive signals from the grid or an aggregator or dispatcher.

Analysis: The IoT load has two kinds of connectivity – electrical connectivity to the grid and communication connectivity to the internet. The traditional load only has electrical connectivity to the grid. IoT devices represent a vast expansion of cyber-security vulnerability since the load can be accessed through the internet. The lesser vulnerability involves providing a path from the internet (and unknown actors) through the IoT device and into utility systems (possibly going through an aggregator to an ISO/BA to a generator) for example. Another path is from the internet to a set of controllable loads. Because these loads are electrically connected to the grid, controlling loads en mass can be a threat and in this case no communication goes through any utility system. The load devices themselves do not have to be hacked – they can be accessed via the cell phone remote control apps of the load device owners. Putting malware into cell phones is not something that a utility can defend against since again no communication goes through the utility. Finally, utilities can be attacked by commandeering IoT devices in general (not just utility loads) and using them by the thousand to millions to perform denial of service attacks against grid single points of failure like communication ports used for generator and DER dispatch (similar to the DDOS attack against DNS supplier Dyn in 2016 – note that websites like Twitter,

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[5] JD Taft and A Becker-Dippmann, *The Emerging Interdependence of the Electric Power Grid & Information and Communication Technology*, August 2015, available online: http://gridarchitecture.pnnl.gov/media/white-papers/Electric%20Power%20Grid%20Interdependencies.pdf

[6] JD Taft and A Becker-Dippmann, Grid Architecture, January 2015, see figure 4.3. Available online: http://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf

[7] P De Martini and L Kristov, *Distribution Systems in A High Distributed Energy resources Future*, October 2015, available online: http://gridarchitecture.pnnl.gov/media/advanced/FEUR_2%20distribution%20systems%2020151022.pdf

[8] DER – Distributed Energy Resources VER – Variable Energy Resources

SoundCloud, Spotify, and Shopify became unusable even thought there was nothing wrong with them and they were not attacked directly).[9]

Conclusion: Securing utility devices is challenging enough, but in this case, the devices that must be secured are not owned by the utility but by ordinary consumers, who are not subject to NERC CIP rules. Even if they were to take cyber security seriously, the problem of ensuring proper security posture for millions to billions of devices, many of which are not even utility load devices has no feasible solution. The dilemma here is the fact that utility does not have the choice between IOT-based loads and traditional loads, due to the fact that the loads are not utility property. However, this analysis does illuminate an issue that utilities, regulators, and others must consider as cyber-security continues to be a major concern.

2.4 Tool 4: Are Economic or Social Inequities Introduced or Amplified?

The grid is a community asset and is intended to provide a public good as a regulated monopoly. Changes to grid structure, operations, markets, or tariffs have the potential to modify the costs of electric service, access to electric service, and quality of electric service. This tool asks if one grid alternative introduces or exacerbates an access, quality, or cost imbalance more than another alternative. This could involve cost shifting, socializing costs while privatizing profits, unequal access to new value stream opportunities, locational or demographic outage restoration priorities or capabilities, and unintended conveyance of inherent market power.

2.4.1 Case Study 4A: Net Energy Metering

Net Energy Metering (NEM) tariffs provide for small customers who sell excess electricity (say from their own rooftop solar PV) back to the electric company at retail rates. Such arrangements provide more value to the customer receiving the benefit than excess electricity provides to the grid and some DER developers have been seeking additional administratively determined compensation.[10]

Conclusion: Such tariffs result in subsidy for the owners of the rooftop solar PV, at the expense of ratepayers. On that basis, Tool 4 suggests that this is not a preferred approach, vs. most non-NEM alternatives.

2.4.2 Case Study 4B: Transactive Energy Markets at Distribution Transformers

It has been suggested that congestion at distribution service transformers due to charging of electric vehicles could be managed by operating a transactive market mechanism involving the customers connected to that transformer. Given that each transformers has only a few connected customers (2-9, with 5 being typical) and given that not all would be capable of participating in such a market, it is clear the both price volatility and market power problems would exist in such an arrangement.

Conclusion: Once again, this Tool 4 would suggest that this arrangement is not a good choice, vs. no market function at this level.

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[9] S Khandelwal, *Massive DDOS Attack Against Dyn DNS Service Knocks Popular Sites Offline*, October 21, 2016, available online: http://thehackernews.com/2016/10/dyn-dns-ddos.html

[10] P De Martini, et. al., *Evolving Distribution Operational Markets*, available online: http://resnick.caltech.edu/docs/EDOM.pdf

2.5 Tool 5: Is There a Role/Responsibility Mismatch?

The legacy grid has long since had a specific set of roles and responsibilities for the various entities that operate it. Grid modernization efforts can suggest changes in these roles due to changes in industry structure (e.g. DSO) or changes in circuit and control structure. Not all possible choices for reassignment of responsibilities can work equally well. Consideration should be given to technical function, business processes and issues, and structural limitations on the ability of a particular assignment to work effectively.

2.5.1 Case Study 5: Using Merchant DER for Core Grid Operations Functions

Voltage regulation and associated circuit level telemetry are traditionally supplied by the distribution operator. The distribution utility owns and operates the tap changers, voltage regulators, serial line drop compensators, and capacitors, as well as line sensors and communications systems needed to obtain circuit telemetry and send control signals.

A proposed alternative is to use third party systems like roof top solar units, their internet communications and cloud processing to provide the necessary telemetry and Volt/VAr control. In this model, the utility does not need line sensing or a distribution communication network.

Analysis: Keeping in mind that the responsibility for grid reliability lies with the distribution operator, it is evident that this approach entails a number of problems, including:

- Inability to assure data quality, no utility control over sensing calibration
- Lack of data timeliness due to latency (sensor to internet to cloud to internet to utility)
- Inability to assure cyber security methods are being employed properly
- Creation of new cyber vulnerabilities
- Lack of firm operation due to use of DER
- Business risk that company supplying core grid function will fail, leaving the grid without crucial functionality.

Conclusion: Use of third parties to perform core grid operations such as Volt/VAr regulation or supply of grid telemetry is a mismatch of roles and responsibilities, as compared to the alternative of having the distribution operator continue to do this.

3.0 Final Comment

Weak choices often result from unstated assumptions – this is true everywhere and grid modernization is no exception. One of these unstated assumptions is the use of constraint thinking instead of abundance thinking. Constraint thinking is very common in conventional grid design and operations but is not always appropriate for considering grid modernization alternatives. Constraint thinking leads automatically to the view that in a high DER or transactive environment, grid constraints should be pushed onto the consumers, causing them to serve the grid instead of being served by it. This leads to complex schemes for enabling consumers to absorb grid constraints.

Another source of weak choices is the desire to use advanced technology for the sake of the technology itself or to support an unstated assumption like the one just discussed. This leads to misalignment of goals, introduction of sources of grid weakness, and misallocation of roles and responsibilities. It can be the case that at the public policy level, a false choice is being posed between the legacy grid and some technological alternative, when in fact other paths are or could be available. Use of the Multi-Tool and Grid Architecture methods for separating objectives, requirements, and function definitions from implementations can be of assistance in resolving this problem.

Occam's Multi-Tool has been developed to help cut through the effects of unstated assumptions and the fog of complexity. It can and should be used by anyone seeking to sort out grid modernization options. This includes utilities, regulators, product suppliers, system integrators, and consumers. It should be used early in the planning process for grid modernization, and at any time when alternatives are presented that fit the criteria listed at the beginning of the paper.

While a great many considerations go into the planning and implementation of a grid modernization program, this tool can be especially helpful in the early stages where detailed performance and cost analyses may be incomplete or unavailable. Consider it a key part of a complete decision maker's toolkit for grid modernization.

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