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TECHNICAL REPORT

colour inside

Information technology – Home electronic system (HES) application model – Part 3-7: GridWise transactive energy systems research, development and deployment roadmap

ISO/IEC TR 15067-3-7:2020-09(en)

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INFORMATION TECHNOLOGY – HOME ELECTRONIC SYSTEM (HES) APPLICATION MODEL –

Part 3-7: GridWise transactive energy systems research, development and deployment roadmap

FOREWORD

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ISO/IEC TR 15067-3-7, which is a Technical Report, has been prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
JTC1-SC25/2900/DTR	JTC1-SC25/2966/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the ISO/IEC 15067 series, published under the general title *Information technology – Home electronic system (HES) application model*, can be found on the IEC and ISO websites.

In this document, the following print type is used:

- ***Bolded italics*** represent condensed encapsulations of the transactive energy (TE) principles described in ISO/IEC TR 15067-3-8:2020, 6.4.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

It has been said that if Thomas Edison could see the electricity industry today, he would recognize it as being much the same as 100 years ago, but that may not be the case for much longer. The century-old paradigm of large-scale generation and distribution is starting to change as renewable resources make more of an impact. New distributed devices, both consumer and utility-owned, affect the grid directly and also interact with each other. Preparations are already underway to integrate these new resources and technologies by considering operational and policy changes based on measured and effective choices. For example, the industry is undergoing a fundamental shift from a "load following" paradigm, where central generation adjusts to varying demand, to a "supply following" paradigm, where responsive demand absorbs variable generation such as solar and wind. During the transition to a more distributed system, the industry cannot afford to design purely for either extreme. A key to success is to use technologies that support flexible coordination of both centralized and distributed elements. One such approach is provided by transactive energy (TE) systems.

Transactive energy systems are systems of economic and control mechanisms that allow the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter. This definition is from ISO/IEC 15067-3-8:2020, 3.28 [1][1].

This broad definition allows us to recognize the existing use of transactive techniques in bulk energy markets and to consider how to enable new techniques for possible use in distribution systems, at the interface between transmission and distribution, and perhaps even more broadly.

The need for transactive energy systems is being driven by economic, technological, and customer preference opportunities that were just beginning to exist five years ago. Better performance and declining costs for many renewable energy sources and storage technologies now being deployed suggest use of distributed energy resources will continue growing. Distribution systems were not designed for large-scale deployment of distributed energy resources with potential power flows in multiple directions. Ad hoc arrangements have worked so far, but as the combined effects of changes that are often outside of regulatory and utility observation and control become significant, a more robust response to maintaining and enhancing safety, reliability, and resilience of distribution energy systems and markets is required.

ISO/IEC TR 15067-3-7 is adapted from the GridWise®[2] Architecture Council document, *Transactive Energy Systems Research, Development and Deployment Roadmap* [2], which provides a broad perspective of how transactive energy systems and their use will evolve over time. It has been edited to align with the format of IEC documents.

1 Numbers in square brackets refer to the Bibliography.

2 GridWise is a registered trademark of Gridwise, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC or ISO.

INFORMATION TECHNOLOGY –
HOME ELECTRONIC SYSTEM (HES) APPLICATION MODEL –

Part 3-7: GridWise transactive energy systems research, development and deployment roadmap

1 Scope

This part of ISO/IEC 15067, which is a Technical Report, explains the organization and structure of the transactive energy systems research, development, and deployment roadmap.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
congestion
characteristic of the transmission system produced by a constraint on the optimum economic operation of the power system, such that the marginal price of energy to serve the next increment of load, exclusive of losses, at different locations on the transmission system is unequal

3.1.2
cyber-physical system
smart system that includes engineered interacting networks of physical and computational components

3.1.3
deterministic
<model> always producing the same output when given a particular input (no randomness)

3.1.4
distribution system operator
DSO
entity responsible for planning and operational functions associated with a distribution system that is modernized for high levels of distributed energy resources (DERs) and handles the interface to the bulk system transmission system operator (TSO) at a locational marginal price (LMP) node or transmission-distribution substation

Note 1 to entry: A range of other DSO models are under consideration in the industry.

3.1.5
prosumer
person or entity who both consumes and produces

3.1.6
stochastic optimization
minimization or maximization of a function in the presence of randomness in the optimization process

3.2 Abbreviated terms

NOTE This list also includes some terms not used in this document, but which relate to other terms and so could be useful for the user.

ADMS	advanced distribution management system
AMI	advanced metering infrastructure
BEM(S)	building energy management (system)
CVR	conservation voltage reduction
DER	distributed energy resource
DERMS	distributed energy resource management system
DMS	distribution management system
DOE	U.S. Department of Energy
DR	demand response
DSO	distribution system operator
FERC	U.S. Federal Energy Regulatory Commission
GWAC	GridWise® Architecture Council
IOU	investor-owned utility
LMP	locational marginal price
MDM	meter data management (system)
PSC	public service commission
PUC	public utility commission
PV	photovoltaic
RTO	regional transmission operator
T&D	transmission and distribution
TE(S)	transactive energy (system)
TSO	transmission system operator
VVO	volt-var optimization
X2G	anything to grid

4 Overview of the roadmap

4.1 General

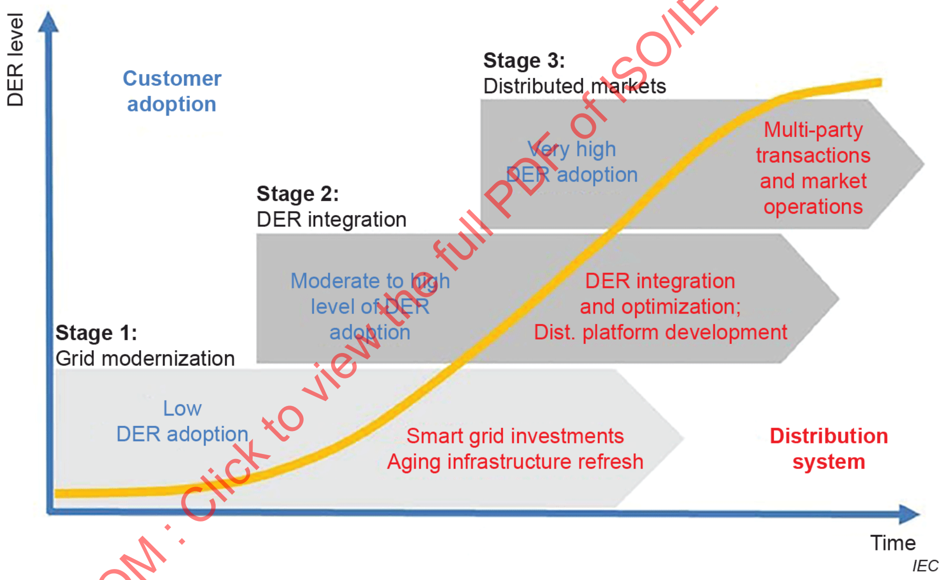
The GridWise® Architecture Council (GWAC) transactive energy roadmap outlines a vision and path forward to achieve deployment of transactive energy systems at scale as an operational element of the electric power system to facilitate the integration of DERs and dynamic end uses, such as connected buildings. It also considers the application of transactive energy systems (TESs) for the coordination and control of end uses – for example, in managing energy in buildings and campuses.

The roadmap considers drivers of change, triggers for transactive energy system deployment, and required infrastructure for deployment at scale. Gaps in technology and infrastructure that could require investment are identified.

The roadmap captures potential changes over time (stages) and organizes them by business and technical tracks. Within each track, it also groups potential changes into "swim lanes" that identify what we hope to see, what it takes for this to occur, what we see as a result, and what these features do to add value.

4.2 Stages

The roadmap is based on considering what is required to support increasing levels of DER penetration in electricity distribution systems. The roadmap considers the overall vision in three stages, depicted in Figure 1, primarily characterized by the level of market development around DER penetration. These stage definitions help the user determine what stage a given distribution system is in, based on how its characteristics align with these definitions. Note that there are implications for the relationship between the distribution utilities and the bulk power system, and given the regional nature of the bulk power system, all distribution utilities within a given region will not usually find themselves at the same stage.



SOURCE: LBNL-1003797 [3].

Figure 1 – Distribution system evolution

– Stage 1

In stage 1, DER penetration is limited. DER value is administratively set (such as in net-metering tariffs). DER has minimal but perceivable effects on distribution system operations. In the following clauses, this stage is characterized as "persistently demonstrated".

– Stage 2

Levels of DER penetration grow as device prices continue to drop. Net-metering tariffs begin to be replaced with market interactions that establish the value of the DER assets. Aggregated DER or large DER assets interact with bulk power markets based on a limited number of value streams. Effects of DER penetration on distribution system operations are manageable. In the following clauses, this stage is characterized as "broadly applied".

– Stage 3

DER penetration grows, affecting distribution system operations and requiring new means for asset owners to realize return on investment. Combinations (stacks) of value streams are realized through DER participation in local, distribution-level markets. The stacked value streams have spatial and temporal variability that reflects operational needs in the distribution and bulk power systems. In the following clauses, this stage is characterized as "at scale".

4.3 Roadmap tracks

4.3.1 General

The roadmap tracks generally follow the ISO/IEC TR 15067-3-8 [1] breakdown of considerations for TE systems into the four tracks outlined in 4.3.2 to 4.3.5.

4.3.2 Regulatory and policy

This track describes the actions needed by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The objective of the actions in this track is to establish an environment that enables transacting parties to understand rules of engagement and compensation in addition to performance requirements (and penalties for non-performance). The actions also focus on achieving a consistency of approach across jurisdictions, as much as possible, to promote interoperability. The actions described could be carried out by different policy-making bodies depending on the individual jurisdictions and types of utilities.

Many of the actions described in this track support development and implementation actions described in the "business models and value realization" track (4.3.3), and to a limited extent, the actions included in the "system design and architecture" (4.3.4) and "physical and cyber technologies and infrastructure" (4.3.5) tracks.

4.3.3 Business models and value realization

This track focuses on the various stakeholders, their roles in TE, and how their business models need to evolve for them to provide and realize value in each of the three stages. While the "regulatory and policy" track describes the actions policy makers need to take to establish the needed TE environment, this track focuses on the actions to assess and implement needed business model changes by various categories of stakeholders, recognizing that business model changes include value propositions on both supply and demand sides.

4.3.4 System design and architecture

This track focuses on system design and architecture actions necessary to support each stage, specifically dealing with information interoperability to support TE valuation, and operation and control aspects to understand and manage the effects on the electricity grid. This track depends on the business model to describe the content and timing of required information exchange between TE parties. This is where each stakeholder needs to develop or understand their existing architecture and their planned architecture, then develop a set of transitional states to get them there and transition between stages.

4.3.5 Physical and cyber technologies and infrastructure

This track focuses on the changing cyber-physical needs and required actions through the progression of the three stages. This track addresses the technical layers of the GWAC Stack and the physical layers of the Control Abstraction Stack as described in ISO/IEC TR 15067-3-8. It includes the activities aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electricity grid. This track depends on the information exchange requirements considered in the "system design and architecture" track to ensure the ability to exchange information in support of transactions without impairing the reliability of the electrical network.

Each of these areas is informed by the drivers for change, such as increased penetration of rooftop solar, energy storage, electrification of transportation, etc.

4.4 Swim lane definitions

For each of the roadmap tracks, there is a separate table that describes the features of that track in each of the three stages. Also, for each stage, there are four swim lanes that provide a more detailed breakdown of the features not only by stage but also by the following different perspectives.

- Vision – what we hope to see at each stage.
- Enablers – elements required for the vision to be realized.
- Results – outcomes made possible by new patterns of use.
- Benefits – how these outcomes add value (compared to the status quo).

4.5 Organization of material

In order to show the effects of changes based on the use of tracks, stages, and swim lanes, this document is organized into clauses based on tracks. In addition to the tracks mentioned above, Clause 4 gives an overview that captures some of the key concepts from the other tracks. It provides an executive summary for the roadmap.

At the start of each subclause in Clauses 5 to 8 is a list of three to five main concepts that were considered important to represent in that clause. These core concepts state the fundamental concept in as timeless (stage-free) a manner as possible so that one can then apply the concept by stating how it manifests through the stages. These manifestations are arranged in tables. Also included in the core concepts are condensed encapsulations of the TE principles described in ISO/IEC TR 15067-3-8:2020, 6.4 [1].

Within each clause there are four tables, one for each swim lane. Each row in a table captures something that represents a change or evolution occurring over time, with three columns to describe what is seen in stages 1, 2, and 3, as the examples in Table 1 to Table 4 show.

Table 1 – Example vision table

Vision **What we hope to see at each stage**	**Stage 1** **Persistently demonstrated**	**Stage 2** **Broadly applied**	**Stage 3** **At scale**
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

Table 2 – Example enablers table

Enablers **Elements required if the vision is to be realized**	**Stage 1** **Persistently demonstrated**	**Stage 2** **Broadly applied**	**Stage 3** **At scale**
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

Table 3 – Example results table

Results **Outcomes made possible by new patterns of use**	**Stage 1** **Persistently demonstrated**	**Stage 2** **Broadly applied**	**Stage 3** **At scale**
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

Table 4 – Example benefits table

Benefits **How these outcomes add value**	**Stage 1** **Persistently demonstrated**	**Stage 2** **Broadly applied**	**Stage 3** **At scale**
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

The core concepts provide a means to check for gaps (where a concept has not been invoked) or duplication (where a concept has been used multiple times). Although the core concepts provide a basis for verifying the completeness of the initial draft of the roadmap, multiple invocations of concepts are inevitable in cases where different rows have different scope but some overlap.

4.6 Core concepts

4.6.1 General

Each section in this roadmap includes relevant core concepts (also described in Annex A) that state the fundamental concepts in as timeless (stage-free) a manner as possible for each track of the roadmap.

4.6.2 Questions to bear in mind

It can be helpful for users to consider the following questions based on the core concepts as this document is being read. These or other interrogatives can help make some of the entries in the tables less conceptual and more concrete.

- Can you describe how the consistency of regulation across jurisdictions affects the minimum requirements for implementing transactive systems both locally and regionally?
- When it comes to intra- and interjurisdictional market monitoring and oversight functions, how shall directives be issued and who should be responsible for enforcing them?
- What types of incentives and opportunities for transactive energy systems do you think might exist in the next two to three years and who do you think should be accountable for standards of performance?
- Can you explain how to ensure that the alignment of business model values across the participating entities is observable and auditable?
- From a TES perspective, what do you think are the important elements to include in any standard set of definitions and structure for interfaces for anything-to-grid (X2G) operations at all levels?
- Do you think the interactions with buildings and customer-managed grid within a building or campus will be featured more prominently over time, and if so, what will be the drivers?

- What needs to happen to enable modelling and simulation solutions for TESs to produce consistent results with each other and allow them to exchange data?
- How do you think the devices participating in TESs can support better measurement, verification, and situational awareness of the electricity grid?
- What sort of markets and benefits might emerge that TESs can support in terms of distributed devices securely integrating their actions into control schemes?
- What type of advances and services do we need that will enable consumer devices to support sub-cycle to long-term market activities including operations support?

4.6.3 Benefits and enablers summary

Each of Clauses 5 to 8, which represent the four tracks, begins with an overview of selected benefits and enablers from each track. Most of the roadmap comprises tables showing the evolution of several concepts. Since this involves a large amount of information, this overview presents a few examples of benefits and enablers for each track and presents them in the form of a summary.

The examples in the tables were offered by the committee members who developed this document. There are undoubtedly additional scenarios that could be added to this document and these will naturally occur as technology, regulation, and businesses evolve.

It should be noted that, as the effects of DER increase and opportunities for TESs arise, the customer base of TE expands as adoption scales up.

5 Regulatory and policy

5.1 General

This track describes the actions needed by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The objective of the actions in this track is to establish an environment that enables transacting parties to understand rules of engagement and compensation in addition to performance requirements (and penalties for non-performance). The actions also focus on achieving a consistent approach across jurisdictions as much as possible to promote interoperability. The actions described can be carried out by different policy-making bodies depending on the individual jurisdictions and types of utilities.

Many of the actions described in this track support development and implementation actions described in the "business models and value realization" track, and to a limited extent, the actions included in the "system design and architecture" and "physical and cyber technologies and infrastructure" tracks. Regulatory and policy enablers and benefits are illustrated in Figure 2.

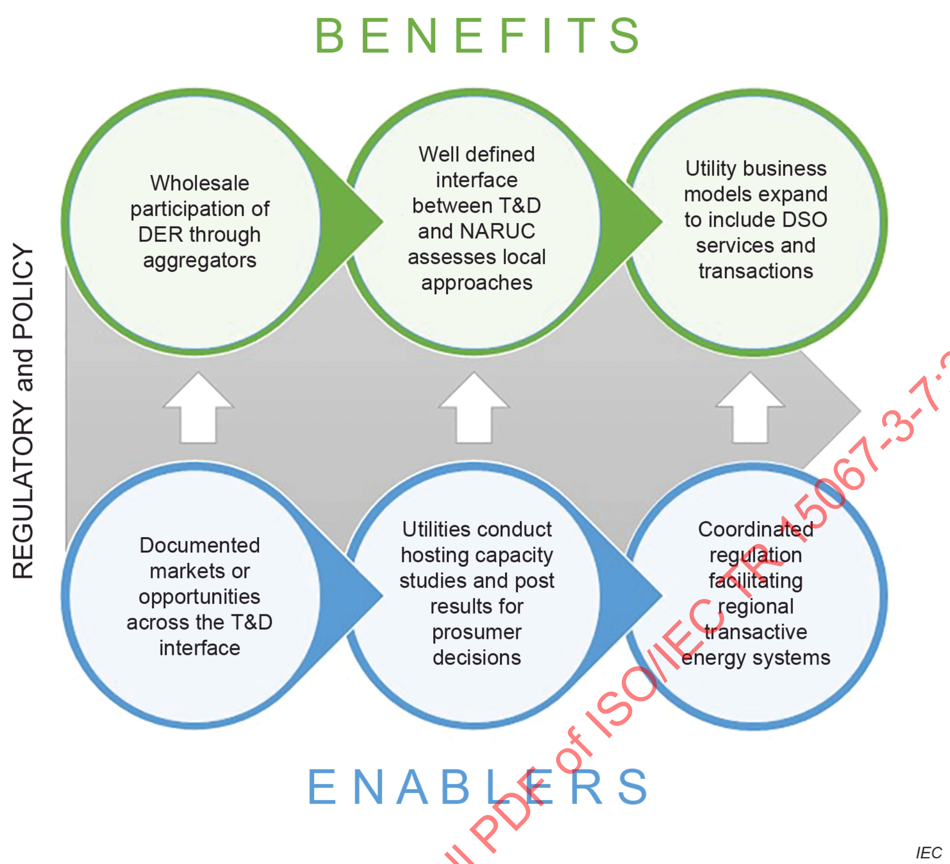


Figure 2 – Example benefits and enablers for the "regulatory and policy" track

5.2 Vision – what we hope to see at each stage

The vision(s) consists of conditions we expect to be realized over time as they relate to regulatory and policy actions by regulators and other policy makers to enable TESs as envisioned in each of the three stages. The main regulatory and policy (RP) concepts are listed below.

- RP1 – Retail power markets are supported with *non-discriminatory participation*.
- RP2 – Regulation and minimum requirements are consistent from state to state.
- RP3 – Information and value (including real-time retail tariffs) are dynamically exchanged between wholesale and retail markets across the transmission and distribution (T&D) interface.
- RP4 – Intra- and interjurisdictional market monitoring and oversight functions are described in policy (and regulation).

Characteristics of the regulatory and policy vision at each stage are shown in Table 5.

Table 5 – Regulatory and policy vision (RPV)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
RPV01	Wholesale market transactive DER interactions, where allowed, mainly through aggregators, with no change in legacy market products and services developed for the capabilities of conventional bulk generation / system operation resources.	The existence of a well-defined T&D interface from a regulatory and market perspective that allows both a distribution-level market for individual participants and participation in the wholesale market for qualifying participants.	Enhancement of bulk power/wholesale market rules to align system operational needs with market-based incentives.
RPV02	Questions from policy makers regarding when and how to create transactive retail markets.	Several jurisdictions create regulatory support for retail energy (and derivative) markets.	Some jurisdictions have retail transactive energy market regulations with (mostly) consistent requirements and terminology.
RPV03	Transactive exchanges available in bulk-power bilateral and centralized wholesale markets, stopping at the T&D interface, with exceptions.	Evolution of new bulk power / wholesale products and services (flexibility reserves, ramping, primary frequency response, synthetic inertia) along with provisions for DER assets to provide such services.	Transactive DER participation in bulk-power and wholesale markets based on bids and offers.
RPV04	Limited use of TE in distribution except for pilots and proofs of concept.	Geographic footprints of TE trades expand over larger areas of the country, creating opportunity for wide-scale power purchase agreements.	End-to-end transactive exchanges among prosumers within different layers of the distribution system as well as across the T&D interface.

5.3 Enablers – elements required if the vision is to be realized

Enablers are the elements that need to be in place to support and facilitate actions by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The main policy concepts are listed below.

- RP1 – Support exists for retail power markets with *non-discriminatory participation*.
- RP2 – Regulation and minimum requirements are consistent across jurisdictions.
- RP3 – Information and value (including real-time retail tariffs) are dynamically exchanged between wholesale and retail markets across the T&D interface.
- RP4 – Intra- and interjurisdictional market monitoring and oversight functions are described in policy (and regulation).

Characteristics of regulatory and policy enablers at each stage are shown in Table 6.

Table 6 – Regulatory and policy enablers (RPEs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
RPE01	Understand what cyber needs will be and determine cost of policies to correct inequities or barriers to access.	Balanced need for big data and more sophisticated grid-edge data analysis with consumer privacy concerns and security.	Security, privacy, and non-discriminatory participation are addressed in policy at all levels.
RPE02	Analysis of steps required to enable T&D integration through rate-making policy.	Prioritized list of interjurisdictional regulatory barriers between distribution markets to address.	Common distribution system operator (DSO) approaches allow consistent T&D integration.
RPE03	Documented opportunities and value proposition of markets each side of the T&D interface.	Opportunities and value proposition for markets across the T&D interface.	Minimum standards identified to allow for basic consistency of market rules between jurisdictions.
RPE04	Minimal regulatory changes, but increased attention, including development of streamlined interconnect agreement(s).	Active regulatory involvement, and new regulations to enable TE.	Coordinated regulatory involvement opening the way for regional TESs.
RPE05	Insights into operational cost inform how charge, billing, and rate structure can cover the overhead transaction costs and identify incentives, regulations, and dynamic rate definitions.	Identify how cost and benefits are being created and distributed, and how to police bad actors where necessary; possibly through software-defined rates and smart contracts.	Obligation to serve redefined for TE markets.

5.4 Results – outcomes made possible by new patterns of use

These results are important for realizing the benefits that can be created by regulators and other policy makers to enable TESs as envisioned in each of the three stages

Characteristics of regulatory and policy results at each stage are shown in Table 7.

Table 7 – Regulatory and policy results (RPRs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
RPR01	Lack of consumer guidelines for participation in TE systems.	Interest in development of consumer guidelines for participation in services offered by DSOs.	Consumer guidelines for participation in energy and ancillary services markets.
RPR02	Limited awareness but growing interest in TE from policy makers.	Active support from some jurisdictions allows recovery of some approved utility costs to encourage TE.	Emergence and persistence of retail TE markets.
RPR03	Rule changes to permit demand-side participation in wholesale markets.	Growth of customer participation in grid management through ancillary services and reliability coordination.	Dynamic trading between DSOs and TSOs to support markets and reliability.
RPR04	Utility business models largely unchanged.	Utility business models expand to include DSO transactions and services.	DSO role is fully distinct/disaggregated from the utility role, with some DSOs merging to perform regional services.
RPR05	Quantification of cost of policies to correct inequities or barriers to access.	Regulatory requirements for consumer privacy and security.	Common security, privacy and non-discriminatory participation policies for all DSO markets.

5.5 Benefits – how these outcomes add value

These are benefits that can be shaped by regulators and other policy makers as DER penetration increases through each of the three stages. The main policy concepts are listed below.

- RP1 – Support exists for retail power markets with non-discriminatory participation.
- RP2 – Regulation and minimum requirements are consistent from state to state.
- RP3 – Information and value (including real-time retail tariffs) between wholesale and retail markets are exchanged dynamically across the T&D interface.
- RP4 – Intra- and interjurisdictional market monitoring and oversight functions are described in policy (and regulation).

Characteristics of regulatory and policy benefits at each stage are shown in Table 8.

Table 8 – Regulatory and policy benefits (RPBs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
RPB01	Policy makers recognize the need for regulatory changes to address DER integration.	DERs provide opportunities for distribution-level revenue generation through provision of grid services.	Changes to the regulatory process by some jurisdictions provide tangible foundations for more change.
RPB02	Understanding of equity or barrier-to-access costs allows policy-making to develop new models.	Regulatory definition of consumer privacy and security requirements create opportunities for service providers.	Sharing of best practices and common policies for DSO markets creates opportunities for shared services and service provider growth.
RPB03	The benefits from or need for demand-side resources to participate in grid services are recognized.	Consumer awareness of the complications of grid operation and the benefits of participation.	Enhanced flexibility to support reliability.
RPB04	Provides confidence in TE as a viable/integration solution with potential for customer benefits.	Provides the capability to regulate (and deliver) the same grid services on either side of, and across, the T&D interface.	Enables energy trading and service provision through common services and rules.
RPB05	Creates the perception of electricity as a service with value, as opposed to being taken for granted.	Valuation of electricity as a service creates a foundation for innovation.	Optimizes value at a personal, community, and distribution system level for specific needs.
RPB06	Messaging developed in each relevant area for how to prepare the public and stakeholders for effects of DERs, and how and why to tolerate them, in stages 2 and 3.	Benefits of TE systems well understood in general by policy makers with respect to creating more flexibility and value.	Benefits of TESs well understood in general by consumers with respect to creating more flexibility and value.

6 Business models and value realization

6.1 General

This track focuses on the various stakeholders, their roles in TE, and how their business models need to evolve for them to provide and realize value in each of the three stages. While the "regulatory and policy" track describes the actions policy makers needed to establish the TE environment, this track focuses on actions to assess and implement business model changes by various categories of stakeholders, recognizing that business model changes include value propositions on both supply and demand sides. Business model and value realization benefits and enablers are illustrated in Figure 3.

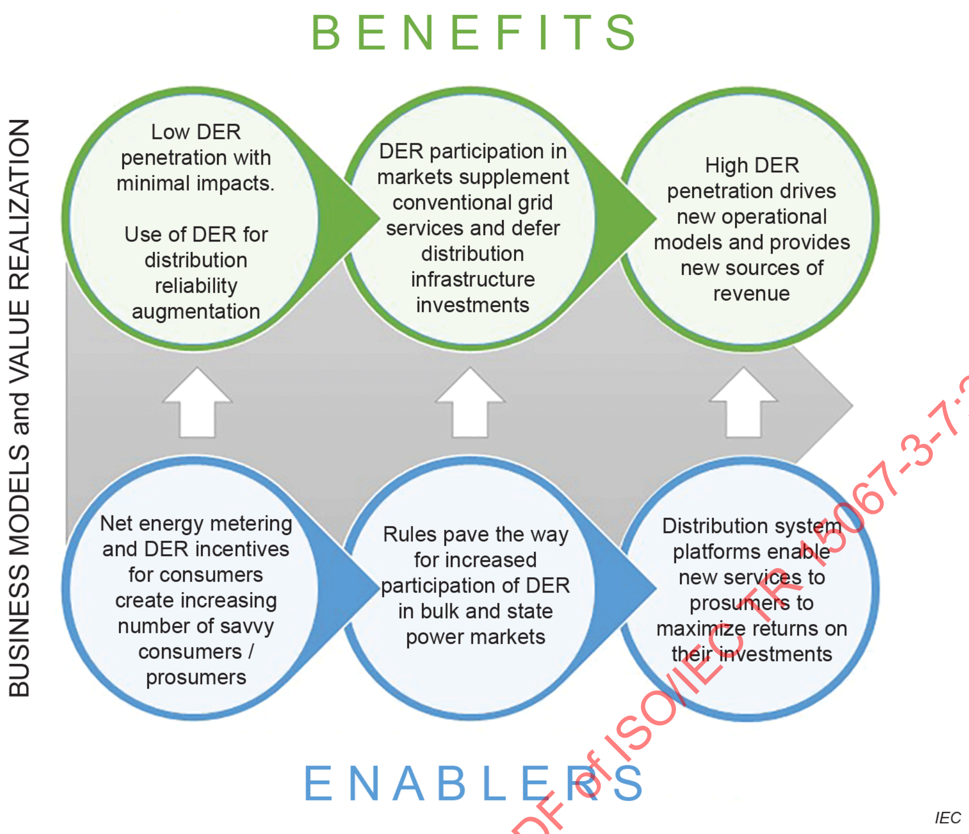


Figure 3 – Example benefits and enablers for the "business models and value realization" track

6.2 Vision – what we hope to see at each stage

The vision(s) consists of conditions we expect to be realized over time as they relate to business model changes to enable TESs to evolve and realize value in each of the three stages. The main business model (BM) and value concepts are listed below.

- BM1 – Incentives and opportunities exist for all stakeholders with all parties accountable for standards of performance.
- BM2 – A means exists to optimally assign value when comparing alternatives (for example, wired and non-wired alternatives).
- BM3 – Business models align values across the participating entities in an observable and auditable manner.
- BM4 – Opportunities exist for value creation (services) across multiple streams.

Characteristics of the business model and value realization vision at each stage are shown in Table 9.

Table 9 – Business model and value realization vision (BMV)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
BMV01	Limited use of demand response (DR) for distribution capacity relief and utility DR programmes.	DER transactive participation based on capacity auctions primarily to defer infrastructure upgrade.	Proliferation of bilateral peer-to-peer forward transactive exchanges among prosumers, including microgrids, building energy management systems (BEMS), etc.
BMV02	Main economic use of DERs for load shifting or peak shaving using aggregators and direct control.	Evolution of distribution-level products and services that optimize value for incentivized stakeholders (phase balancing, distribution constraint relief services, etc.).	Distributed ledgers and smart contracts offer the opportunity to build new models on top of the existing infrastructure.
BMV03	DERs are used for local generation and reliability augmentation without use of transactive systems.	Transactive exchanges across the T&D interface, mainly for large consumers and prosumers, and through intermediaries such as aggregators for smaller prosumers.	Evolution of DSOs into pseudo-balancing entities at the T&D interface while accommodating peer-to-peer bilateral exchanges across the distribution system.
BMV04	The need to develop business model simulation and valuation techniques is recognized.	Business model simulation and valuation techniques begin to be developed for TESs and DERs.	Tools are available to model value flow to support business model simulation and valuation from different stakeholder perspectives.

6.3 Enablers – elements required if the vision is to be realized

Enablers are the elements that need to be in place to support and facilitate actions by various stakeholders, their roles in TE, and how their business models need to evolve for them to provide and realize value in each of the three stages. The main business model and value realization concepts are listed below.

- BM1 – Incentives and opportunities exist for all stakeholders with all *parties accountable for standards of performance*.
- BM2 – A means exists to optimally assign value when comparing alternatives (for example, wired and non-wired alternatives).
- BM3 – Business models align values across the participating entities in an observable and auditable manner.
- BM4 – Opportunities exist for value creation (services) across multiple streams.

Characteristics of business model and value realization enablers at each stage are shown in Table 10.

Table 10 – Business model and value realization enablers (BMEs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
BME01	DER penetration is sufficient to provide tangible benefits from integrated use.	Transactive exchanges across the T&D interface enable evaluation of results and evolution of capabilities.	Local and regional platforms for energy and service exchanges (markets).
BME02	Management of capacity and spinning reserves allow for DER participation.	Increased DER participation as capacity and spinning reserves are based on DER peer-to-peer agreements.	Peer-to-peer exchanges among prosumers, microgrids, and BEMSs contribute to additional services markets.
BME03	Aggregators and direct control make effective use of DR.	Distribution-level products and services that are based on DR are defined.	Incentives and opportunities exist for business models based on multiple value streams from DR.
BME04	DER opportunities available for buildings to utilize are handled locally.	External business opportunities exist for DER owners to consider.	Business opportunities exposed through market interfaces can be created by all types of parties.
BME05	Stakeholders determine which benefits and values are monetizable and which are primarily for public good or to reduce negative consequences.	The potential for addressing spoofing and bad actors from technology and economic standpoints is built into the business model.	New TESs include modelling fair operation and game theory as part of preoperational simulations.
BME06	Limited early interest from consumer electronics companies.	Ability for consumer electronics to interact on a broad basis locally.	Appliance capabilities from consumer electronics companies allowing interaction with market signals is the norm.

6.4 Results – outcomes made possible by new patterns of use

These are results that are important to realize the benefits that can be created for various stakeholders, their roles in TE, and how their business models need to evolve for them to provide and realize value in each of the three stages. The main business model and value realization concepts are listed below.

- BM1 – Incentives and opportunities exist for all stakeholders with all *parties accountable for standards of performance*.
- BM2 – A means exists to optimally assign value when comparing alternatives (for example, wired and non-wired alternatives).
- BM3 – Business models align values across the participating entities in an observable and auditable manner.
- BM4 – Opportunities exist for value creation (services) across multiple streams.

Characteristics of business model and value realization results at each stage are shown in Table 11.

Table 11 – Business model and value realization results (BMRs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
BMR01	Aggregators create viable market opportunities and services.	DSOs start to become established.	"Aggregators" offering business models based on multiple value streams move into DSO space.
BMR02	Participation is attractive for the more affluent.	Participation is attractive for many consumers.	Widespread participation drives rethinking the scope of obligation to serve as all stakeholders will have more responsibility for power.
BMR03	Current business models or revenues unchanged.	A variety of changes and new business models implemented.	Regulations are used to quantifiably compare proposed wired and non-wired solutions.
BMR04	Several varieties of TES designs.	More standardization of TES designs.	Many sizes and types of TES designs, based on common core principles.
BMR05	DR demonstrated for distribution capacity relief.	DER TESs demonstrate financial and reliability benefits of deferred infrastructure upgrades.	Prosumers, microgrids, and buildings realize broad benefits from TE through the use of DERs.
BMR06	Effective use of DERs for load shifting or peak shaving.	Non-utility assets actively providing phase balancing, distribution constraint relief services, etc.	Sophisticated, coordinated actions integrated with financial benefits and incentives through the use of smart contracts.

6.5 Benefits – how these outcomes add value

These are benefits that can be created through business model evolution for various stakeholders as DER penetration increases through each of the three stages. The main business model and value realization concepts are listed below.

- BM1 – Incentives and opportunities exist for all stakeholders with all parties accountable for standards of performance.
- BM2 – A means exists to optimally assign value when comparing alternatives (for example, wired and non-wired alternatives).
- BM3 – Business models align values across the participating entities in an *observable and auditable* manner.
- BM4 – Opportunities exist for value creation (services) across multiple streams.

Characteristics of business model and value realization benefits at each stage are shown in Table 12.

Table 12 – Business model and value realization benefits (BMBs)

TE Systems	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
BMB01	People start considering and looking for non-traditional solutions such as TE for DERs.	Best practices start to develop and drive standards for TE.	Standards for TESs create a platform for more technical and fiscal innovation.
BMB02	Very limited or no ability to balance supply and demand from individual distribution feeder phases to transmission circuits.	Grid resilience increases by integrating distribution and transmission actions using limited market integration across the T&D interface.	Flexible and cost-effective ancillary services exist due to policy incentives for transactive integration.
BMB03	DR recognized as an effective grid resource.	TE systems create multiple value streams from DR.	TE provides an engine for service innovation.
BMB04	Appearance of new participants in grid and market operation.	The existing utility monopoly business model and regulatory process are challenged as new business requirements drive the need for new business models.	Markets adapt to favour those who create the most value.
BMB05	Buildings and campuses find value in stand-alone solutions.	Buildings and campuses start to work together with common interests.	Parties of all types work together with value creation and exchange as the driver.
BMB06	Insights gained into which markets, sales-channel entry points, and approaches are likely to be most enduring.	Early operational cost and revenue lessons learned highlight overhead transaction costs and how to value them.	Greater opportunities for value creation through convergence of residential, commercial, and industrial buildings.
BMB07	Prosumers incentivized by centralized, local-level signals.	Prosumers incentivized by local- and regional-level signals.	Prosumers incentivized by peer-to-peer signals.
BMB08	DERs provide ability to generate revenue.	DERs create revenue and attract investment capital.	Investment capital drives innovation in business models.
BMB09	The need for simulation of business models and valuation techniques is recognized.	Business model simulation and valuation techniques begin to be developed for TESs and DERs.	Tools are available to model value flow and business model simulation from different stakeholder perspectives.

7 System design and architecture

7.1 General

This track focuses on system design and architecture actions necessary to support each stage, specifically dealing with (1) information interoperability to support TE valuation, and (2) operation and control aspects to understand and manage the effects on the electricity grid. This track depends on the business model to describe content and timing of required information exchange among TE parties. This is where each stakeholder needs to develop or understand their existing architecture and their future architecture, then develop a set of transitional states of progress and transition between stages. System design and architecture benefits and enablers are illustrated in Figure 4.

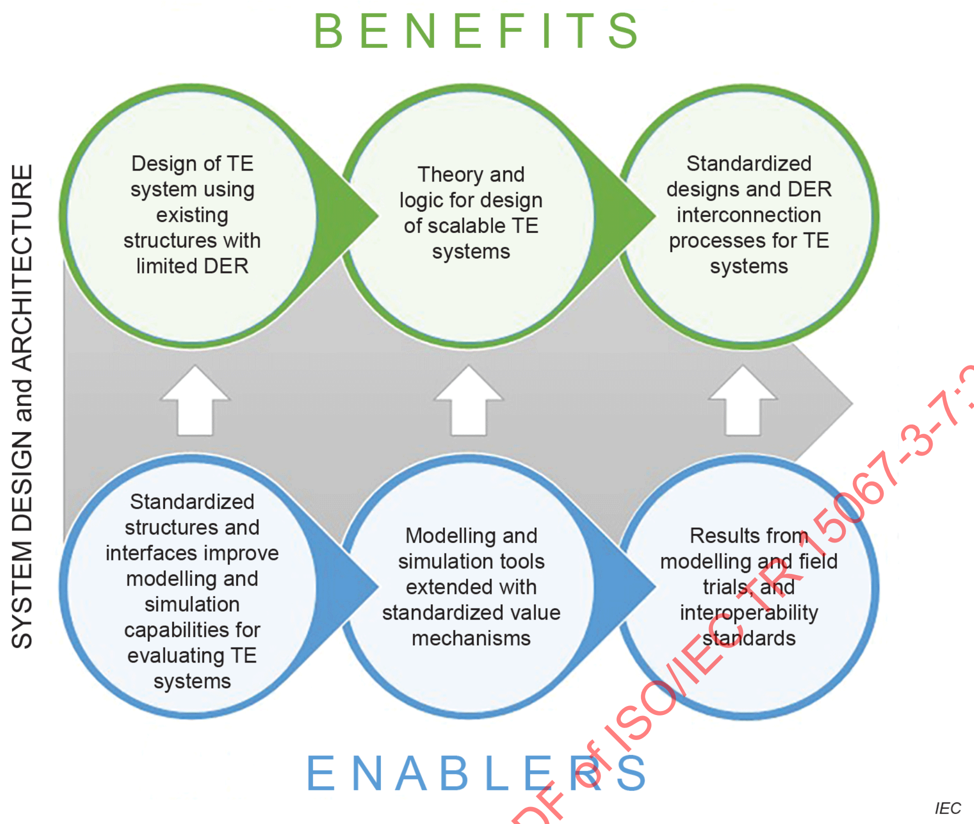


Figure 4 – Example benefits and enablers for the "system design and architecture" track

7.2 Vision – what we hope to see at each stage

The vision(s) consists of conditions we expect to be realized over time as they relate to design and architecture activities necessary to support each stage, specifically dealing with (1) information interoperability to support TE valuation, and (2) operation and control aspects to understand and manage the effects on the electricity grid. The main design and architecture (DA) concepts are listed below.

- DA1 – A standard set of definitions and structure develops for interfaces with X2G operations at all levels.
- DA2 – Systems transition from centralized to decentralized based on highly coordinated self-optimization.
- DA3 – Reliability and control are assigned value when integrated into all TE systems that interact with the grid.
- DA4 – Buildings and facility-grids have more prominent roles over time.
- DA5 – Modelling and simulation solutions for TE systems produce mutually consistent results and can exchange data.

Characteristics of the system design and architecture vision at each stage are shown in Table 13.

Table 13 – Design and architecture vision (DAV)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
DAV01	The grid consists of transmission and distribution with interfaces driven by local interconnection requirements.	The grid consists of a collection of independent or semi-independent systems operating in a coordinated way.	Standardized interfaces create reusability of applications at all levels within the grid.
DAV02	Characterized by centralized distribution control by utilities.	Mix of centralized and distributed control still largely using centralized optimization across service territory with utility beginning to act as DSO.	Distributed system operations and controls coordinated via DSO with all stakeholders across the region.
DAV03	Local management of transactive systems used to optimize behind-the-meter building, campus, and microgrid value.	DERs at connected buildings interact with the grid, enabled by TESs.	Distributed optimization of buildings and other DER facilities supports reliability and resilience.
DAV04	Local devices respond to grid events on a deterministic basis.	Local device behaviour is a mix of deterministic and stochastic, requiring modelling and simulation.	Stochastic optimization[a] is employed as a means of more accurately accounting for uncertainties in interactions (and simulations) across a large number of devices and participants.

[a] Stochastic optimization refers to the minimization (or maximization) of a function in the presence of randomness in the optimization process. It should include financial risk management tools and approaches.

7.3 Enablers – elements required if the vision is to be realized

Enablers are the elements that need to be in place to support and facilitate system design and architecture actions necessary to support each stage, specifically dealing with (1) information interoperability to support TE valuation, and (2) operation and control aspects to understand and manage the effects on the electricity grid. The main design and architecture concepts are listed below.

- DA1 – A standard set of definitions and structure develops for interfaces with X2G operations at all levels.
- DA2 – Systems transition from centralized to decentralized based on highly coordinated self-optimization.
- DA3 – Reliability and control are assigned value when integrated into all TE systems that interact with the grid.
- DA4 – Buildings and facility-grids have more prominent roles over time.
- DA5 – Modelling and simulation solutions for TESs produce mutually consistent results and can exchange data.

Characteristics of system design and architecture enablers at each stage are shown in Table 14.

Table 14 – Design and architecture enablers (DAEs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
DAE01	Pilot applications involve a limited number of prequalified partners with proprietary solutions.	Standardized models of transactive system nodes allow more partners with increasingly open solutions and exchanges of value.	Broadly applied TESs optimize locally but coordinate actions by valuing control as a key parameter.
DAE02	Centralized control schemes.	Creation of early DSOs and distributed control schemes.	Building management systems, microgrids, and other devices include support for coordination with distributed control schemes.
DAE03	Local interconnection requirements enable DER connections.	Common interconnection requirements enable participants to operate more easily in multiple locales.	Grid interfaces are standardized using specific required elements.
DAE04	Quicker, more efficient distribution modelling and forecasting techniques.	Modelling and simulation of bidirectional power and DER events.	Modelling tools available for microgrids provide for federated modelling capabilities.
DAE05	Interoperability addressed through definition of basic information exchanges between transactive nodes.	General models of transactive nodes defined, including interfaces between nodes and between nodes and other elements including DERs.	Standards developed supporting general models of transactive nodes and low-cost integration of transactive nodes and components.
DAE06	DER implementations start to cause design modifications to existing infrastructure.	Wired and non-wired designs are developed to adapt to future scenarios.	Increased islanding capability supported by DERs creates opportunities for TESs at scale.
DAE07	The integration of DERs helps popularize campus microgrids.	Microgrids created from the distribution grid or installed as an overbuild network with new wires.	Coordinating microgrids is a central part of managing distribution grids.

7.4 Results – outcomes made possible by new patterns of use

These are results that are important to realize system design and architecture changes necessary to support evolution at each stage; specifically deals with information interoperability to support TE valuation, and operation and control aspects to understand and manage the effects on the electricity grid. The main design and architecture concepts are listed below.

- DA1 – A standard set of definitions and structure develops for interfaces with X2G operations at all levels.
- DA2 – Systems transition from centralized to decentralized based on highly coordinated self-optimization.
- DA3 – Reliability and control are assigned value when integrated into all TE systems that interact with the grid.
- DA4 – Buildings and facility-grids have more prominent roles over time.
- DA5 – Modelling and simulation solutions for TESs produce mutually consistent results and can exchange data.

Characteristics of system design and architecture results at each stage are shown in Table 15.

Table 15 – Design and architecture results (DARs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
DAR01	Local reliability and control managed by utilities.	DSOs appear in a few jurisdictions, enabling DERs to provide reliability and control benefits.	Significant numbers of DSOs result in highly coordinated self-optimization for buildings and local grids (campuses, facilities).
DAR02	Technical capabilities of TESs proven at local level.	Increased scale of TESs includes diverse value systems that prove the optimization methods.	Large-scale deployments monetize control as a key parameter to be optimized with other goals.
DAR03	Raising awareness of device and system interoperability drives interest in interoperability measurement.	Increased awareness of interoperability for system modelling and simulation capabilities (co-simulation data exchange).	Interoperability of policy and regulation. Certification for interoperability maturity.
DAR04	Support for transactive systems for campuses, microgrids, and buildings.	Support for transactive systems for non-contiguous sites.	Support for transactive systems in most system and market designs.
DAR05	Implementation of CVR, VVO and phase balancing based on central control.	Bidirectional power and voltage management by coordinating DER activities and ancillary services through TESs.	Federated modelling capabilities based on the ubiquity of TESs to create value and flexibility.
DAR06	System designed for peak load, lower load factors.	TESs permit designs for higher load factors and deferred upgrades.	New designs incorporate TESs as de facto elements.

7.5 Benefits – how these outcomes add value

These are system design and architecture benefits that can be created as DER penetration increases through each of the three stages. The main design and architecture concepts are listed below.

- DA1 – A standard set of definitions and structure develops for interfaces with X2G operations at all levels.
- DA2 – Transition from centralized to decentralized systems based on *highly coordinated self-optimization*.
- DA3 – *Reliability and control* are assigned value when integrated into all TE systems that interact with the grid.
- DA4 – Buildings and facility-grids feature more prominently over time.
- DA5 – Modelling and simulation solutions for TESs produce mutually consistent results and can exchange data.

Characteristics of system design and architecture benefits at each stage are shown in Table 16.

Table 16 – Design and architecture benefits (DABs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
DAB01	Recognition that proprietary solutions produce local benefits but have limited coordination capabilities.	Standardized definitions and structure develop for interfaces that include value, driven by TES coordination.	Including value in grid interfaces and valuing control explicitly leads to less congestion.
DAB02	Predictable performance supports centralized architecture.	Hybrid of deterministic and stochastic behaviour drives new modelling and simulation capabilities.	Improved modelling and simulation capabilities support better designs that use stochastic optimization to reduce uncertainties.
DAB03	Increased awareness of TESs as a solution for both local optimization and community coordination.	Lessons learned from increasing numbers of TESs that coordinate remote sites and organizations with each other.	Grid architecture becomes much more flexible as it includes and coordinates many distributed TESs.
DAB04	Quick and affordable ways to get consumers interacting with the grid.	Improved modelling creates opportunities for much more decentralized and customer-driven solutions.	Coordination between stakeholders using TESs creates market opportunities beyond the grid.
DAB05	Does not require changes to the current utility business and regulatory structure	Acts as a catalyst for design change across the T&D boundary.	Provides a foundation for new designs for system architecture and energy services.
DAB06	Increasing interest in interoperability driven by need to integrate DERs.	DER interface standardization reduces the need to modify existing systems to interoperate with them.	Reduced integration cost for DERs decreases costs to deploy and integrate new TE systems.

8 Physical and cyber technologies and infrastructure

8.1 General

This track focuses on the changing cyber-physical needs and required actions through the progression of the three stages. This track addresses the technical layers of the GWAC Stack and the physical layers of the Control Abstraction Stack[3]. It includes the activities supporting the electrically connected network and the communications networks necessary to monitor and control the electricity grid. This track depends on the information exchange requirements considered in the "system design and architecture" track to ensure the ability to exchange information in support of transactions without detrimentally affecting the reliability of the electrical network. Enablers and benefits of physical and cyber technologies and infrastructure are illustrated in Figure 5.

3 Control abstraction is the abstraction of actions. The Control Abstraction Stack referenced in ISO/IEC TR 15067-3-8 [1] helps put the concept of cyber-physical systems in context for TE management.

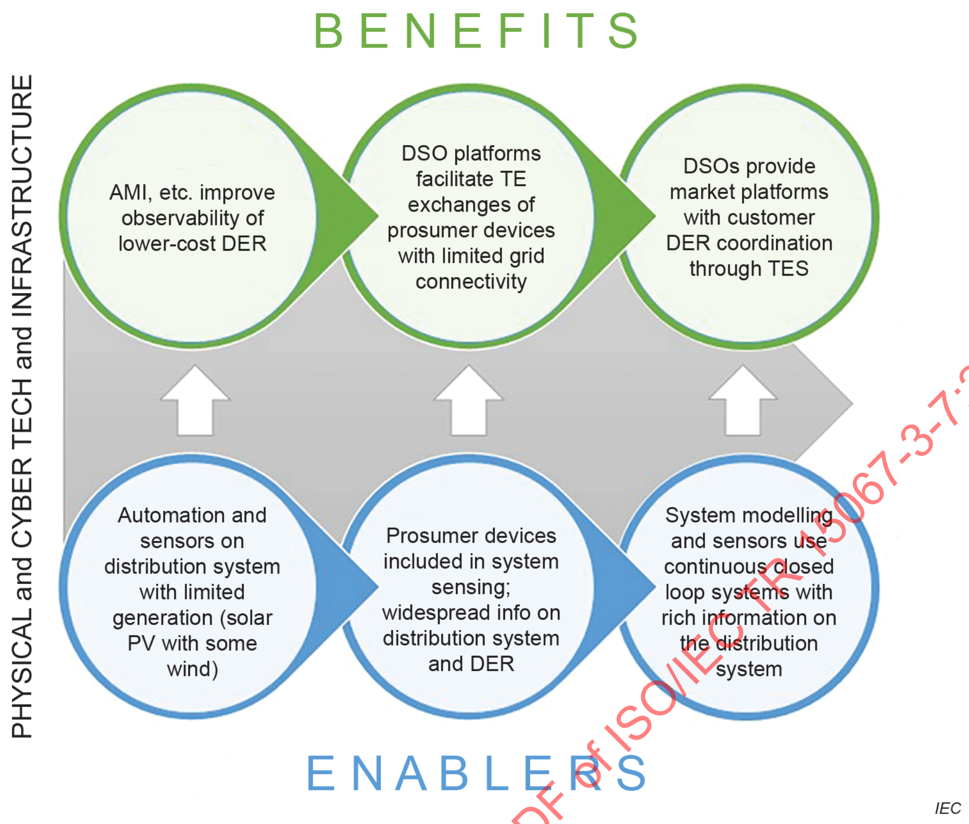


Figure 5 – Example benefits and enablers for the "physical and cyber technologies and infrastructure" track

8.2 Vision – what we hope to see at each stage

The vision(s) consists of conditions we expect to be realized over time as they relate to physical and cyber technologies and infrastructure changes aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electricity grid. The main physical and cyber technologies and infrastructure (PC) concepts are listed below.

- PC1 – Measurement, verification, and situational awareness have been improved.
- PC2 – Affordability of devices and communications enables *scalable, adaptable, and extensible* deployment.
- PC3 – Distributed devices are securely integrated into control schemes.
- PC4 – Consumer devices can support sub-cycle to long-term activities (markets and operations).
- PC5 – Explicit, well-defined trust models that define identity, authentication, service-level agreements, and privacy are built into all TE systems.

Characteristics of the physical and cyber technologies and infrastructure vision at each stage are shown in Table 17.

Table 17 – Physical and cyber technologies and infrastructure vision (PCV)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
PCV01	Proliferation of advanced metering infrastructure (AMI) or other measures to improve visibility of DERs to DSOs.	Evolution of DSOs with distributed system platforms primarily using distributed energy resource management systems (DERMS) and advanced distribution management systems (ADMS), and facilitating new transactive exchanges.	DSO construct realized at scale with distribution market platforms and broad awareness of effects across the T&D interface.
PCV02	Deployment of distribution management systems (DMS) and ADMS by most utilities. Limited circuit switching capability.	Enhancement and evolution of DMS and ADMS for better situational awareness and control. Automated switching for more distribution circuits.	Distribution state estimators and phasor measurement systems in use for distribution systems and used in TES optimization.
PCV03	Cost of smart devices for use by utilities continues to drop, driving broad deployment.	Proliferation of low-cost prosumer devices leads to improved local control systems and limited connectivity to grid systems.	Customer and facility devices and control systems coordinate with utilities and DSOs through TESs.

8.3 Enablers – elements required if the vision is to be realized

Enablers are the elements that need to be in place to support and facilitate activities aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electricity grid. The main physical and cyber technologies and infrastructure concepts are listed below.

- PC1 – Measurement, verification, and situational awareness have been improved.
- PC2 – Affordability of devices and communications enables *scalable, adaptable, and extensible* deployment.
- PC3 – Distributed devices are securely integrated into control schemes.
- PC4 – Consumer devices can support sub-cycle to long-term activities (markets and operations).
- PC5 – Explicit, well-defined trust models that define identity, authentication, service-level agreements, and privacy are built into all TE systems.

Characteristics of physical and cyber technologies and infrastructure enablers at each stage are shown in Table 18.

Table 18 – Physical and cyber technologies and infrastructure enablers (PCEs)

Reference	Stage 1 Persistently demonstrated	Stage 2 Broadly applied	Stage 3 At scale
PCE01	Automation and utility sensors established on the distribution system.	Prosumers and non-utility devices are included in system sensing.	System is continuously monitored and modelled.
PCE02	Devices that can provide load reduction with some load shifting.	Interactive devices that can perform load reduction and shifting with some load increases.	Fully integrated cyber-physical system for DERs that balances distributed supply and demand.
PCE03	Limited generation on the distribution system. Mostly solar with some wind.	Widespread generation on the distribution system. Mostly solar with some wind. Storage benefits being realized.	Widespread generation and storage on the distribution system.
PCE04	Integration of supply and demand incorporating DERs on the distribution system.	Device addressability that creates more connected opportunities without the need for excessive layers of communication and control.	Commercially available open platforms with main functions of DSO being standardized across regulatory jurisdictions and incorporating standards-based requirements.
PCE05	Inverters provide basic DC-to-AC conversion.	Inverters can ride through frequency and voltage excursions.	Inverters provide artificial inertia and electric-parameter regulation services.
PCE06	Affordable, reliable, wireless data infrastructure with secure communications.	Quicker, cheaper, and more secure direct communication paths.	Trust models provide identity, authentication, service-level agreements, and privacy.
PCE07	DER testing and certification established for standards compliance.	Increased use of simulation as an enabler for testing.	Increased interoperability as a result of simulation and testing.

8.4 Results – outcomes made possible by new patterns of use

Physical and cyber technologies and infrastructure results are aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electricity grid. The main physical and cyber technologies and infrastructure concepts are listed below.

- PC1 – Measurement, verification, and situational awareness have been improved.
- PC2 – Affordability of devices and communications enables *scalable, adaptable, and extensible* deployment.
- PC3 – Distributed devices are securely integrated into control schemes.
- PC4 – Consumer devices can support sub-cycle to long-term activities (markets and operations).
- PC5 – Explicit, well-defined trust models that define identity, authentication, service-level agreements, and privacy are built into all TE systems.

Characteristics of physical and cyber technologies and infrastructure results at each stage are shown in Table 19.