Grid Characteristics: Using Definitions and Definition Structure for Decision-Making

February 2019

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1.0 Issues in the Use of Grid Characteristics, Quantifications, and Valuations

Managing the complexity of grid modernization is a daunting task due to the Ultra-Large-Scale nature of the grid. Correspondingly, describing, measuring, and valuing grid transformation measures is also challenging. In fact these three topics are related sequentially; each one depends critically on the one(s) preceding it as illustrated in Figure 1.

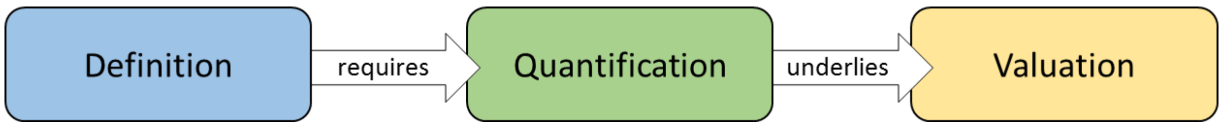

Figure 1. Definition, Quantification and Valuation are Related Sequentially

Clearly, weakness in an earlier stage makes it very difficult to succeed in later stages and in fact this is the situation at hand in the electric utility industry, with many efforts at specification, quantification, and valuation proceeding along multiple uncoordinated paths. Properly formed definitions are at the root of this situation.

The issue of definition is foundational and appears in work on Grid Architecture, in the development of grid modernization strategies and investment roadmaps, and in the setting of objectives for grid modernization, as is happening in many regulatory bodies. In this document we will use methods derived from the discipline of Grid Architecture to resolve complications with several definitions and in the process convert them to practical tools for reasoning about grid modernization.

2.0 Properties, Qualities, and Structure

We will use three tools to attack the definition problem: core principles, categorization, and structure.

Core principles – the definitions of grid characteristics must themselves have certain characteristics; they must follow certain rules. Specifically, the definitions of grid characteristics:

- Should be clear and unambiguous
- Should not conflate externalities
- Should be distinct and non-overlapping (multiple characteristics should not be mixed into the same definition)
- Should be capable of quantification
- Should be applicable at all system and spatio-temporal scales

Categorization – grid characteristics fall into one of two groups: those that are seen and understood *from the outside* of the grid by consumers and third parties (users), and those that are seen and understood *from the inside* by those that design, build, and operate power grids (providers). In the work on Grid Architecture, we have arbitrarily labeled the externally seen characteristics as “Qualities” and the internal ones as “Properties.” It is important not to mix these two types and to understand the relationships involved. Figure 2 show how architectural elements relate to internal properties and external qualities.

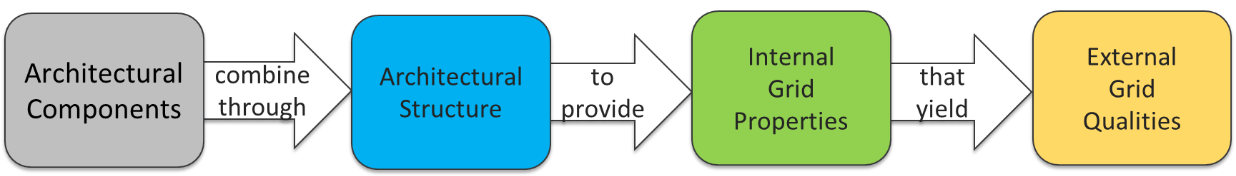

Figure 2. Architecture, Properties, and Qualities

Grid properties arise from the way that grid components are connected or related (architecture) and these properties are what cause the system to yield the qualities seen by the users. Figure 3 shows another illustration of the relationship from the point of view of synthesizing an architecture.

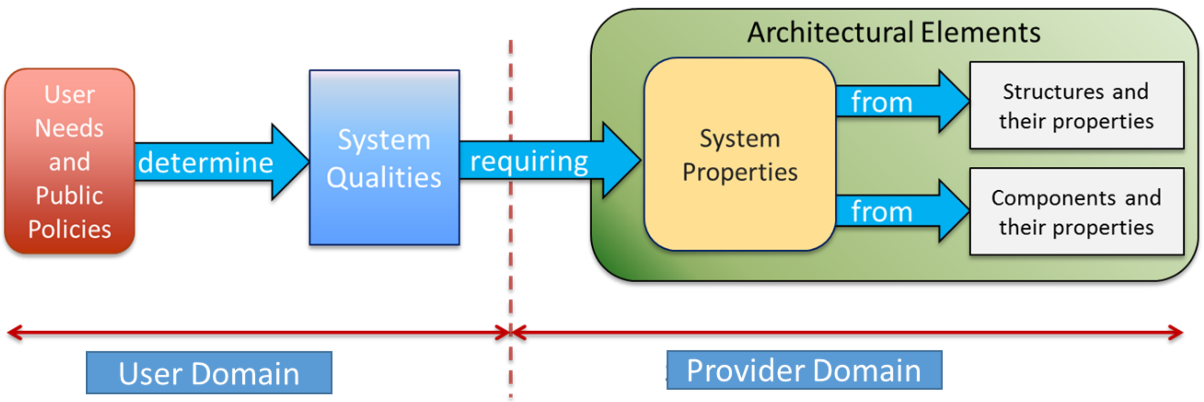

Figure 3. Synthesizing an Architecture from Qualities and Properties

There is an important relationship between this view and the processes that regulators and electric utilities use in defining grid modernization strategies and roadmaps. These processes typically start with a set of objectives that lead to a determination of the necessary assets and improvements to be made in the grid modernization process. The relationship of that process to the categorization of characteristics is shown in Figure 4.

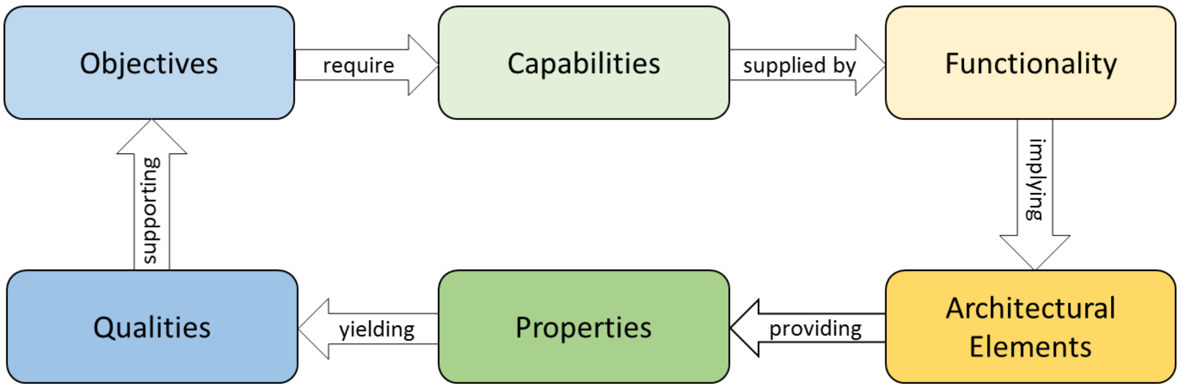

Figure 4. Relationship of Strategy Processes to Characteristics Categories

In practice, it is not unusual to see objectives that relate directly to properties rather than to qualities, but this is because the nature of these two categories, their relationships, and the reasons for them are typically not understood.

Structure – grid characteristics do not exist in isolation. Properties in particular are often related to other properties and the nature of these relationships imposes an underlying structure. Failure to understand and take this structure into account is another source of confusion in the use of grid properties for architecture, as well as for strategic and investment planning. However, the use of structure in this context is useful for achieving clarity in the definition of grid characteristics.

A well-defined set of property definitions combined with an understanding of the underlying structure relating them is a powerful tool for reasoning about grids and grid modernization.

3.0 Grid Property Definitions and Structure

This section presents some grid property definitions along with the relevant relationships and structure. We start with two terms that have already been used without formal definition and then provide definitions for three groups of grid properties.

Capability - the ability to perform certain actions or achieve specific outcomes.

Functionality - the set of tasks, operations, or services that a grid can supply or carry out. Functions provide the means to implement capabilities.

3.1 Visibility, Transportability, and Observability

Grid visibility is the capability to obtain usable measurements on grid parameters. This involves two functions:

- sensing and metrology at points on the grid
- moving the sensed data to points of use

The need to move the sensed data from remote grid locations to point of use given the imperfection of data communications leads to another definition:

Transportability is the ability to transfer sensed grid data from sensing points to points of use. This is essentially about the capabilities of the communication systems used for grid data.

Grid observability is the ability to combined sensed data with grid models and various types of computations (analytics, estimators, forecasters) to generate actionable grid state information to be used by decision and control processes.

Figure 5 illustrates the relationships of these properties. Visibility (sensing and measurement plus ability to transport data) is a subset of observability. Observability depends upon (requires) visibility.

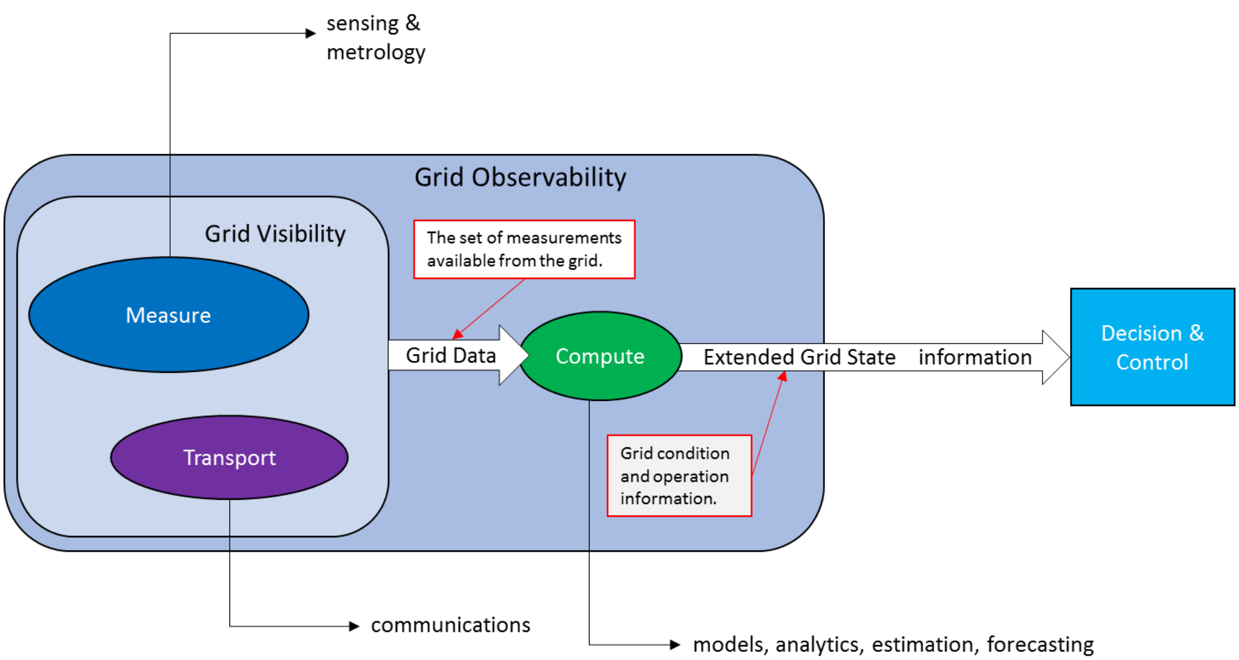

Figure 5. Relationship of Visibility and Observability

Figure 6 provides a synthesis view of these properties and functions.

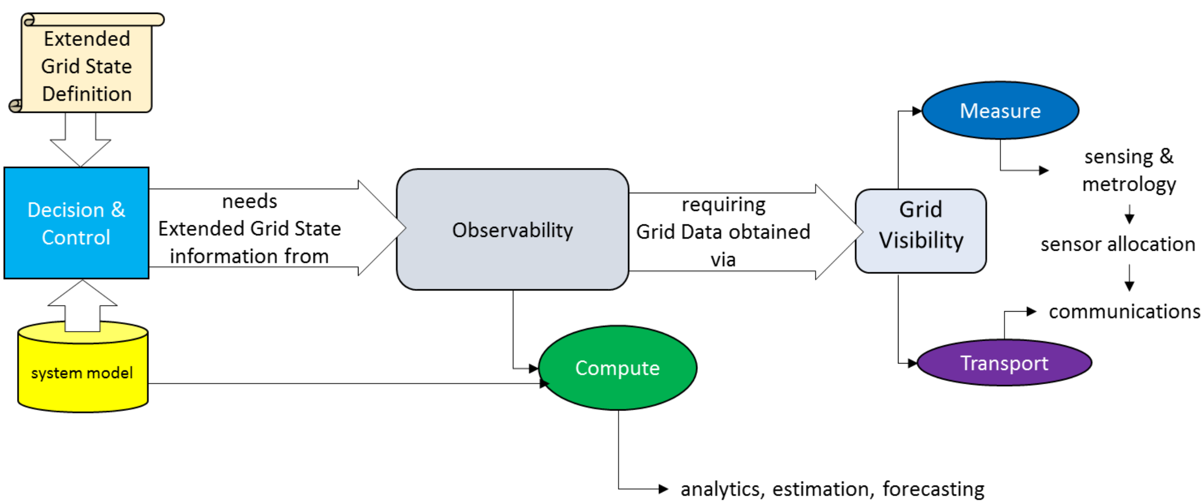

Figure 6. Synthesis View of Observability and Visibility

3.2 Electric Reliability, Availability, and Usability

Electric Reliability - the degree to which electric service that meets applicable usability standards is available over any given time period in a given service area.

Electric Availability - the percentage of time a voltage is uninterrupted. This is primarily about outage and restoration, outage being a failure event and restoration being a utility function.

Electric Usability - the degree to which electricity supply can be satisfactorily employed for any specific use. In general this may apply to both AC and DC, but in practice at present this is about AC power quality.

AC Power Quality - absence of deviation from a perfect sinusoidal voltage waveform.[1]

Note that the definition of usability also covers some functional aspects of grid operation such as voltage regulation, so a definition is provided here for completeness. These functions are generally not described in terms of "ility" words.

V/VAR/Phase Regulation – control of voltage, reactive power, and sinusoidal waveform timing to keep parameters within specified limits or aligned with system operational parameters (in the case of phase synchronization, such as with microgrids or inverters connected to main grids). This includes frequency regulation in AC systems.

The relationships among, electric reliability, electric availability, and usability are illustrated in Figure 7.

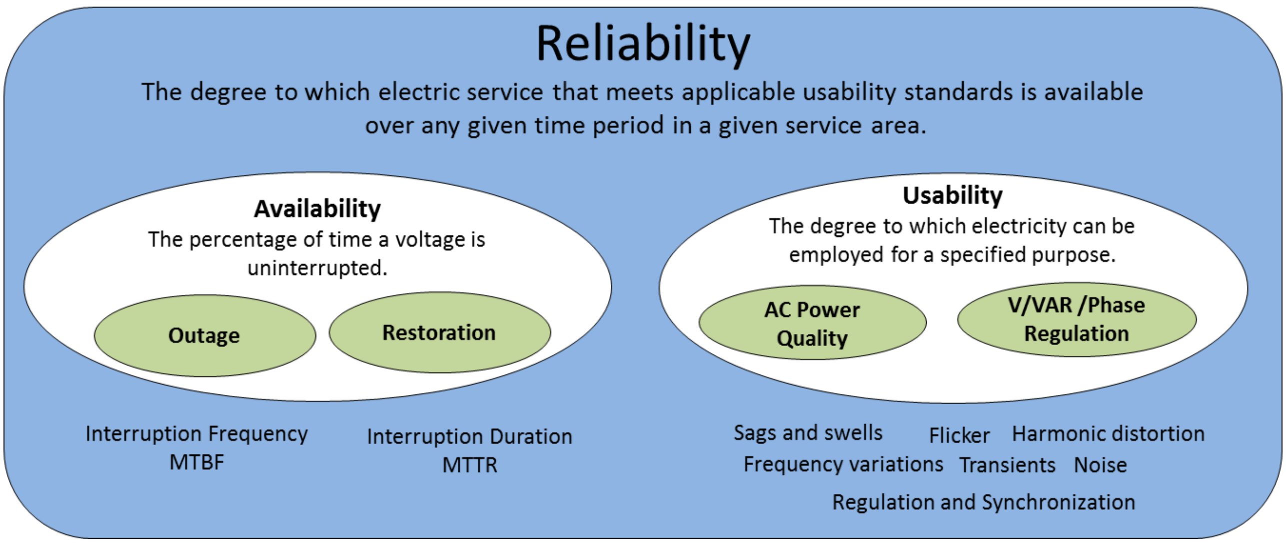

Figure 7. Reliability Relationships

Availability is typically quantified in terms of two types of measures: failure rates (the frequency indices) and restoration time (the duration indices). Note that the failure rate indices (x-AIFI) are essentially the inverse of what is known in other industries as Mean Time Between Failures (MTBF) and the restoration indices (x-AIDI) are known as Mean Time to Repair (MTTR), leading to the relationship

$$\text{Availability} = \text{MTBF} / (\text{MTBF}+\text{MTTR})$$

For electric utilities, the corresponding measure is Average Service Availability Index (ASAI).[2]

While electric service availability is about outages and historical evaluations depend on actual data and therefore past external events, understanding inherent reliability of the grid for architectural and planning

[1] Reliability has sometimes been defined as a subset of Power Quality since loss of voltage is clearly a deviation from the ideal voltage. Here we invert that relationship.
[2] In fact, there are more than 40 measures that have been created and are used to some extent to characterize electric reliability in various ways.

purpose can and should be based on component and structural characteristics, as is done in the electronics and aerospace industries. The x-AIFI and x-AIDI measures are conflated with external events and so can be useful for identifying historically problematic areas to be dealt with tactically but are not as useful for larger scale architectural and system planning purposes.

3.3 Grid Resilience and Electric Reliability

The relationship between resilience and reliability is complicated by the fact that most definitions of resilience are conflated with reliability and externalities, and are scale dependent. The following definition addresses those issues.

Resilience - the ability of the grid to avoid or withstand stress events without suffering operational compromise or to adapt to and compensate for the strain so as to minimize compromise via graceful degradation.[3]

The definition of resilience is expanded in Figure 8, which also illustrates the relationship to electric reliability.

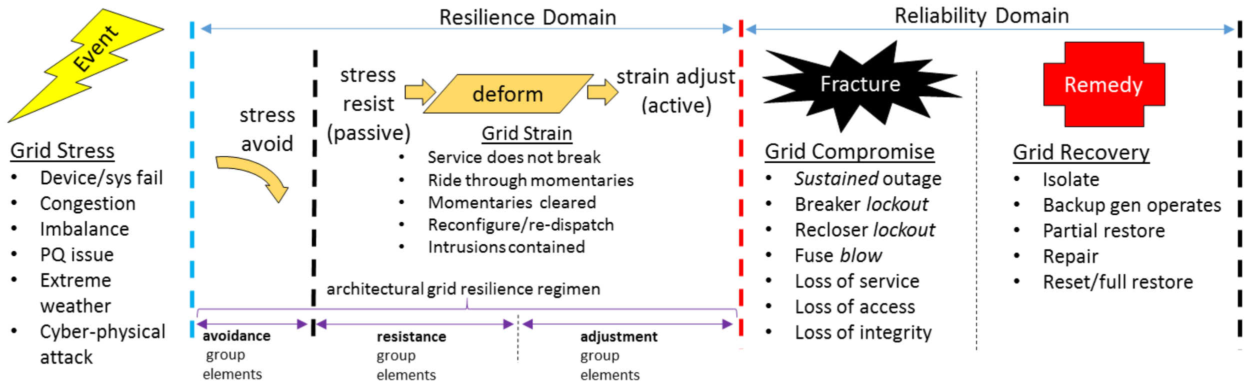

Figure 8. Resilience and Reliability in Electric Power Systems

3.4 Flexibility, Extensibility, Agility, and Robustness

Flexibility - the ability to adjust to or compensate for variations in operating conditions from within a fixed set of functions, capabilities, and structures.

Extensibility - the ability to add, subtract, and scale system functions and capabilities with only incremental changes in structure and with no impact to other functions or capabilities.

Agility - the ability to make adjustments quickly. The key issue here is not the nature of the adjustments, but the speed with which they can be applied. Being able to respond quickly in either domain (keeping in mind that the time scales for the two domains are quite different) is an enhancement of each capability.

Robustness - the ability to tolerate perturbations and uncertainty. Here we mean perturbations to grid operations.

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[3] JD Taft, Electric Grid Resilience and Reliability for Grid Architecture, PNNL -26623, March 2018, available online: https://gridarchitecture.pnnl.gov/media/advanced/Electric_Grid_Resilience_and_Reliability_v4.pdf

Flexibility applies to operation with a given set of assets and capabilities. Extensibility refers to the ability to extend that set of assets and capabilities. Agility addresses the time dimension for <u>both</u> flexibility and extensibility.

Figure 9 expands the definitions and describes the relationship between flexibility and extensibility for electric power systems.

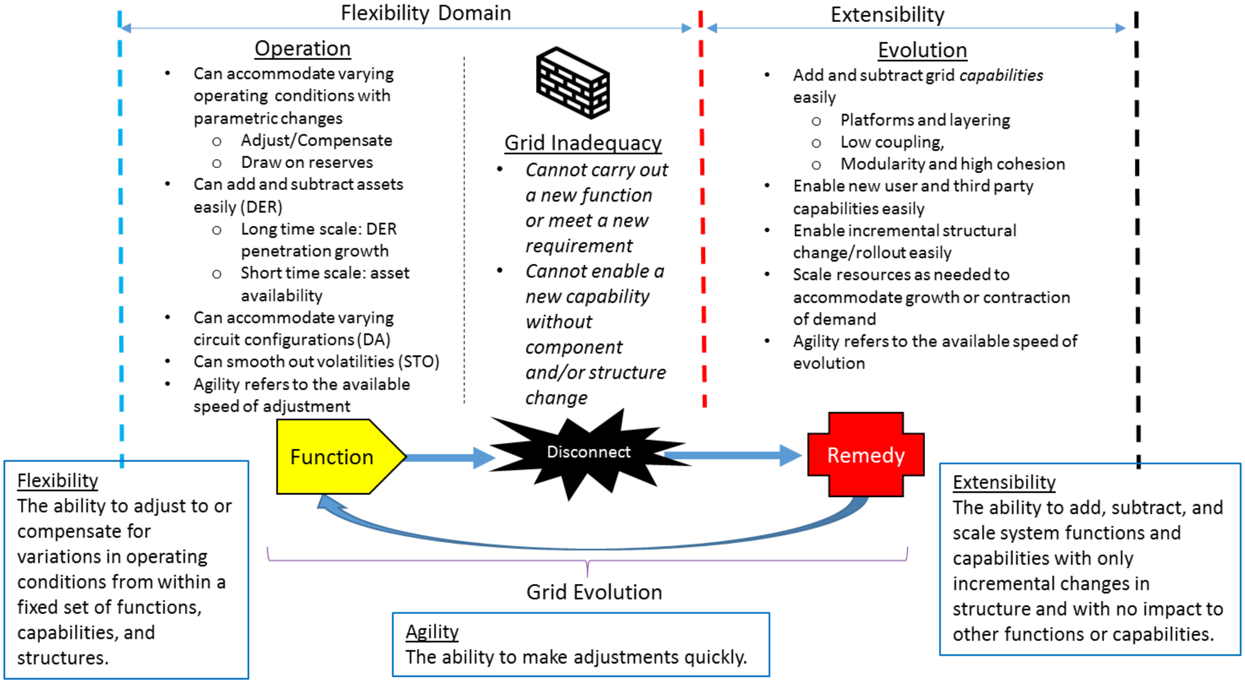

Figure 9. Flexibility and Extensibility

Figure 10 illustrates the relationships among the robustness properties and functionality.

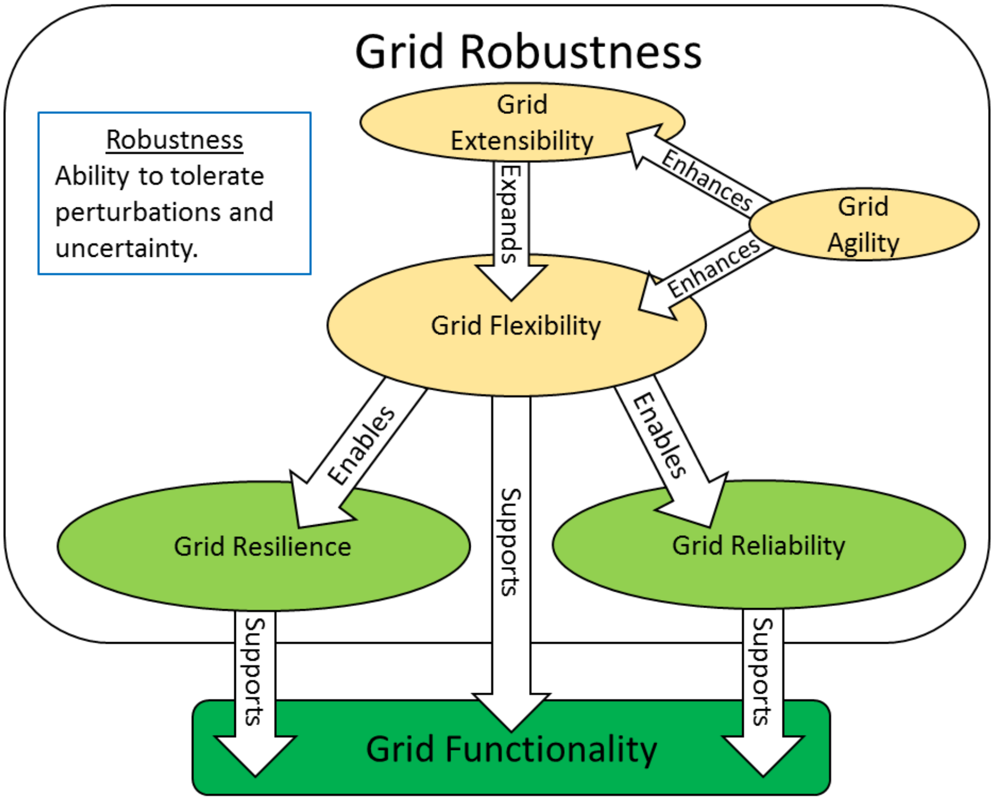

Figure 10. Robustness Relationships

4.0 Grid Qualities

Grid qualities must have the following characteristics:

- They must reflect an external view of grid behavior. They represent what the users want the grid to provide or do and so relate to the objectives for the grid.
- They must span the entire set of grid functions and responsibilities and not just hot button issues. For example, the 2015 DOE EPSA list of desirable characteristics of the grid cover only a limited set of topical issues and not the entire set of grid functions.
- They must have formal definitions to eliminate ambiguity caused by the use of words with nontechnical, vague, or multiple meanings.
- They must provide enough granularity to support nontrivial representations and analyses.
- They must overlap as little as possible. Mathematically, this means the set of qualities should be as nearly orthogonal as possible. It may be necessary to carry out formal orthogonalization on the mathematical definitions for quantification of the quality set.

The architecture team uses external (user) stakeholder inputs in selecting the qualities. With the qualities identified, the team develops formal text definitions for the qualities and mathematical formulations.

In the work on Grid Architecture, we have devised a set of grid qualities that does not make use of the ”ility” words typically seen in descriptions of preferred grid characteristics (the “ility” words are terms like flexibility, reliability, scalability, etc., and are most often appropriate for properties, not qualities).

The qualities we use in the Grid Architecture work are:

- Delivers - provides the amount of energy a user wants, when the user wants it, and in the form the user wants.
- Conserves - uses irreplaceable resources sparingly (e.g., fuels).
- Preserves - minimizes wastes and emissions.
- Protects - safeguards and secures people, assets, and information.
- Adapts - adjusts on short time scales changes and evolves on long time scales to meet changing conditions (relates to flexibility and extensibility).
- Enables - accommodates broad access to the grid and supports energy innovation.
- Merits - presents sufficient useful capability and public good to justify continued public and private investment (relates to the properties of affordability, financeability, and social well-being).

5.0 Final Comments

Well-designed grid characteristics definitions are crucial to communication about the grid and grid modernizations. Good definitions have certain characteristics of their own and just as importantly, have underlying structural relationships. Use of not just the definitions, but also the structures, is a powerful means for reasoning about the grid.

Separating characteristics into the set seen externally (“qualities”) and the set seen internally (“properties”) is also crucial because this is the different between how the users experience the grid and how provides design, build, and operate it. In the Grid Architecture work, we map architecture elements to properties and properties to qualities so that we can provide traceability of the architectural elements back to basic requirements (objectives, as determined by emerging trends, user expectations, public policy, etc.).

The set of definitions provided here should be used by policy makers, regulators, utility executives and engineers, developers, researchers, and grid users so that the common language can facilitate common understanding of the issues of grid modernization.

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