EASY-RES

SUMMER SCHOOL
"ENABLING DRES TO OFFER ANCILLARY SERVICES"
20TH – 24TH SEPTEMBER 2021

ICT Architecture for Enabling Ancillary Services

Prof. Hermann de Meer, Armin Stocker // 23.09.2021

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Agenda

- Motivation
- Distributed Systems
- Virtualization
- EASY-RES ICT Architecture

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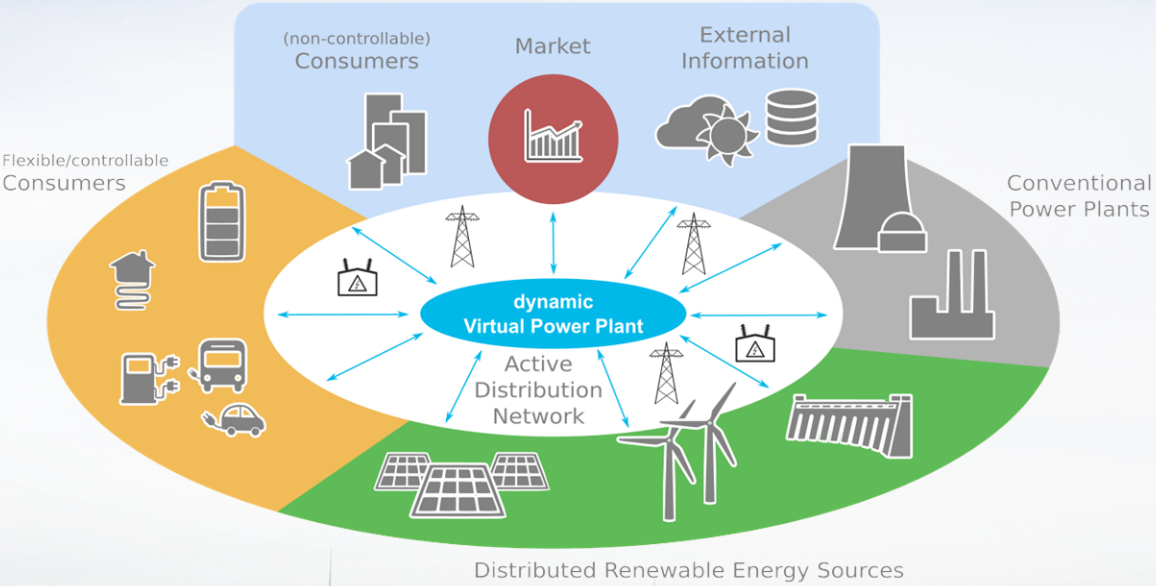
What we want to achieve!



Virtual Power Plant

- Grid Monitoring
- Resource Management
- Grid Protection
- Grid Control/Optimization
- Ancillary services
  (as a virtual synchronous generator)

How to build such a system?

Motivation

Systems

System

- “a **combination of interacting elements** organized to **achieve one more stated purpose**” [ISO/IEC/IEEE 15288]

Software-intensive systems

- …are systems in which **software development and/or integration are dominant considerations** (i.e., most complex systems these days). This includes computer-based systems ranging from individual software applications, information systems, embedded systems, software product lines and product families and systems-of-systems. [ISO/IEC/IEEE 42010]

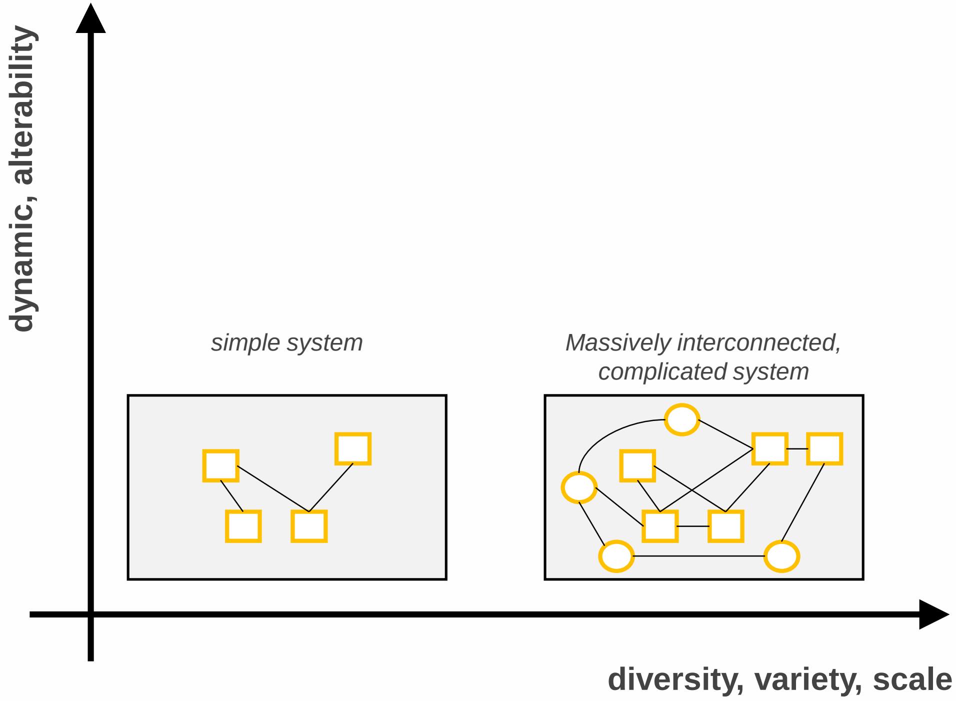
Aspects of systems

- Man-made
- Created and utilized to provide services in defined environments for the benefit of users and other stakeholders
- Configured with one or more of the following:
  - hardware
  - software
  - humans
  - processes (e.g., review process)
  - procedures (e.g., operator instructions)
  - facilities
  - naturally occurring entities

ISO/IEC/IEEE 15288 2015; ISO/IEC/IEEE 42010

Motivation

Classification of Systems



Simple system: comprises only a few **statically** interconnected elements with a low intensity of interaction. They can be described in their entirety explicitly by means of mathematical and/or analytical methods.

Example: Q(U) voltage controller at a DRES

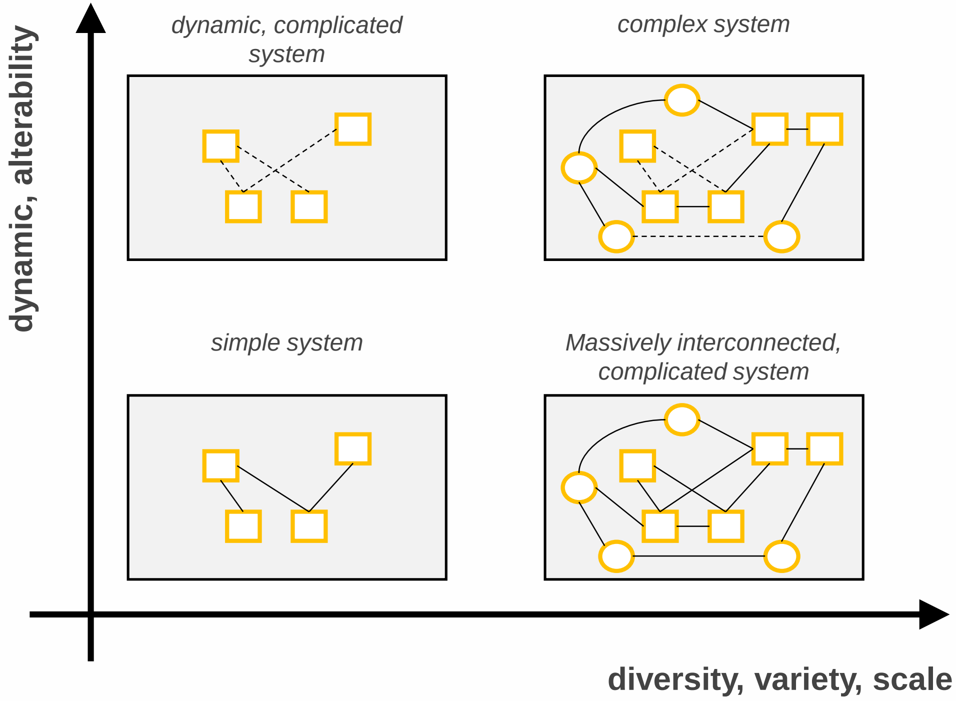
Massively interconnected, complicated system: Characterized by huge number of **statically** connected elements and their variety. Explicit description is hard to obtain. Description of system‘s behavior mostly only by computer simulations.

Example: Interconnected power system

[Haberfellner 2019]

Motivation

Classification of Systems



[Haberfellner 2019]

Dynamic, complicated system: characterized by their **temporal**, often **non-linear** variety between elements in respect to their type of interaction, intensity and structure. Amount and intensity of inter-dependencies is limited.

Example: Different AS at a DRES using different components

Complex system: characterized by a **huge number** of elements and connections with a high variety and **dynamically established connections**. System-wide interdependencies between elements exist.

Example: Dynamic virtual power plant coordinating different AS at different locations

Motivation

System-of-Systems (SoS)

Definition

- "Interoperating collection of component systems that produce results unachievable by the individual systems alone" [Strickland 2011]

System of systems

- Combination of power system and ICT system
- Massively interconnected
- Dynamically interacting effects

Two fundamental paradigms

- **Abstraction** („Divide and Conquer“)
  - Hide details on higher levels
  - Treat on lower levels

  → Decide on abstraction levels and granularity
- **Separation of Concerns**
  - Deal with different aspects in different views

  → Decide on views

Motivation

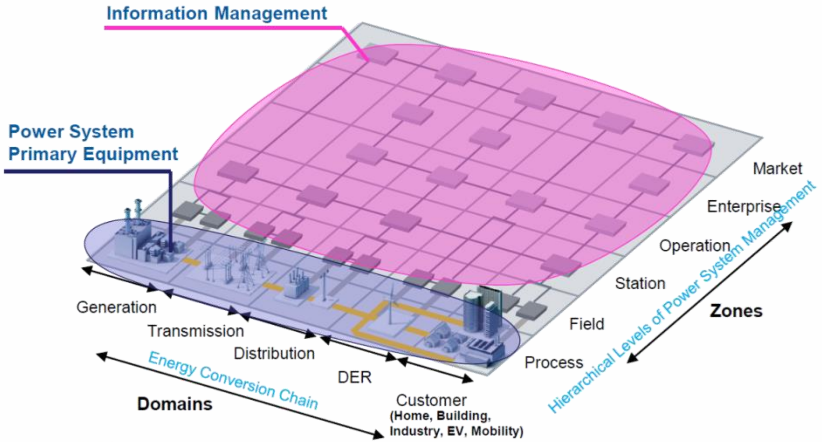
Smart Grid Architecture Model (SGAM)

SGAM-Plane: problem decomposition

- Domains: Energy conversion chain
- Zones: Automation pyramid

Examples

- Smart meter: Customer, Field
- Grid control center: Distribution, Operation
- dVPP: Distribution/Transmission, Operation



CEN-CENELEC-ETSI 2012

Motivation

Smart Grid Architecture Model (SGAM)

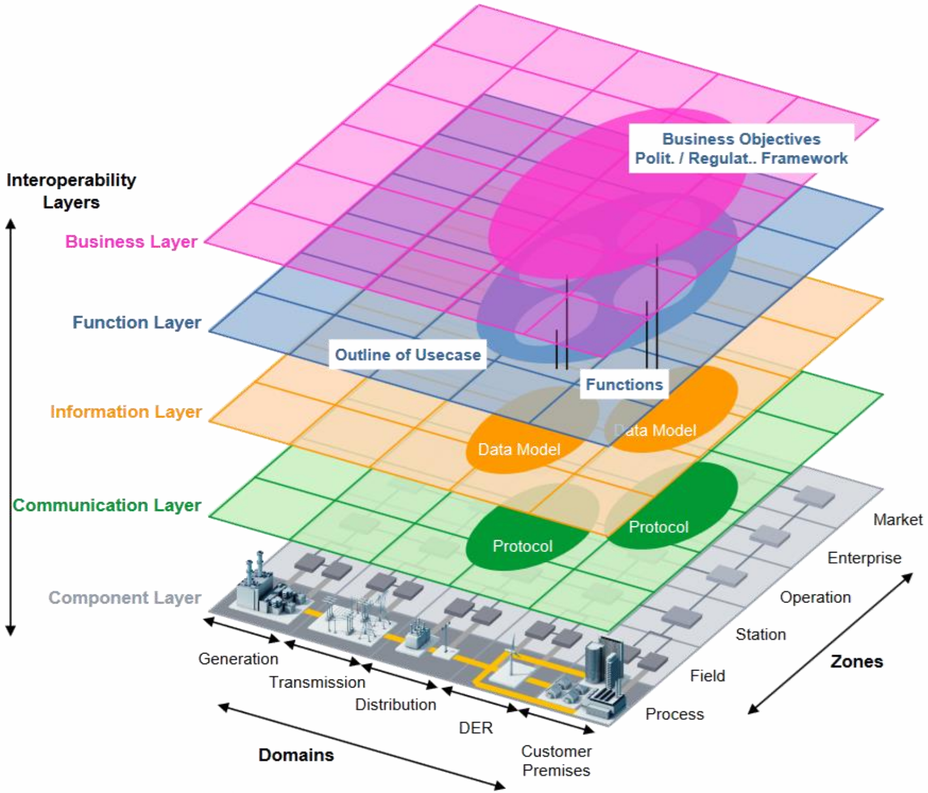
SGAM-Plane: problem decomposition

- Domains: Energy conversion chain
- Zones: Automation pyramid

Interoperability on different layers („SGAM Layers“)

- Business, *e.g. use cases*
- Function, *e.g. algorithms*
- Information, *e.g. data representation*
- Communication, *e.g. encryption protocols*
- Component

Reuse of standards, e.g. data models, protocols, etc.



CEN-CENELEC-ETSI 2012

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- EASY-RES ICT Architecture

Distributed Systems

Definition

- Before 1985: computers were large, expensive, independent
- Starting in the mid-1980s:
  - "A Distributed System is a **collection of autonomous and cooperative computers** that appears to users as a **single coherent system**" [vanSteen 2017]

    reads,
  - Invention of high speed computer networks

    "A dVPP is a **collection of autonomous and cooperative CI-DRES and ICT units** that virtually appears to AS customers as a **single coherent synchronous generator**"

    nected
- The... of networked and geographically dispersed computers → called Distributed Systems

Distributed Systems

Characteristics

dVPP

- **Collection of autonomous computing elements** → **Collection of autonomous CI-DRES and ICT units**
  - Different types of nodes:
    - Hardware device and software process → E.g. CI-DRES and central optimization algorithms
    - Act independently
    - Programmed to achieve common goals
  - Management of group membership (e.g., admission control) → ICT and related quality of service
  - Organized as overlay networks → E.g. Overlay network with increasing voltage level for voltage control optimization

Distributed Systems

Characteristics

dVPP

- **Single coherent system**
  - Coherent:
    - System behaves according to the expectations → E.g. fault current is provided according to the configurations
  - Distribution transparency
    - Location of data storage is not concerned → Exact location of inertia provisioning is not concerned
    - Location of the web service might be relevant to performance → Voltage control is location-dependent
  - Main challenge: failure masking
    - Partial failures of system components are unavoidable
    - In case of failure:
      - Some applications continue. For example, an ICT replica takes over → E.g. shifting inertia response to anther CI-DRES in the same area.
      - Some applications halt → E.g. lack of resources for voltage control

Design Goals

dVPP

- **Accessibility and Resource Sharing**
  - Makes it easy for users to access and share remote resources → Using uniform AS & CI-DRES interfaces
  - Resources can be virtually anything, e.g., storage facilities, data, files, services, and networks. → E.g. batteries, and CI-DRES
  - Reasons for resource sharing: Economics, collaboration and information exchange → E.g. optimal inertia allocation, ramp-rate limitation
  - Security and privacy issues → E.g. secure accounting transactions, integrity and confidentiality of AS monitoring and control
- Transparency
- Openness
- Scalability

Distributed Systems

Design Goals

dVPP

- Accessibility and Resource Sharing
- **Transparency:**
  - **Access**: Hides differences in data representation and how a resource is accessed → Using uniform AS & CI DRES interfaces
  - **Location**: Hide where a resource is located → E.g. hiding where inertia is provided
  - **Migration**: Hide that a resource may move to another location → E.g. shifting inertia response to another CI-DRES in the same area
  - **Replication**: Hide that a resource is replicated → E.g. replicated batteries for ramp-rate limitation
  - **Concurrency**: Hide that a resource may be shared by several competitive users → E.g. CI-DRES provides multiple AS
  - **Failure**: Hide the failure and recovery of a resource → E.g. shifting inertia response to another CI-DRES in the same area
- Openness
- Scalability

Distributed Systems

Design Goals

dVPP

- Accessibility and Resource Sharing
- Transparency
- **Openness**: Components follow standard rules for syntax and semantics of the services provided
  - **Interoperability**: The possibility for two different implementations to cooperate
  - **Portability**: The degree to which an application for a distributed system A can be run on another distributed system B, which has implemented the same interfaces
  - **Extensibility**
    - Easy configuration and modifications
    - Easy integration or replacement of components
    - Defining internal interfaces is crucial
- Scalability

→ Using uniform vendor-independent AS & CI-DRES interfaces

Distributed Systems

Design Goals

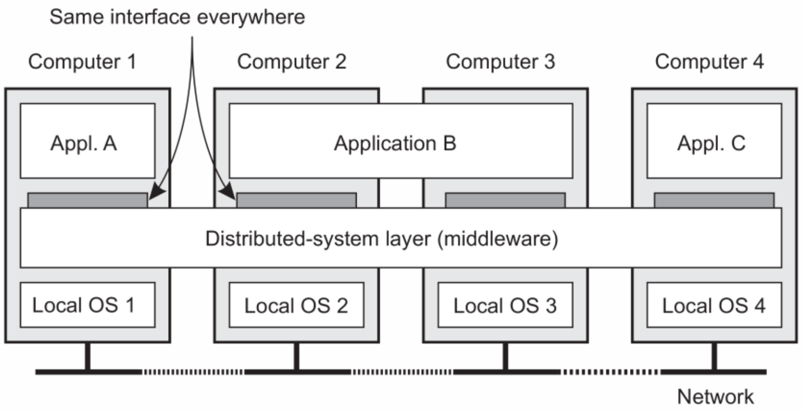
dVPP

- Accessibility and Resource Sharing
- Transparency
- Openness
- **Scalability**
  - **Size Scalability**: easily add more users and resources to the system without any noticeable loss of performance → E.g. adding more CI-DRES by several orders of magnitude
  - **Geographical Scalability**: users and resources may lie far apart, but the fact that communication delays may be significant is hardly noticed → E.g. system can scale to a whole synchronous zone
  - **Administrative Scalability**: easy management of a system even if it spans many independent administrative organizations → E.g. multiple system operators and aggregators

Distributed Systems

Middleware

- For distributed communication, often a middleware is used (abstraction layer)
- Provides resource management, communication, transaction management, service composition, security services, masking failures, ...
- It is logically placed between 2 layers:
  - Higher level layer for users and applications
  - Underlying layer for operation systems and communication facilities

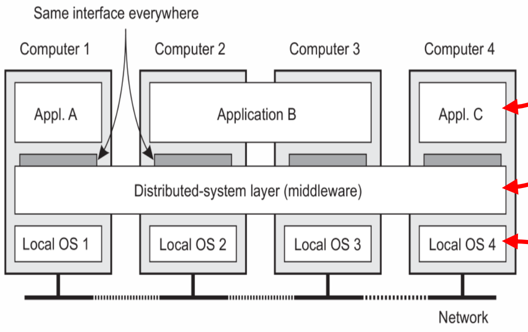


A distributed system organized in a middleware layer, which extends over multiple machines, offering each application the same interface

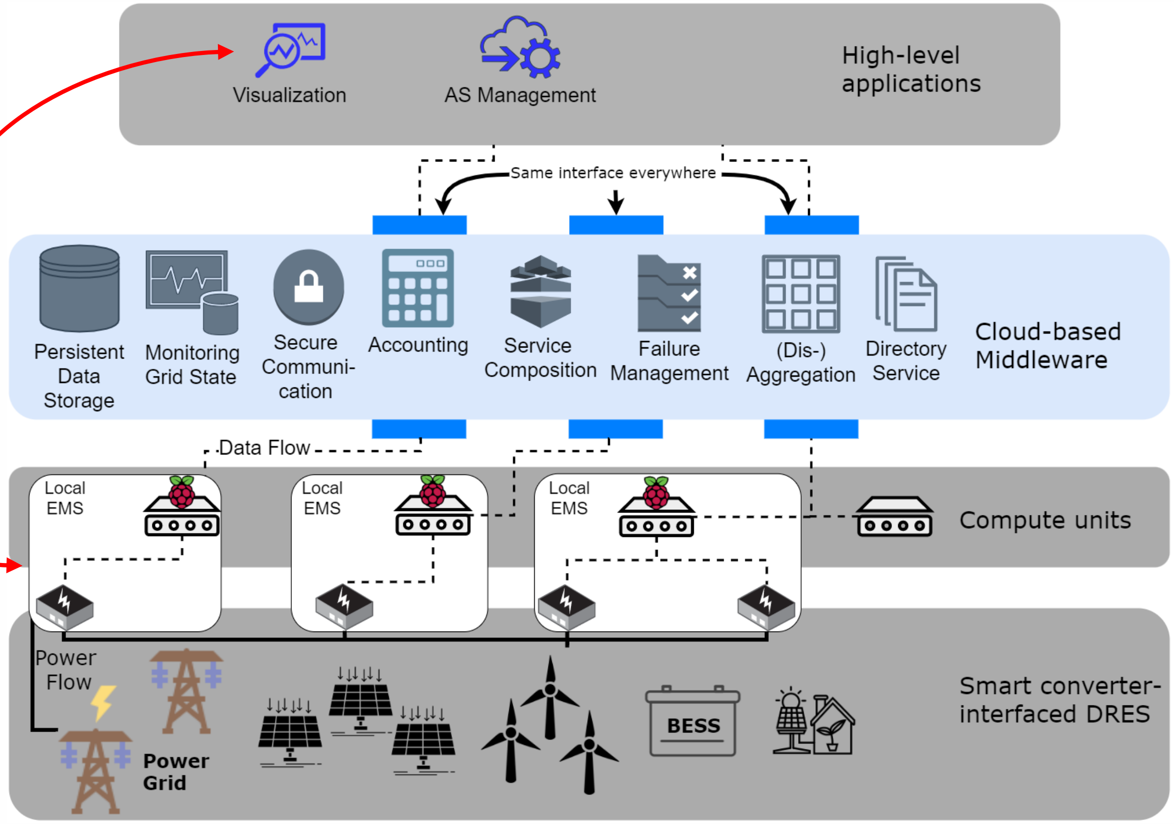
[vanSteen 2017]

Distributed Systems

Middleware



Dynamic Virtual Power Plant



Distributed Systems

Q&A

- The nodes of a distributed system are

A. Autonomous and non-cooperative

B. Autonomous and cooperative

C. Non-autonomous and cooperative

D. Non-autonomous and non-cooperative

Distributed Systems

Q&A

- Which transparency type does enable identical operation on local and remote resources?

A. Access transparency

B. Location transparency

C. Replication transparency

D. Concurrency transparency

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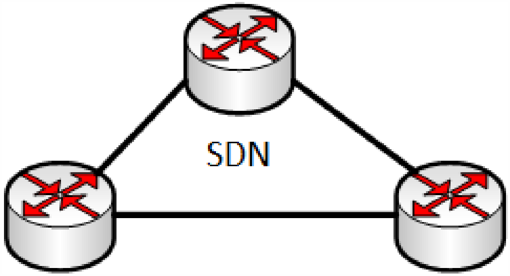
Virtualization

ICT virtualization

- Original virtualization concept: dynamic allocation of computing resources (CPU, memory, disk,..) in the form of virtual machines.
- Enables the flexible deployment of the distributed system (processes).
- Flexibility is critical in dense and heterogeneous environments (such as smart grids)
- Virtualization categories:
  - Connectivity virtualization:
    - Deploying data streams with certain specifications while providing QoS (Quality of Service) guarantees.
    - SDN (Software-defined Networking) architecture.
    - IEEE 802.1 TSN (Time-sensitive Networking).



Connectivity virtualization

dVPP

Communication within the middleware (compute units, CI-DRES)

Virtualization

ICT virtualization

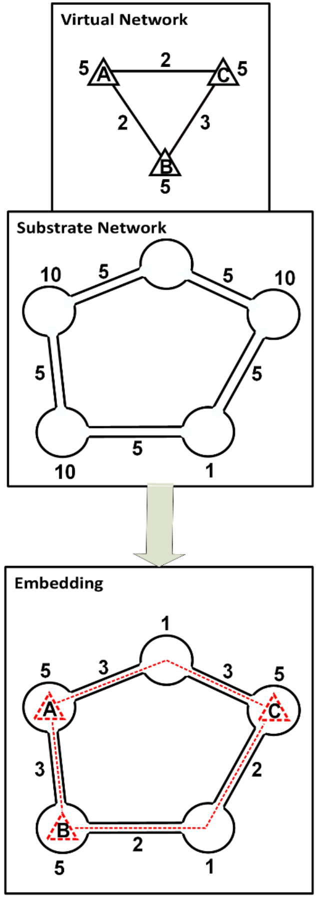
dVPP

- Virtualization categories (cont..):
  - Functionality virtualization:
    - NFV (Network Function Virtualization) architecture: Decoupling network and application functions from hardware to standard servers
    - High availability (replication and migration)
    - Performance challenges
  - Resource virtualization:
    - VNE (Virtual Network Embedding): Graph theory-based methods to allocate resources

Example: decoupling optimization and security functions from the proprietary hardware.

For example, allocating the communication services between the optimization functions and set-pointing functions

Resource virtualization



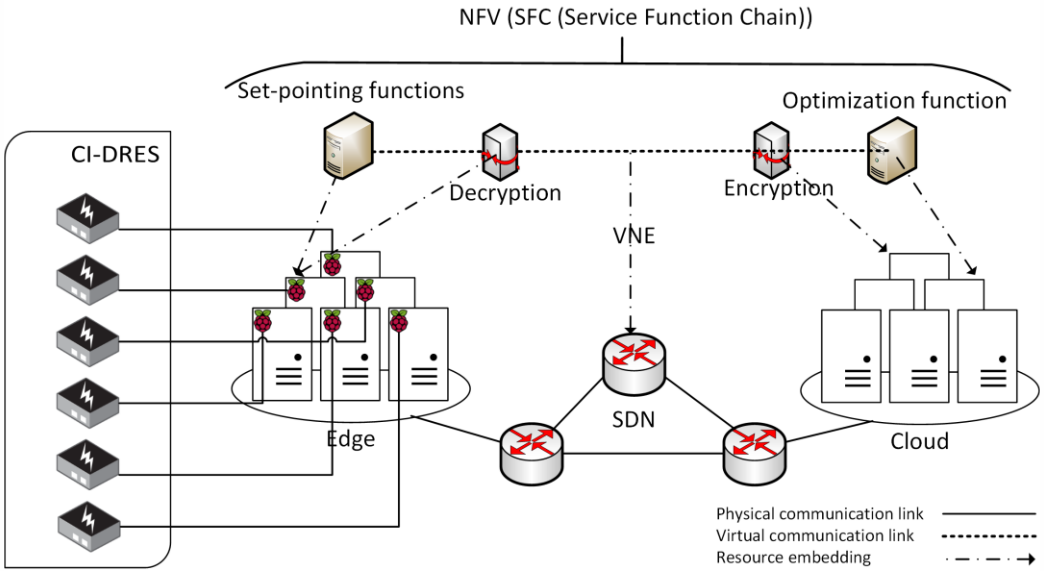
Virtualization

Virtualization Example

dVPP

Using virtualization to deploy a function chain for AS management with QoS guarantees

Functionality: Optimization → Encryption → Decryption → Set-pointing
Connectivity: SDN for deploying the virtual communication links
Resource: VNE for allocating set-pointing functions to the edge (Raspberry PIs), and optimization functions to the cloud servers



Virtualization

Q&A

- In our virtualization example, which virtualization methodology is used for allocating set-pointing functions to the edge (Raspberry PIs)?

A. SDN

B. NFV

C. VNE

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EASY-RES ICT Architecture

Role of ICT System

Synchronous Generator	Distribution System	Active Distribution System
• (Re-)Active power generation • Ancillary service provision • Control & scheduling • Reliability	• Fluctuating load • Frequency & inertia balancing (External) • Little control over DRES • Unreliable standalone sources	• Fluctuating load & generation • Ancillary service provision • Control & scheduling of DRES • Reliability by aggregating unreliable sources → **Managed by ICT**

→Key takeaway: Enable distribution system AS capabilities by ICT

EASY-RES ICT Architecture

Role of Virtualization

- Management via ICT to improve distribution system capabilities requires:
  - Representation of the power grid for various use cases
  - Secure, reliable, low latency communication & computation
  - Representation of ICT resources for computation and communication

ICT Virtualization	Power Grid Virtualization

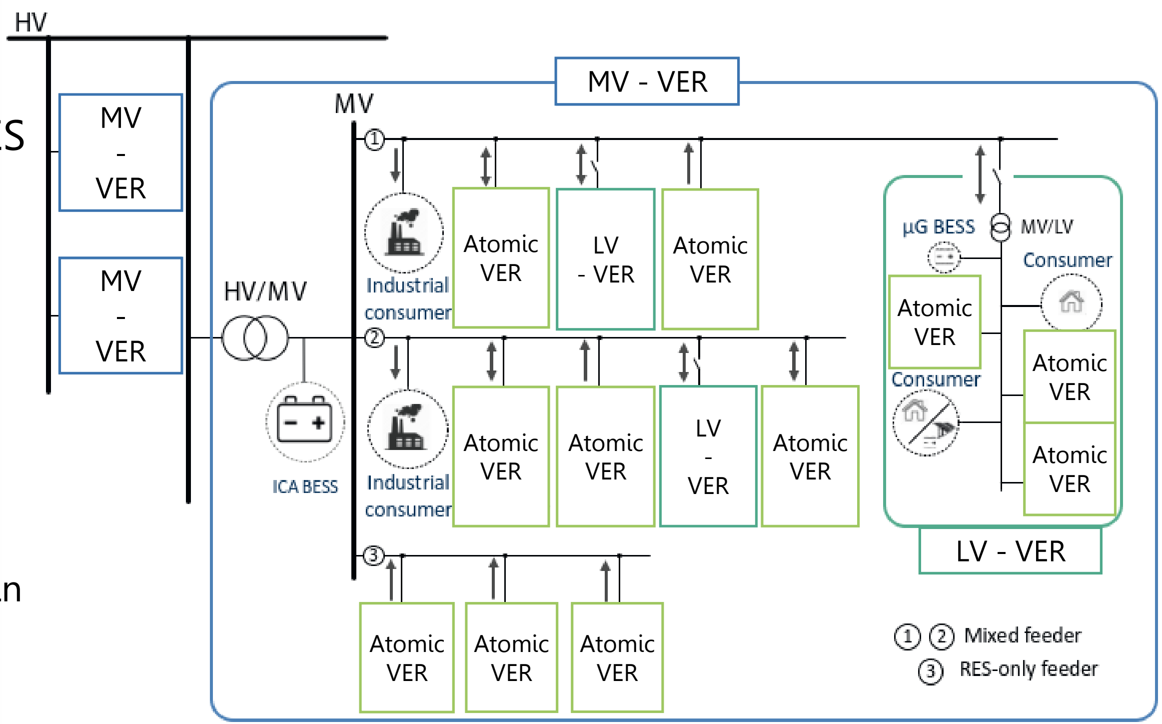
• Security via VPN, PKI
• Reliable computations via NVF
• Reliable communication via SDN
• (Dis-)Aggregation
	• UVSG applied to CI-DRES
	• Hide irrelevant aspects of:
	  • Device characteristics
	  • Measurements
	  • Grid topology
	  • See also DDGM (from part 7c)

Combined in Virtual Energy Resource (VER): • Use ICT virtualization & Power grid virtualization • Represent one DRES or grid area • Provides interface to request ancillary services • Ensures proper & optimal operation internally	

EASY-RES ICT Architecture

VER example:

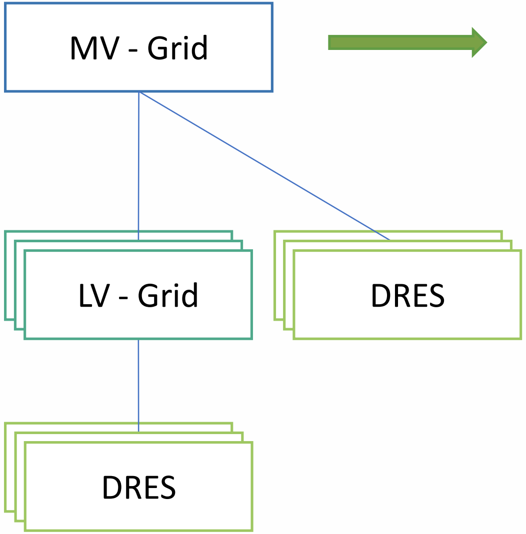
- Hide differences between DRES installation and aggregation:
  - Same virtual representation
  - → Atomic VER for DRES
  - → MV- / LV-VER at respective voltage level
- Aggregation, monitoring and other functions require communication:
  - → MV / LV – VER need to contain power & ICT resources

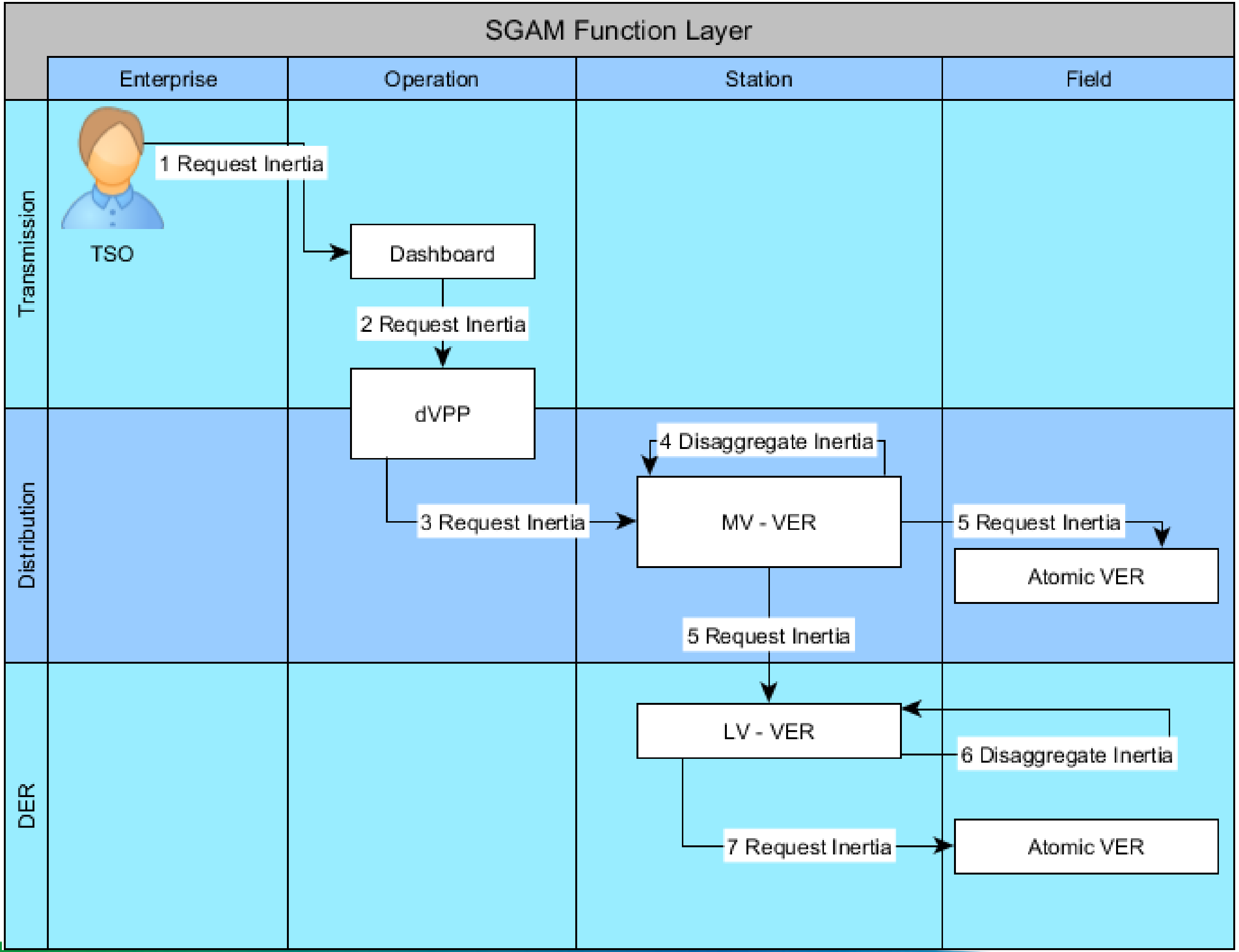


EASY-RES ICT Architecture

Scenario

2nd step of inertia Disaggregation (Talk 7b)



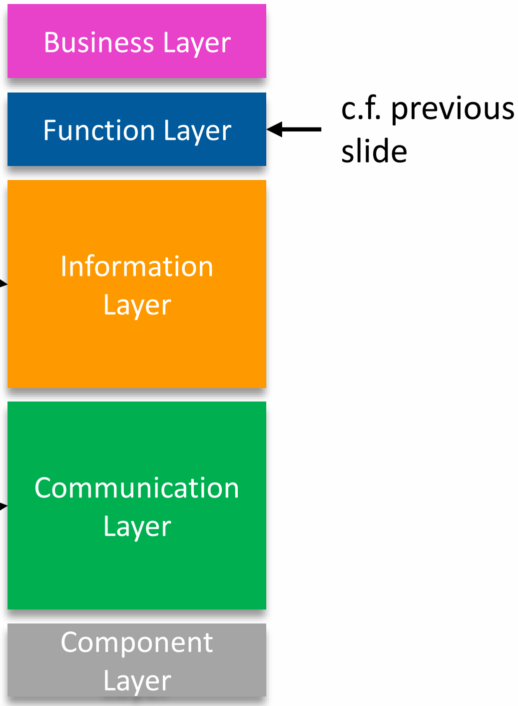


EASY-RES ICT Architecture

VER implemented as a "Thing"

- W3C Web of Things - Thing Description
  - Example: Atomic VER
- „What can it do?"
  - Interaction Affordances
    - Properties: e.g. maximum inertia capability
    - Actions: e.g. enable AS and set inertia constant
    - Events: e.g. accounting metrics
  - Data Schemas: e.g. inertia constant as floating number
- „How to communicate with it?"
  - Security Configuration: e.g. encryption, authorization
  - Protocol Binding, e.g. Modbus-TCP, MQTT…

SGAM Interoperability Layers



https://www.w3.org/TR/wot-thing-description

EASY-RES ICT Architecture

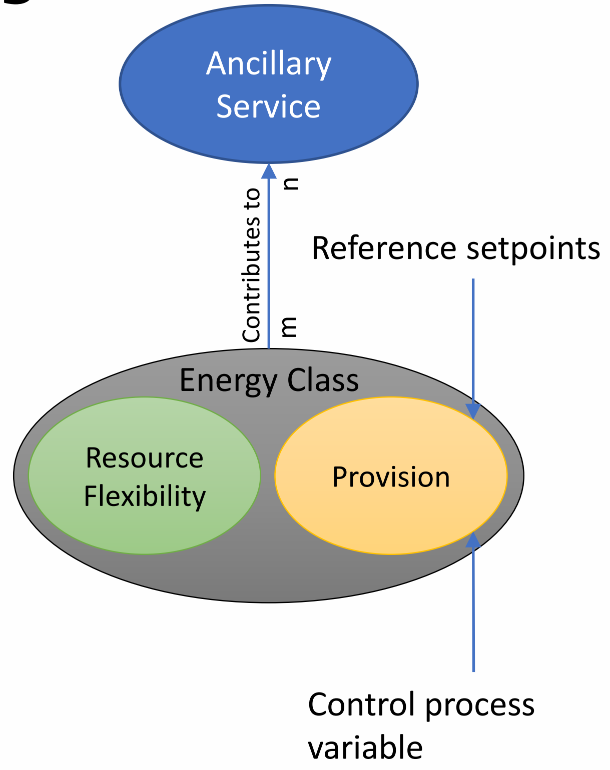
Achieving Design Goals: Openness

- Openness requires abstraction of internal differences
- Creation of standard interface to all DRES
  - Characterize required service for contribution to AS
  - Characteristics of the flexibility:
    - Ramp Rate
    - Capacity
    - Active or Reactive power (magnitude)
  - Characteristics of the provision:
    - Control process variable → PFR: Power output
    - Measured inputs → PFR: Frequency
    - Reference setpoints → PFR: P(f)-droop curve

dVPP

→ Result: Energy Class (EC)

- Device-agnostic
- Interchangeability of different generation technologies

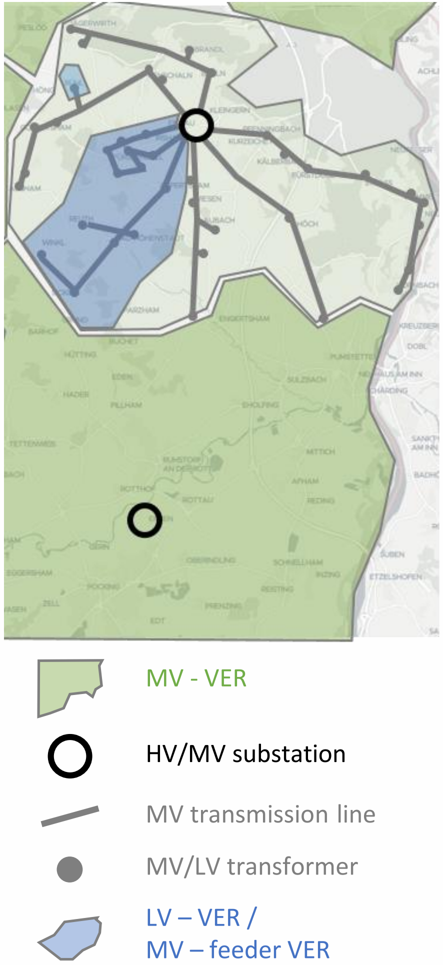


EASY-RES ICT Architecture

Achieving Design Goals: Transparency

- Need-to-know principle: Operations only have access to required data items
- Location transparency:
  - Only aggregated resources visible at higher hierarchy levels
- Access transparency:
  - Access CI-DRES with direct connection and aggregated resources in the same way
- Replication transparency:
  - Hide the existence of contingency resources to ensure service in case of (ICT -) failure
- Migration transparency:
  - Hide that service is shifted within a grid area while keeping total service the same
- Concurrency transparency:
  - Prevent conflicts when providing multiple services

→ Solution: Hierarchical (dis-)aggregation of Virtual Energy Resource each offering the Energy Class Interface



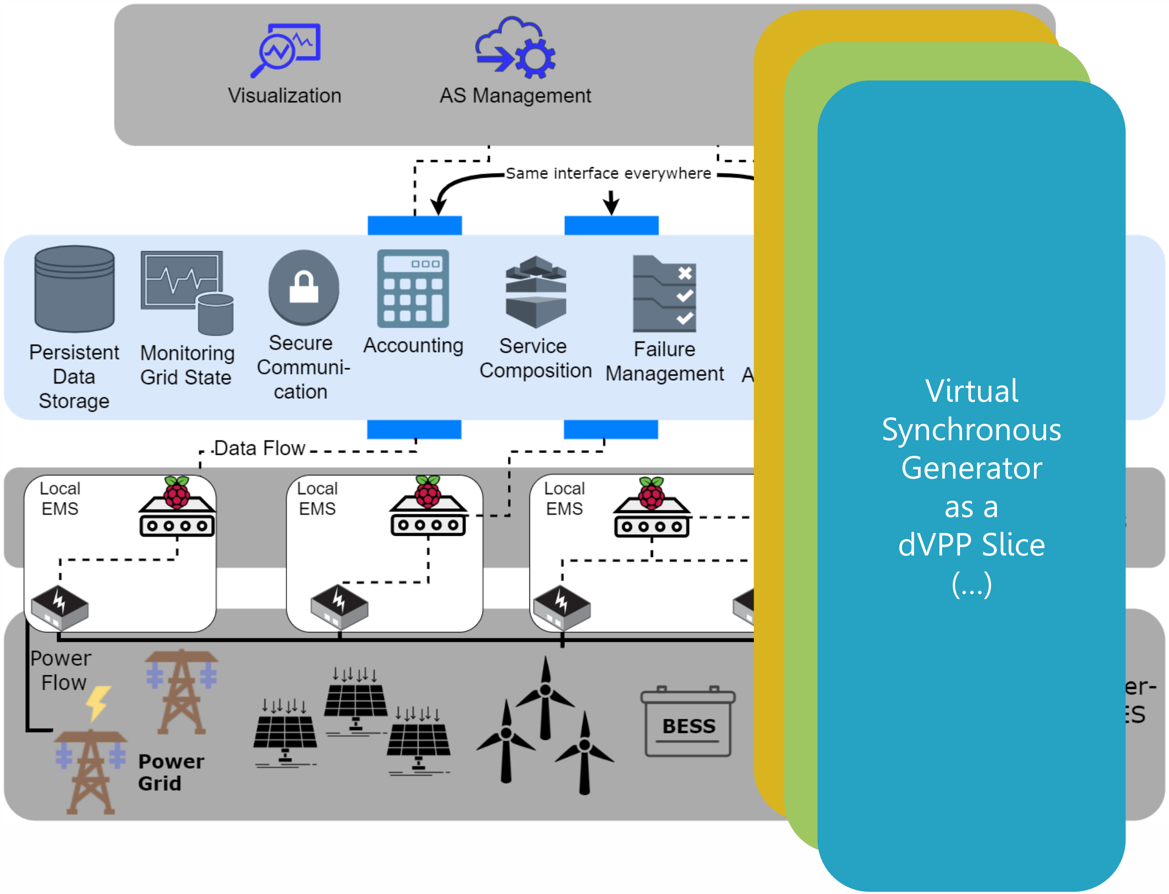
EASY-RES ICT Architecture

Functional View

- Abstraction levels:
  - High level applications at the top
  - Enabled by middleware:
    - Monitoring, Discovery
    - VERs used for (Dis-) Aggregation
  - Selectively hidden details of component layer
- Virtual Synchronous Generator as a service:
  - Slice of the dVPP
  - Using resources on all layers
  - Multiple AS in parallel

  → Separation of concerns: Different view for different AS
- Middleware and applications form central control

Dynamic Virtual Power Plant



[Stocker 2022]

EASY-RES ICT Architecture

Conclusion

- ICT middleware for active distribution networks automation for system services
  - Achieving high level of transparency
  - Openness with respect to:
    - CI-DRES from multiple vendors
    - Different renewable sources
  - Scalability in all dimensions
  - Utilizing both ICT virtualization and power virtualization
  - Novel key concepts:
    - Virtual Energy Resources
    - Energy Classes
- Offering Virtual Synchronous Generator as a service:
  - Slice of the whole Dynamic Virtual Power Plant:
    - Tailored set of ancillary services
    - Provided by an optimized set of resources (CI – DRES & ICT units)

Q&A

- Which of these components present the highest level of abstraction?

A. CI - DRES

B. MV - VER

C. Atomic VER

D. LV – VER

E. They all present the same level of abstraction

EASY-RES ICT Architecture

Q&A

- What concept is used to achieve the Openness Design Goal?

A. Virtual Energy Resources

B. Energy Class Interface

C. Software Defined Networking

D. None of the above

EASY-RES ICT Architecture

Q&A

- Which transparency is **NOT** achieved using Virtual Energy Resources?

A. Location transparency

B. Access transparency

C. Migration Transparency

D. Replication transparency

E. Concurrency transparency

F. None of the above

References and Further Readings

[vanSteen 2017] Maarten van Steen, Andrew S. Tanenbaum,"Distributed Systems, Principles and Paradigms", Pearson Education, Inc. Edition: 3rd (3. Jan. 2017), ISBN-10: 1543057381, ISBN-13: 978-1543057386+

[Haberfellner 2019] Haberfellner, R., de Weck, O., Fricke, E., & Vössner, S. (2019). Systems Engineering–Grundlagen und Anwendung. 12. *Auflage. Zürich: Orell Füssli*.

[Strickland 2011] Strickland, J. (2011). *Systems Engineering Processes and Practice*. Lulu. com.

[Boardman 2006] Boardman, J., DiMario, M., Sauser, B., & Verma, D. (2006, July). System of systems characteristics and interoperability in joint command and control. In *2nd Annual System of Systems Engineering Conference, Defense Acquisition University, Ft. Belvoir, Virginia*.

[Kurose 2016] Computer Networking: A Top Down Approach, 7th edition, Jim Kurose, Keith Ross. Addison-Wesley, April 2016

[Stocker 2022] Stocker et al., An ICT Architecture for Enabling Ancillary Services in Distributed Renewable Energy Sources Based on the SGAM Framework [to be submitted]

The Consortium

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