FI.ICT-2011-285135 FINSENY

D2.1 version 1.0

Distribution Network Building Block

Contractual Date of Delivery to the CEC: 31st July 2011 *(as specified in the contract)*

Actual Date of Delivery to the CEC: 3rd August 2011

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Workpackage: (WP2 – Distribution Networks)

Estimated person months: 16

Security: PU

PU = Public

PP = Restricted to other program participants (including the Commission Services) – FP7

RE = Restricted to a group specified by the consortium (including the Commission Services), here FI-PPP projects

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Internal

Nature: R (**R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other**)**

Version: 1.0 (2 digits separated by a dot. The first digit is 0 for draft, 1 for project approved document, 2 or more for further revisions requiring approval by the project)

Total number of pages: 98

Abstract:

Advanced ICT solutions that could provide Future Internet and the economies of scale that could be reached are essential for the development of the Smart Distribution Network. This deliverable presents a Reference Model for the Distributed Network Scenario and selects and describes a set of building blocks (UC) that should be representative enough for a further analysis of ICT requirements of smart DN solutions.

For doing that, this deliverable has not started from scratch. It has been using the results of several R&DD projects. The methodology applied for selecting and describing building blocks (UC) has had three iterative steps. The first one, the identification of High level Services and functionalities of smart distribution network which are relevant for complying with the expected impact of FINSENY and for a further ICT analysis. The second one, the selection of building blocks (UC) which cover these selected smart grid DN functionalities. And finally, the third one, the description of selected building blocks (UC).

Keyword list:

FI-PPP, FINSENY, Distribution Network Scenario, Reference Model, Building Block (UC), ICT Solutions, ICT Requirements, Functional ICT Architecture

Disclaimer:

N/A (Please refer to all-FINSENY related disclaimers)

Executive Summary

All smart grid solutions rely on the Distribution Network so this must be seen as a key enabler for any future improvement in efficiency, safety and sustainability of the energy supply. However, any improvement in the Distribution Network will be very expensive because its size is huge, including thousands of primary substations, hundreds of thousands of secondary substations, tens of millions of grid user connections in each European Country.

Advanced ICT solutions that could provide Future Internet and the economies of scale that could be reached are essential for the development of the Smart Distribution Network. This deliverable presents a Reference Model for the Distributed Network Scenario and selects and describes a set of building blocks (UC) that could be representative enough for a further analysis of ICT requirements of smart DN solutions.

The Reference Model for the DN Scenario is presented as different entities interconnected to each other for information and power exchange. The following roles and responsibilities have been identified: centralized generation, market, aggregator, retailer, distributed energy resource, customer, metering operator, TSO and DSO.

In order to select and describe building blocks (UC), this deliverable has not started from scratch. There are plenty of R&DD initiatives on smart grid. The work of the DG Energy Task Force for Smart Grid (SGTF) and in concrete, the deliverable of the Expert Group 1 (EG1) titled “Functionalities of Smart Grid and Smart Meters“[1] have been widely used in D2.1. EG1 deliverable identifies service and functionalities of smart distribution network and in which R&DD projects these functionalities are analyzed.

The methodology used for selecting and describing building blocks (UC) has had three iterative steps. The first one, the identification of High level Services and functionalities of smart distribution network which are relevant for complying with the expected impact of FINSENY and for a further ICT analysis. The second one, the selection of building blocks (UC), which cover these selected smart grid DN functionalities. And finally, the third one, the description of selected building blocks (UC).

The DN High level services selected have been the following ones: enabling the network to integrate users with new requirements, enhancing efficiency in day to day grid operation and ensuring network security, system control and quality of supply. From these DN High level services, eleven DN functionalities, which are relevant for a further ICT analysis, have been chosen.

Building blocks (UC) finally selected are briefly described below:

- Mobile Work Force Management (MWFM): It covers the ability for field crews to have access to work orders in the field. The main issue about this UC is to use pervasive means of communication options especially in case of disturbance of regular communication.
- Fault Location, Isolation and Service Restoration (FLIR): This building block (UC) describes the procedures after a fault until the service is restored. It includes the identification of a fault, determining its location, isolating the faulty section and reconfiguring the grid to re-energize these sections as quickly as possible.
- MV DAC from utility control centre (MVDAC): Data Acquisition and Control of real and non-real time information of MV electrical network from the utility control centre. The differences from the already deployed HV or VHV DAC are the size of the network (more than 100 times bigger) and the location of the controllable elements which are closest to the customers.
- SG Energy Control of Power Inverter (SGEC): This use case describes the interactions, mechanisms and the interfaces of power inverters in context of a smart grid. Power consumption from the grid as well as power infeed into the grid is considered.
- Dynamic Control of Active Components (DCAC): This building block (UC) covers the dynamic control (performed automatically) of distributed active network components on substation level with the goal to ensure stable and energy efficient network operation.

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List of Abbreviations

This document uses the list of abbreviations included in the general FINSENY Glossary and Terms [0]. Only those abbreviations that are not included in the FINSENY Glossary and Terms [0] are collected below.

DAC	Data Acquisition and Control
DCAC	Dynamic Control of Active Components
DN	Distribution Network
DNO	Distribution Network Operator
EG1	Expert Group 1 (of SGTG)
ESCO	Energy Service Company
ERGER	European Regulators Group for Electricity and Gas
ERP	Enterprise Resource Planning
FERC	Federal Energy Regulatory Commission
FLIR	Fault Location, Isolation and Service Restoration
IETF	Internet Engineering Task Force
MV	Medium Voltage
MVDAC	Medium Voltage Data Acquisition and Control from utility control centre
MWFM	Mobile Work Force Management
R&DD	Research, Development and Demonstration
SGEC	Smart Grid Energy Control of Power Inverter
SGTF	Smart Grid Task Force (DG Energy)
SHG	Self Healing Grid
TNO	Transmission Network Operator
UC	Use Case

1. Introduction

Smart Grid is called upon to cover the society energy needs in the future. A smart grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety [1].

One of the key elements which will enable the deployment of the Smart Grid is the Distribution Network. The Distribution Network can be seen as an electrical network that manages the regional and local complexity for connecting users to the Transport System. To cover future requirements, Distribution Networks must become much smarter than today.

In the future, energy network architecture will change from uni-directional to bi-directional as increasing numbers of users install renewable energy sources in their own properties and in their own buildings. New control and management systems will be needed to operate the energy network with a new architecture, particularly at the distribution and regional network levels.

Advanced ICT solutions that can provide Future Internet are essential for the development of the Smart Distribution Network. Smart Distribution Network architecture and building blocks aka energy use cases (UC) that could be representative enough for further analysis of ICT requirements are described in this document.

2. Background

There are lots of R&DD projects that are covering the Smart Grid from different perspectives.

The DG Energy Task Force for Smart Grid (SGTF) Expert Group 1 (EG1) has delivered "Functionalities of Smart Grid and Smart Meters" [1] in December 2010. This work identifies services and functionalities of the Smart Grid and the connection of these services with the state of the art of R&DD projects. This source has been widely used in D2.1, firstly to guarantee that all DN Smart Grid functionalities are taken into account and secondly as a reference guide to look for results of other R&DD projects of each Distribution Network high level service.

Smart Grid Mandate M/490 delivered in 1st March 2011 by EU Commission [2] states that CEN, CENELEC, and ETSI must develop a framework to enable European Standardization Organizations (ESOs) to support European Smart Grid deployment. One of the deliverables of this framework will be a first set of building blocks (UC) that will be available in December 2011**.** This framework will build on the Smart Grid Task Force reports [1] as main inputs. As the work is just starting, this source has not been able to be used by D2.1.

EU Commission JRC (Joint Research Center), by request of DG Energy, presented on July 7th the first comprehensive catalogue of Smart Grid projects in Europe. This catalogue is based on a review of 219 projects, accounting for a total investment of about €5.5 billion. The main objectives of this catalogue is to analyze in which direction the EU is moving in the field of Smart Grids and to support future research activities. The JRC's catalogue is only the beginning of a continuing process. At this stage, sharing knowledge and best practices is in fact a crucial step for Smart Grid stakeholders, and the JRC will continue to collect new projects and to include updates on existing ones as they progress. This catalogue has been useful for D2.1 to avoid starting from scratch and proposing new solutions for already well known issues.

3. Methodology

The main objective of D2.1 is to select and describe a set of building blocks (aka energy-related Use Cases - UC) in such a way that the deliverable could include representative enough Smart Grid DN solutions for further analysis of their ICT requirements.

The scope of this deliverable is not to describe an exhaustive set of Smart Grid DN building blocks (UC) in depth. Smart Grid DN is a much too complex scenario to apply this approach successfully. Besides, there are other initiatives that are working on this (CEN, CENELEC and ETSI by Smart Grid Mandate M/490 [2]).

For analyzing ICT requirements, it is better to have a discrete set of building blocks (UC) described in a simple way that could be understandable for a large quantity of stakeholders.

In the following sections, the selection process and the template used for the description of the building blocks (UC) are presented.

3.1 Selection

The next figure summarizes how DN building blocks (UC) have been selected.

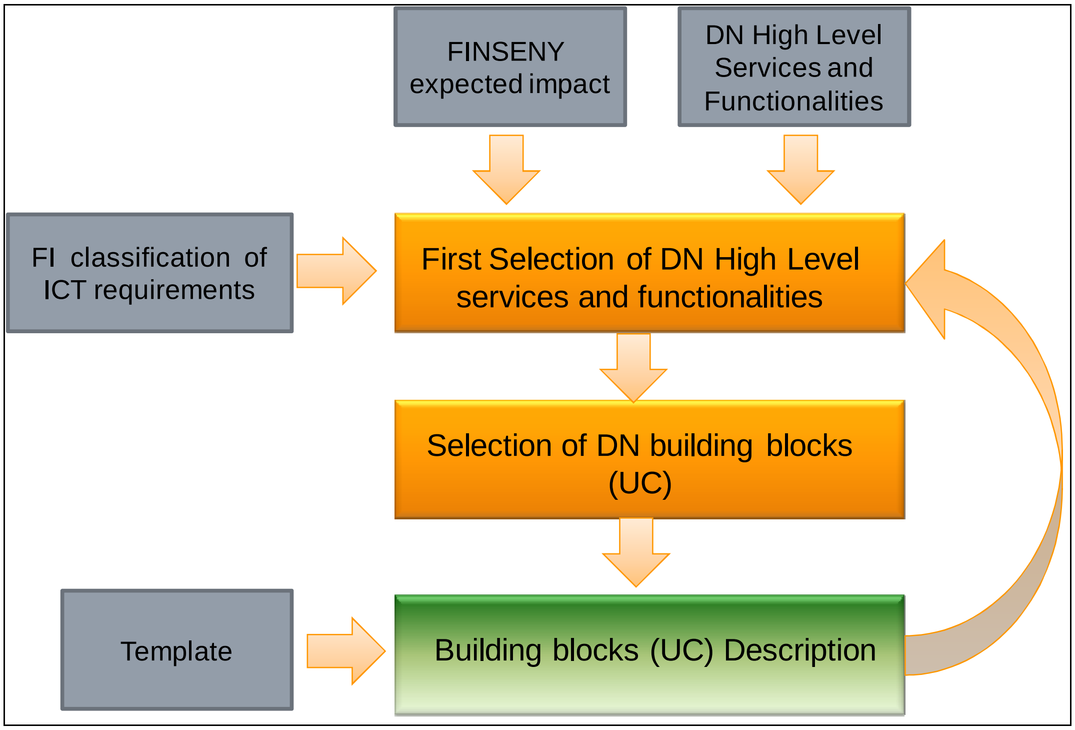


Figure 1 – Selection of DN building blocks (UC)

The following sources have been used as a starting point for the building blocks (UC) selection:

- Distribution Network High Level Services and Functionalities according to EU Commission Task Force for Smart Grid [1]. This source is used in order to guarantee that no Smart Grid main functionalities are missing.
- Classification of ICT Requirements in Future Internet. This source is used to select only those functionalities that are relevant for ICT requirements identification.
- FINSENY expected impact. This source is used to select only those functionalities that cover sufficiently the expected impact of FINSENY

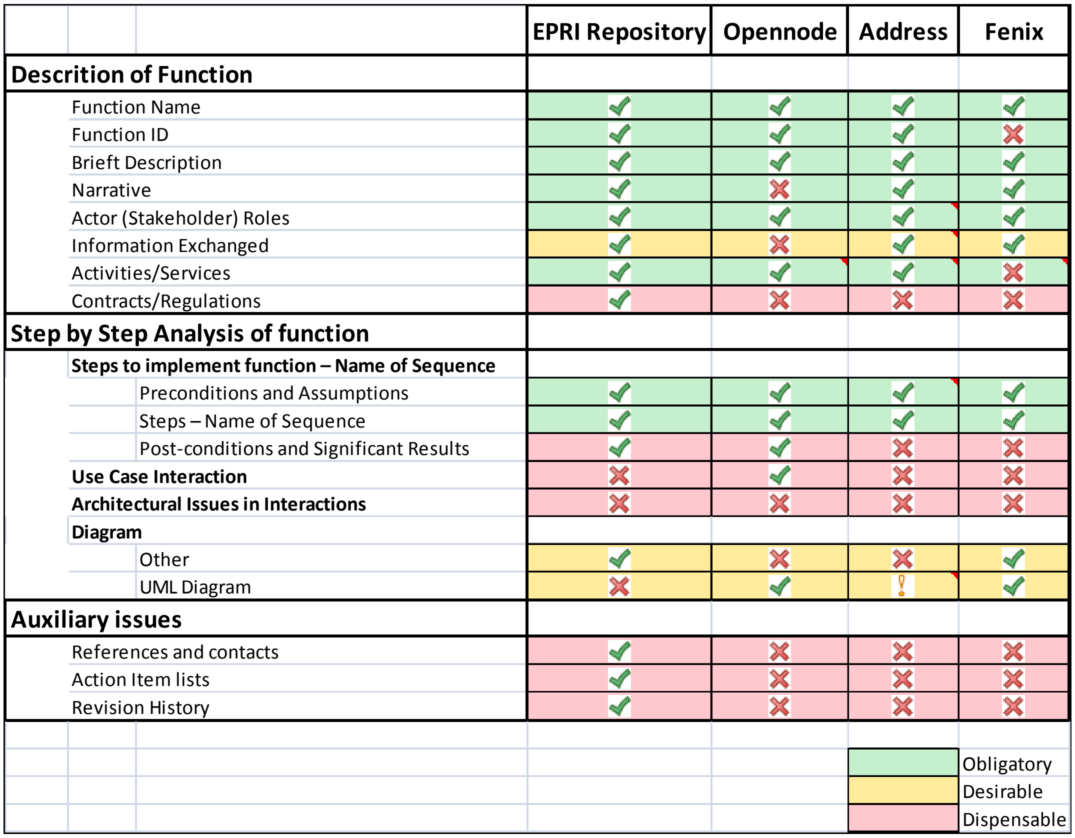
For the building blocks (UC) selection, an iterative process has been done with the following steps:

- Selection of DN High Level Services and functionalities that could be representative enough for analyzing ICT requirements of Smart Grid solutions and cover the expected impact of FINSENY. This step identifies High Level Services and functionalities which must be the scope of the D2.1.
- Selection of DN building blocks (UC). In this step, a comprehensive set of building blocks (UC) is selected for covering above identified DN High Level Services and functionalities.
- Description of the selected DN building blocks (UC). In this step, the description (according to a defined template) of each above identified building block (UC) is done. Once the DN building blocks (UC) are described it could become necessary to repeat the process to check if they are representative enough for analyzing ICT requirements.

3.2 Description

Building blocks (UC) will be described following the Intelligrid methodology which has been developed at first by EPRI, the US Electric Power Research Institute. This methodology has now been widely adopted, and a number of building blocks (UC) have been built following this methodology.

This methodology provides a template [3] which will be used to collect the information from the building blocks (UC). In the following figure, the mapping between the different chapters of the Intelligrid template and the information available in current building block (UC) repositories is identified. To scope this deliverable, as a result of this mapping, chapters are proposed that are obligatory, desirable or dispensable.



	EPRI Repository	Opennode	Address	Fenix
Descrition of Function				
Function Name	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✓
Function ID	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✗
Brieft Description	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✓
Narrative	🟩 ✓	🟩 ✗	🟩 ✓	🟩 ✓
Actor (Stakeholder) Roles	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✓
Information Exchanged	🟨 ✓	🟨 ✗	🟨 ✓	🟨 ✓
Activities/Services	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✗
Contracts/Regulations	🟥 ✓	🟥 ✗	🟥 ✗	🟥 ✗
Step by Step Analysis of function				
Steps to implement function – Name of Sequence				
Preconditions and Assumptions	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✓
Steps – Name of Sequence	🟩 ✓	🟩 ✓	🟩 ✓	🟩 ✓
Post-conditions and Significant Results	🟥 ✓	🟥 ✓	🟥 ✗	🟥 ✗
Use Case Interaction	🟥 ✗	🟥 ✓	🟥 ✗	🟥 ✗
Architectural Issues in Interactions	🟥 ✗	🟥 ✗	🟥 ✗	🟥 ✗
Diagram				
Other	🟨 ✓	🟨 ✗	🟨 ✗	🟨 ✓
UML Diagram	🟨 ✗	🟨 ✓	🟨 !	🟨 ✓
Auxiliary issues				
References and contacts	🟥 ✓	🟥 ✗	🟥 ✗	🟥 ✗
Action Item lists	🟥 ✓	🟥 ✗	🟥 ✗	🟥 ✗
Revision History	🟥 ✓	🟥 ✗	🟥 ✗	🟥 ✗

🟩	Obligatory
🟨	Desirable
🟥	Dispensable

Figure 2 – Chapters of Intelligrid Template which must be filled in obligatory, desirable or dispensable

4. Common Description

4.1 Reference Model for the Distribution Network Scenario

In this chapter the Reference Model for the Distributed Network Scenario is presented. The model defines the entities and roles which are relevant for the Distribution Network scenario and identifies the power and information flows between these entities. First of all, roles and responsibilities of each entity of the model are defined. Afterwards, current and future expected Distributed Network scenario models are described.

The Reference Model provides only an outside view on the Distribution Network and the related entities (black box). A detailed Functional ICT Architecture which also defines functional blocks within the Distribution Network will be provided by deliverable D2.2.

4.1.1 Roles and Responsibilities

The Reference Model for the DN Scenario will be presented as different entities interconnected to each other for information or power exchange. The roles and responsibilities of the different entities are detailed below:

Market

Energy Wholesale Spot Market. It is the place where energy providers send their offers and energy consumers their demand. Following market rules, energy price is calculated and physical and financial transactions are made. Owing specific issues of Energy, normally, there are day-ahead transactions and intraday transactions in order to maintain stability.

The day-ahead market receives offers from any energy provider fulfilling certain criteria (significant power generation, availability and reliability, etc.). Confronting the bids to the load forecast, the day-ahead market determines the "base" schedule (minimum and cheapest generation to supply electricity to the expected demand), the marginal price and the "merit order" (list of the available generation units ordered by price).

The intra-day transactions are used to manage day-ahead forecasting deviation in the same day of the Energy delivery.

System Operator

Market participant who ensures continuity and security of electricity supply and proper coordination of production, transportation and distribution systems, exercising its functions under the principles of transparency, objectivity and independence. For doing that, the System Operator must resolve any technical constraints of the system using market criteria.

System operators have to ensure the safety and stability of the grid, maintaining the energy consumption/generation balance in real-time. To achieve this permanent equilibrium, operation planners prepare in advance, a schedule of generation units available to fit the expected load. In order to achieve a feasible schedule, the system operators use the results from the day-ahead electricity market.

Specific types of system operators are:

> **Transmission System Operator (TSO)**
> According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.
>
> **Distribution System Operator (DSO)**
> According to the Article 2.6 of the Directive: "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity". Moreover, the DSO is responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing.

Centralized Generation

Generating electricity, contributing actively to voltage and reactive power control, required to provide the relevant data (information on outages, forecast and actual production to the energy market).

Retailer

Entity selling electrical energy to consumers – could also be a grid user who has a grid connection and access contract with the TSO or DSO. There might be contract agreements between Retailers and Distributed Energy resources & Customers.

Aggregator

The aggregators are deregulated participants whose main role is to be the mediators between the

Distributed Energy Resources & Customer who provide (sell) their energy and their energy flexibilities (= modifications in consumption, energy storage…) and the markets where the aggregators offer (sell) these energy and flexibilities for the use of the other electricity system players. There might be contract agreements between aggregators and Distributed Energy resources & Customers. Retailers and Aggregators are the ones, which interact with consumers, one selling and buying energy, the other selling and buying flexibility.

Distributed Energy Resource

It includes Distributed Generation (DG), storage and Demand Side Management (DSM).

Customer / consumer:

Depending on their characteristics, consumers could be classified into one or more of the following categories. All of them may be involved in contract based Demand/Response:

- Industrial customer: A large consumer of electricity in an industrial / manufacturing industry.
- Transportation customer: A consumer of electricity providing transport systems.
- Buildings: A consumer of electricity which is a private or business building.
- Home customer: A residential consumer of electricity (including also agriculture users).

Metering Operator

Role which offers services to provide, install and maintain metering equipment as well as services to measure consumption and generation of energy. In most EU Member States the DSO is also metering operator.

4.1.2 Reference Model – Current Status

Distributed Generation and an open energy market (retailers) have already been introduced in a wide scale in Europe. Still the information exchange between the Distribution Network and the surrounding entities is very limited. It is mainly Non-Real Time information.

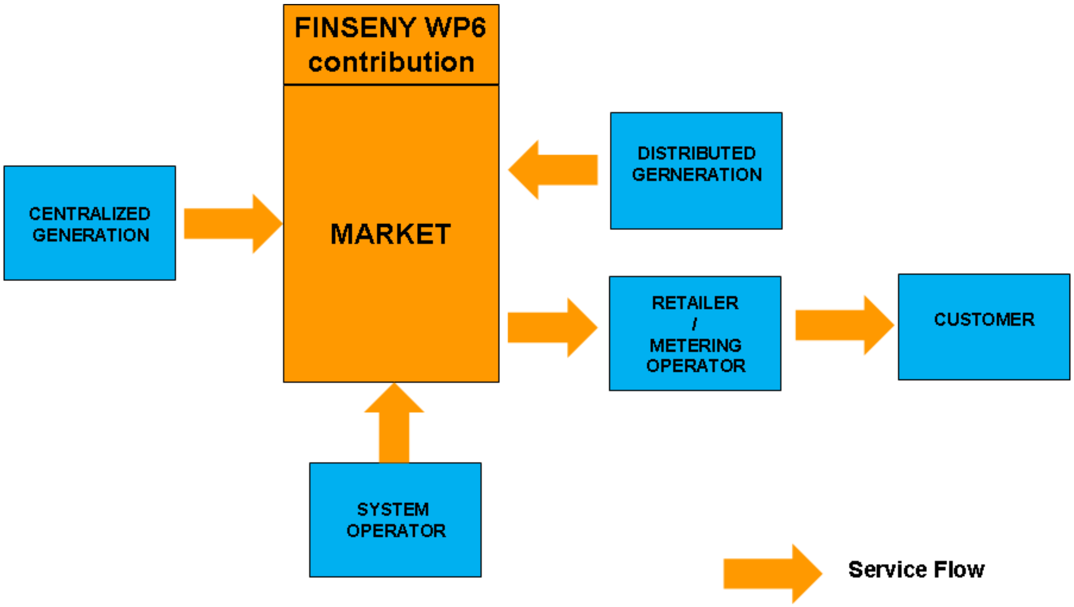


Figure 3 – Energy Commercial Interactions – Current Status

In the below the communication relationship with the Market is not shown explicitly, but of course existent, except for the customer.

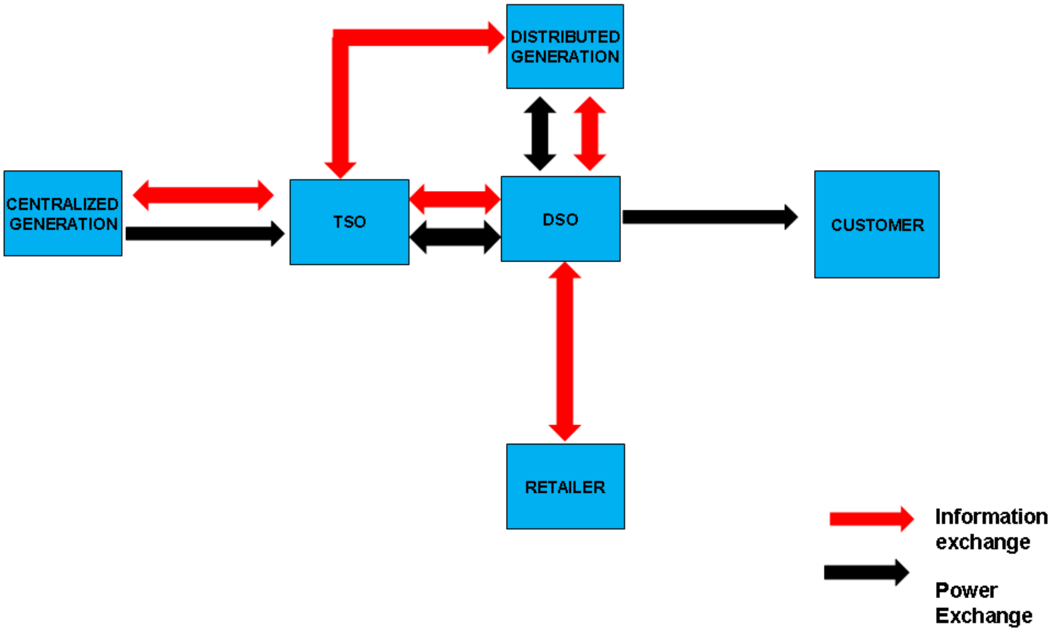


Figure 4 – Energy Technical Interactions – Current Status

4.1.3 General Architecture – Future

The expected increase of Distributed Generation and other kinds of Distributed Energy Resources will change the architecture of the Distribution Network Scenario. It is foreseen that the DSO will have to play a more active role than today for grid stability in the distribution network.

Transmission and Distribution networks will increasingly need to coordinate their operations and to exchange data in real time especially for issues concerning demand and distributed energy resources to ensure the suitable contribution of local resources to the global system security.

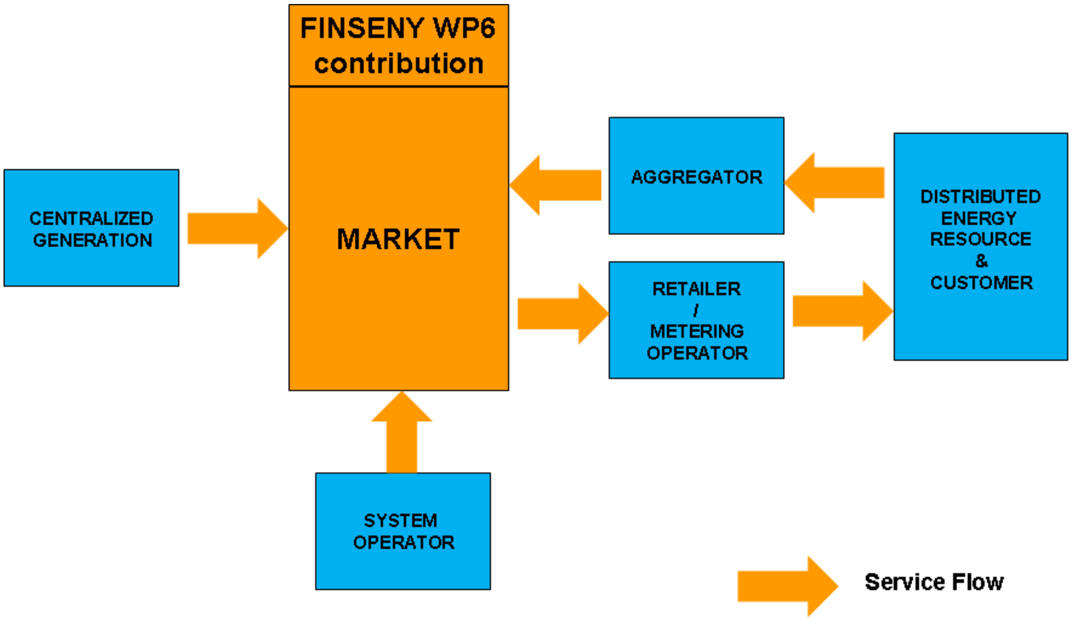


Figure 5 – Energy Commercial Interactions – Future

In the below the communication relationship with the Market is not shown explicitly, but of course existent, except for the customer.

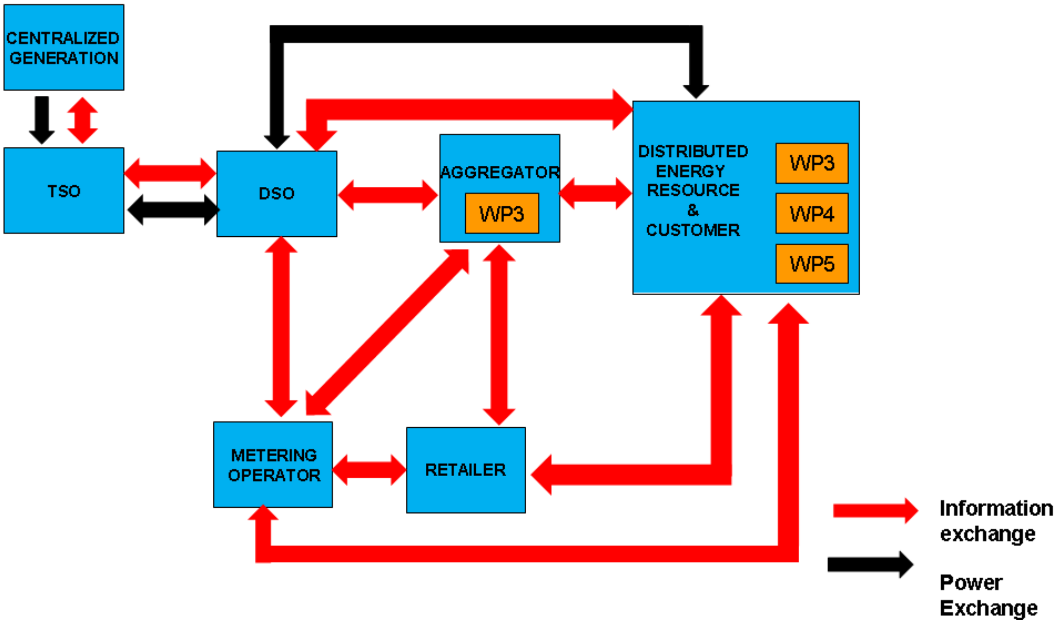


Figure 6 – Energy Technical Interactions – Future

In the following we assume that there is one DSO role, interacting with multiple Aggregators, Retailers, Metering Operators, TSOs and Prosumers.

4.2 Sources for Starting Point

4.2.1 Distribution Network High Level Services and Functionalities

According to EU Commission Task Force for Smart Grid [1], the following represents a list of the broad services and functionalities envisaged, to be provided in smart grid solutions, showing the provider of the service and the primary beneficiaries.

A provider of a service is a participant that is responsible for such a service alone or in combination with other participants. Primary beneficiaries are participants that require or directly benefit from the services, recognizing that the full benefits from these services are shared among a much wider group of participants.

4.2.1.1 High-level services

A. Enabling the network to integrate users with new requirements

Outcome: Guarantee the integration of distributed energy resources (both large and small-scale stochastic renewable generation, heat pumps, electric vehicles and storage) connected to the distribution network.

Provider: DSOs

Primary beneficiaries: Generators, consumers (including mobile consumers), storage owners.

B. Enhancing efficiency in day-to-day grid operation

Outcome: Optimize the operation of distribution assets and improve the efficiency of the network through enhanced automation, monitoring, protection and real time operation. Faster fault identification/resolution will help improve continuity of supply levels. Better understanding and management of technical and non-technical losses, and optimized asset maintenance activities based on detailed operational information.

Provider: DSOs, metering operators

Primary beneficiaries: Consumers, generators, suppliers, DSOs.

C. Ensuring network security, system control and quality of supply

Outcome: Foster system security through an intelligent and more effective control of distributed energy resources, ancillary back-up reserves and other ancillary services. Maximize the capability of the network to manage intermittent generation, without adversely affecting quality of supply parameters.

Provider: DSOs, aggregators, suppliers.

Primary beneficiaries: Generators, consumers, aggregators, DSOs, TSOs.

D. Enabling better planning of future network investment

Outcome: Collection and use of data to enable more accurate modeling of networks especially at LV level, also taking into account new grid users, in order to optimize infrastructure requirements and so reduce their environmental impact. Introduction of new methodologies for more ‘active’ distribution, exploiting active and reactive control capabilities of distributed energy resources.

Provider: DSOs, metering operators.

Primary beneficiaries: Consumers, generators, storage owners.

E. Improving market functioning and customer service

Outcome: Increase the performance and reliability of current market processes through improved data and data flows between market participants, and so enhance customer experience.

Provider: Suppliers (with applications and services providers), power exchange platform providers, DSOs, metering operators.

Primary beneficiaries: Consumers, suppliers, applications and services providers.

F. Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management

Outcome: Foster greater consumption awareness taking advantage of smart metering systems and improved customer information, in order to allow consumers to modify their behavior according to price and load signals and related information. Promote the active participation of all actors to the electricity market, through demand response programs and a more effective management of the variable and non-programmable generation. Obtain the consequent system benefits: peak reduction, reduced network investments, ability to integrate more intermittent generation.

Provider: Suppliers (with metering operators and DSOs), ESCOs.

Primary beneficiaries: Consumers, generators. The only primary beneficiary who is present in all services is the consumer. Indeed, consumers will benefit:

- either because these services will contribute to the 20/20/20 targets
- or directly through improvement of quality of supply and other services

The hypothesis made here is that company efficiency and the benefit of the competitive market will be passed to consumers– at least partly - in the form of tariff or price optimization, and is dependent on effective regulation and markets.

4.2.1.2 Functionalities

The delivery of smart grid services requires specific network functionalities. This chapter lists a series of functionalities grouped according to the high-level services identified in previous chapter.

A. Enabling the network to integrate users with new requirements

1. Facilitate connections at all voltages/locations[1] for all existing and future devices with SG solutions through the availability of technical data and additional grid information to:

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[1] Technical constraints permitting and according to the price signal

- simplify and reduce the cost of the connection process subject to maintaining network integrity/safety
- facilitate an ‘open platform’ approach – close to ‘plug & play’
- make connection options transparent
- facilitate connection of new load types, particularly EV
- ensure that the most efficient DER connection strategies can be pursued from a total system perspective

2. Better use of the grid for users at all voltages/locations, including in particular renewable generators.
3. Registers of the technical capabilities2 of connected users/devices with an improved network control system, to be used for network purposes (ancillary services).
4. Updated performance data on continuity of supply and voltage quality to inform connected users and prospective users

B. Enhancing efficiency in day-to-day grid operation

5. Improved automated fault identification and optimal grid reconfiguration after faults reducing outage times:
    - using dynamic protection and automation schemes with additional information
    - where distributed generation is present
    - strengthening Distribution Management Systems of distribution grids.
6. Enhanced monitoring and control of power flows and voltages.
7. Enhanced monitoring and observability of network components down to low voltage levels, potentially using the smart metering infrastructure.
8. Improved monitoring of network assets in order to enhance efficiency in day-to-day network operation and maintenance (proactive, condition based, operation history based maintenance).
9. Identification of technical and non technical losses through power flow analysis, network balances calculation and smart metering information.
10. Frequent information on actual active/reactive injections/withdrawals by generation and flexible consumption to system operator.

C. Ensuring network security, system control and quality of supply

11. Solutions to allow grid users and aggregators to participate in an ancillary services market to enhance network operation.
12. Improved operation schemes for voltage/current control taking into account ancillary services.
13. Solutions to allow intermittent generation sources to contribute to system security through automation and control.

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[2] Network users/devices, in order to actively participate/be managed in network’s operations and energy management must be characterised by adequate technical capabilities. Considering the active control and demand-response of Distributed Energy Resources (i.e. generators, controllable loads and storage) some of the most relevant technical capabilities that have to be taken into account are:

- Active – reactive power capabilities.
- Dynamic response.
- Electric storage capacity in terms of energy and power.

For example, referring to the renewable generators participation in the network voltage regulation or power flows control, the generator reactive power capability curve and the other capabilities aforementioned, are technical constraints that have to be managed.

14. System security assessment and management of remedies, including actions against terrorist attacks, cyber threats, actions during emergencies, exceptional weather events and force majeure events.

15. Improved monitoring of safety particularly in public areas during network operations[3].

16. Solutions for demand response for system security purposes in required response times.

D. Better planning of future network investment

17. Better models of DG, storage, flexible loads (including EV), and the ancillary services provided by them for an improvement of infrastructure planning.

18. Improved asset management and replacement strategies by information on actual/forecasted network utilization.

19. Additional information on supply quality and consumption made available by smart metering infrastructure to support network investment planning.

E. Improving market functioning and customer service

20. Solutions for participation of all connected generators in the electricity market.

21. Solutions for participation of VPPs in the electricity market, including access to the register of technical capabilities of connected users/devices.

22. Solutions for consumer participation in the electricity market, allowing market participants to offer:
    - time of use energy pricing, dynamic energy pricing and critical peak pricing;
    - demand response / load control programs;

23. Grid solutions for EV recharging:
    - open platform grid infrastructure for EV recharge purposes accessible to all market players and customers.
    - smart control of the recharging process through load management functionalities of EV.

24. Improved industry systems for settlement, system balance, scheduling and forecasting and customer switching.

25. Grid support to intelligent home/facilities automation and smart devices by consumers.

26. Individual advance notice to grids users for planned interruptions.

27. Customer level reporting in event of interruptions (during, and after event).

F. Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management

28. Sufficient frequency of meter readings, measurement granularity for consumption /injection metering data (e.g. interval metering, active and reactive power, etc).

29. Remote management of meters.

30. Consumption/injection data and price signals via the meter, via a portal or other ways including home displays, as best suited to consumers and generators.

31. Improved provision of energy usage information, including levels of green energy available at relevant time intervals and supply contract carbon footprint.

32. Improved information on energy sources.

33. Individual continuity of supply and voltage quality indicators via meter, via portal or other ways including home displays.

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[3] e.g.: control of access to the equipment, detection of fault on overhead networks, protection of the contents of the buildings

4.2.2 Classification of ICT Requirements in Future Internet

The current state of the ICT categories selected by Future Internet Architecture Board is the following:

- Interoperability
- Scalability
- Reliability /Availability
- Physical Media
- Future-Proof System
- Performance
- Quality of Service
- Protocol/Interface
- Service Oriented Applications
- Management
- Usability
- Security/Trust

4.2.3 Expected Impact of FINSENY

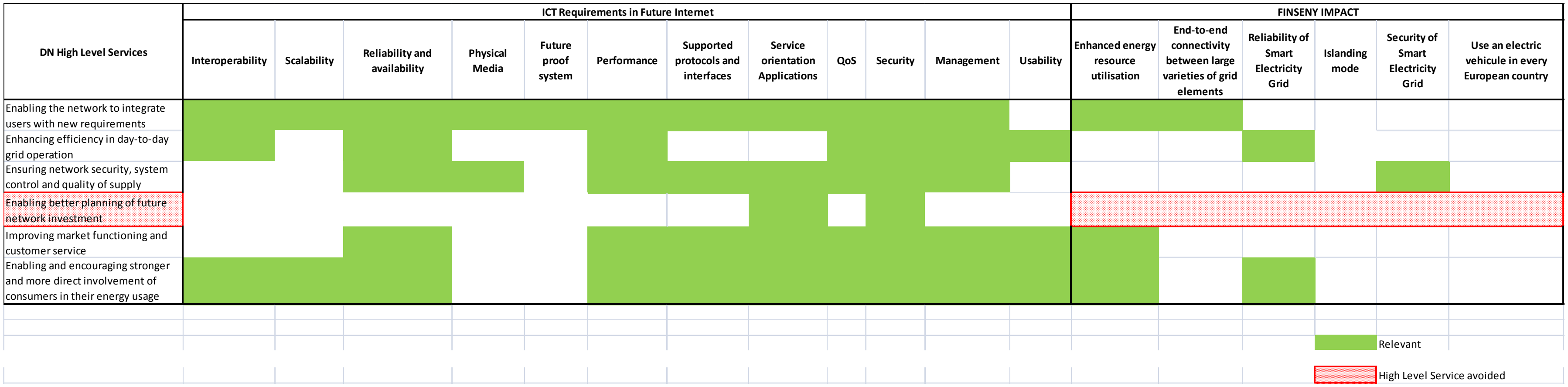
The expected impact of FINSENY could be classified and summarized by the following table. (The below covers the aspects concerning WP2 only)

FINSENY High Level expected impact	Outcome
enhanced energy resource utilisation	Sustinable means of managing energy consmption
	Small scale energy generater
	demand response, balancing services, smooth load curtailment, and dynamic pricing, buying and selling of power in real time are
	decentralised ways for information, coordination, and control to serve the customer
	support the large scale integration of DERs and distributed and intermittent renewable energy resources
end-to-end connectivity between large varieties of grid elements	integrate all the measurement and sensing data, manage the controllable elements in the grid, provide interfaces to back office systems (e.g. billing, customer care, field force management) and interact with external information sources (e.g. weather data)
	the interconnection with micro grids, smart home, building and factory energy systems and the upcoming charging points for electrical vehicles
	Device management and flexible object registers / repositories support mass provisioning, software maintenance.
	Seff configuration and adaptation capabilities
reliability of Smart Electricity Grid	holistic solution for near real time monitoring, control and optimization electricity consumption
	Energy prosumption monitoring control and distrbution
	Network management evolves towards scalable multi-tenant (cloud) operations where organisations can manage their own objects as required.
	energy flow control
	Forecast Optimisation for energy generation and consumptio
	Scalable Energy Management System
islanding mode	
security of Smart Electricity Grid	
use an electri vehicule in every European country	

4.3 Selection of DN High Level Services and Functionalities

4.3.1 Selection of DN High Level Services

In the following figure, the DN High Level Services that are relevant for analyzing ICT Requirements in Future Internet and covering FINSENY impact are identified.



DN High Level Services	ICT Requirements in Future Internet												FINSENY IMPACT					
	Interoperability	Scalability	Reliability and availability	Physical Media	Future proof system	Performance	Supported protocols and interfaces	Service orientation Applications	QoS	Security	Management	Usability	Enhanced energy resource utilisation	End-to-end connectivity between large varieties of grid elements	Reliability of Smart Electricity Grid	Islanding mode	Security of Smart Electricity Grid	Use an electric vehicule in every European country
Enabling the network to integrate users with new requirements	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩				
Enhancing efficiency in day-to-day grid operation	🟩		🟩			🟩			🟩	🟩	🟩	🟩			🟩			
Ensuring network security, system control and quality of supply			🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩						🟩	
Enabling better planning of future network investment								🟩		🟩			▨	▨	▨	▨	▨	▨
Improving market functioning and customer service			🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
Enabling and encouraging stronger and more direct involvement of consumers in their energy usage	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩			

🟩 Relevant

▨ High Level Service avoided

It is clearly seen that the DN High Level Service called "Enabling better planning of future network investment" could be avoided of the scope because it is not directly connected with FINSENY expected impact and is only connected with few ICT categories already covered by the rest of DN High Level Services.

The DN High Level Service called "Improving market functioning and customer service" will be also avoided because it will be covered inside WP6 instead of WP2. In any case, WP2 has been aligned with WP6 for the scope of this work.

The DN High Level Service called "Enabling and encouraging stronger and more direct involvement of customers in their energy usage" will be also avoided because it will be covered inside WP4 instead of WP2. WP2 has been aligned with WP4 for the scope of this work.

In conclusion, for WP2, three DN High Level Services are selected:

- Enabling the network to integrate users with new requirements
- Enhancing efficiency in day to day grid operation
- Ensuring network security, system control and quality of supply

4.3.2 Selection of DN Functionalities

	DN Functionalities	ICT Requirements in Future Internet												FINSENY IMPACT					
		Interoperability	Scalability	Reliability and availability	Physical Media	Future proof system	Performance	Supported protocols and interfaces	Service orientation Applications	QoS	Security	Management	Usability	Enhanced energy resource utilisation	End-to-end connectivity between large varieties of grid elements	Reliability of Smart Electricity Grid	Islanding mode	Security of Smart Electricity Grid	Use an electric vehicule in every European country
	Enabling the network to integrate users with new requirements																		
1	Facilitate connections at all voltages/locations for all existing and future devices with SG solutions through the availability of technical data and additional grid information to: • simplify and reduce the cost of the connection process subject to maintaining network integrity/safety • facilitate an 'open platform' approach – close to 'plug & play' • make connection options transparent • facilitate connection of new load types, particularly EV ensure that the most efficient DER connection strategies can be pursued from a total system perspective	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩				
2	Better use of the grid for users at all voltages/locations, including in particular renewable generators	🟩		🟩						🟩	🟩	🟩		🟩	🟩				
3	Registers of the technical capabilities of connected users/devices with an improved network control system, to be used for network purposes (ancillary services)	🟩		🟩				🟩	🟩		🟩	🟩		🟩					
4	Updated performance data on continuity of supply and voltage quality to inform connected users and prospective users		🟩	🟩			🟩				🟩	🟩		▨	▨	▨	▨	▨	▨
	Enhancing efficiency in day-to-day grid operation																		
5	Improved automated fault identification and optimal grid reconfiguration after faults reducing outage times: • using dynamic protection and automation schemes with additional information • where distributed generation is present • strengthening Distribution Management Systems of distribution grids.			🟩			🟩				🟩	🟩				🟩			
6	Enhance monitoring and control of power flows and voltages						🟩			🟩	🟩		🟩			🟩			
7	Enhance monitoring and observability of grids down to low voltage levels, potentially using smart metering infrastructure			🟩			🟩			🟩	🟩					🟩			
8	Improved monitoring of network assets in order to enhance efficiency in day-to-day network operation and maintenance (proactive, condition based, operation history based maintenance)			🟩			🟩			🟩	🟩			▨	▨	▨	▨	▨	▨
9	Identification of technical and non technical losses through power flow analysis, network balances calculation and smart metering information			🟩							🟩	🟩		▨	▨	▨	▨	▨	▨
10	Frequent information on actual active/reactive injection/withdrawals by generation and flexible consumption among DSOs and TSO	🟩		🟩			🟩				🟩			▨	▨	▨	▨	▨	▨
	Ensuring network security, system control and quality of supply																		
11	Solutions to allow grid users and aggregators to participate in an ancillary services market to enhance network operation			🟩	🟩			🟩	🟩		🟩			🟩					
12	Improved operation schemes for voltage/current control taking into account ancillary services			🟩							🟩	🟩		🟩					
13	Solutions to allow intermittent generation sources to contribute to system security through automation and control			🟩				🟩	🟩		🟩	🟩		🟩				🟩	
14	System security assessment and management of remedies, including actions against terrorist attacks, cyber threats, actions during emergencies, exceptional weather events and force majeure events			🟩				🟩	🟩		🟩							🟩	
15	Improved monitoring of safety particularly in public areas during network operations			🟩			🟩			🟩	🟩			▨	▨	▨	▨	▨	▨
16	Solutions for demand response for system security purposes in required response times			🟩			🟩			🟩	🟩			🟩					

🟩 Relevant

▨ Functionality avoided

The following functionalities have been avoided because they are not directly connected to FINSENY impact and the few ICT categories related to them are well covered by the rest of functionalities:

- 4. Updated performance data on continuity of supply and voltage quality to inform connected users and prospective users
- 8. Improved monitoring of network assets in order to enhance efficiency in day-to-day network operation and maintenance (proactive, condition based, operation history based maintenance)
- 9. Identification of technical and non technical losses through power flow analysis, network balances calculation and smart metering information
- 10. Frequent information on actual active/reactive injection/withdrawals by generation and flexible consumption among DSOs and TSO
- 15. Improved monitoring of safety particularly in public areas during network operations

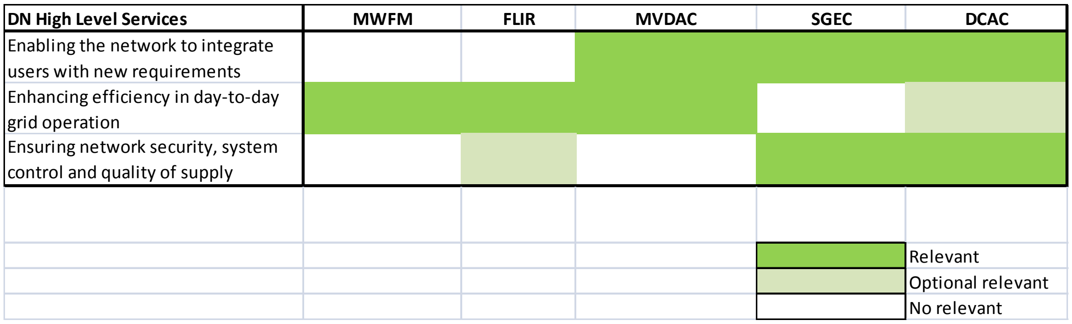
4.4 Identification of building blocks (UC) which cover selected DN High Level Services and Functionalities

4.4.1 DN High Level Services covered by building blocks (UC) identified

The finally identified building blocks (UC) are collected below:

- Mobile Work Force Management (MWFM): It covers the ability for field crews to have access to work orders in the field. The main issue about this UC is to use pervasive means of communication options especially in case of disturbance of regular communication.
- Fault Location, Isolation and Service Restoration (FLIR): This building bloc (UC) describes the procedures after a fault until the service is restored. It includes the identification of a fault, determining its location, isolating the faulty section and reconfiguring the grid to re-energize these sections as quickly as possible.
- MV DAC from utility control centre (MVDAC): Data Acquisition and Control of real and non-real time information of MV electrical network from the utility control centre. The differences from the already deployed HV or VHV DAC are the size of the network (more than 100 times bigger) and the location of the controllable elements which are closest to the customers.
- SG Energy Control of Power Inverter (SGEC): This use case describes the interactions, mechanisms and the interfaces of power inverters in context of a smart grid. Power consumption from the grid as well as power infeed into the grid is considered.
- Dynamic Control of Active Components (DCAC): This building block (UC) covers the dynamic control (performed automatically) of distributed active network components on substation level with the goal to ensure stable and energy efficient network operation.

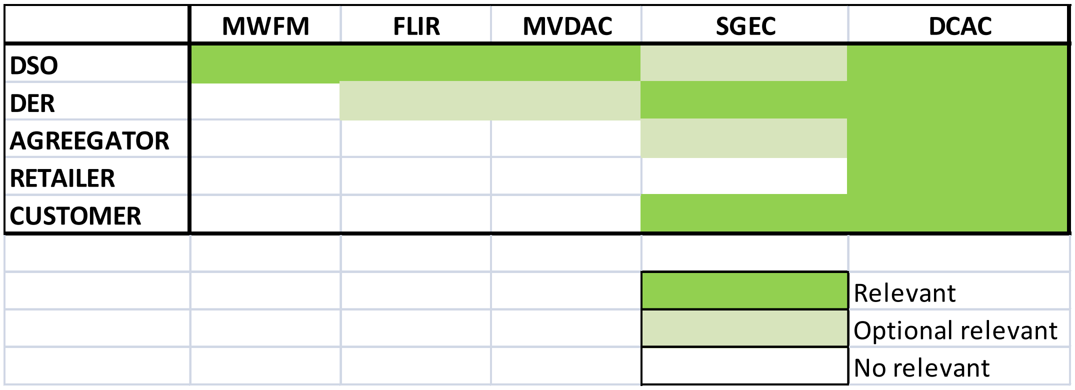
In the next figure, DN High Level Services connected with each building block (UC) are represented.



DN High Level Services	MWFM	FLIR	MVDAC	SGEC	DCAC
Enabling the network to integrate users with new requirements	☐	☐	🟩	🟩	🟩
Enhancing efficiency in day-to-day grid operation	🟩	🟩	🟩	☐	▨
Ensuring network security, system control and quality of supply	☐	▨	☐	🟩	🟩

🟩 Relevant
▨ Optional relevant
☐ No relevant

It could seem that there is some overlap between selected building blocks (UC), but at the end, each building block (UC) covers different functionalities or is focused in different entities of Smart Grid Architecture. In the next figure, the different entities of Smart Grid Architecture which are relevant for each selected building blocks (UC) are identified.

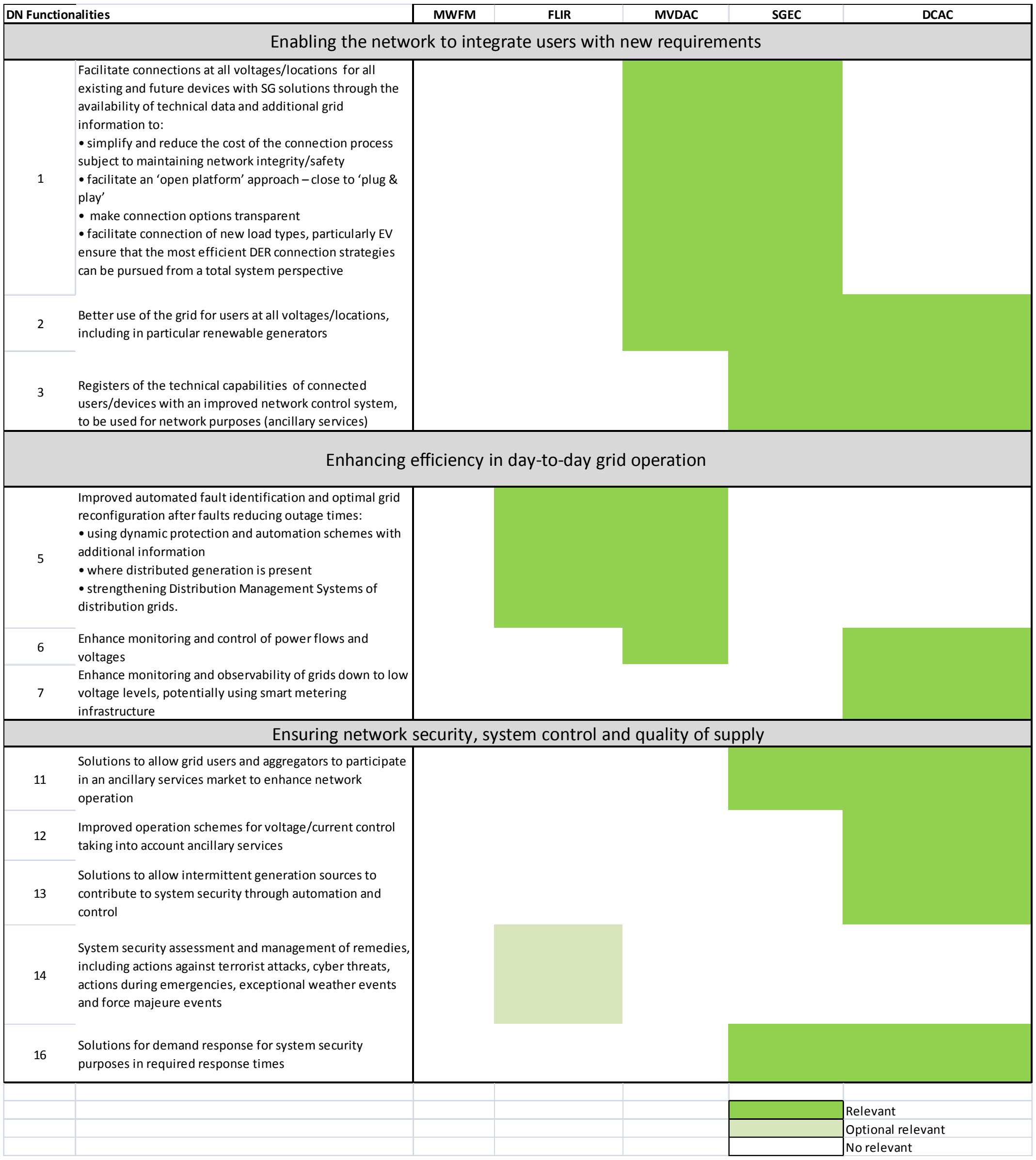


	MWFM	FLIR	MVDAC	SGEC	DCAC
DSO	🟩	🟩	🟩	▨	🟩
DER		▨	▨	🟩	🟩
AGREEGATOR				▨	🟩
RETAILER					🟩
CUSTOMER				🟩	🟩

🟩	Relevant
▨	Optional relevant
☐	No relevant

For example, DCAC and SGEC cover similar issues from different perspectives (DCAC from DSO perspectives and SGEC from DER).

4.4.2 DN Functionalities covered by building blocks (UC) identified



DN Functionalities		MWFM	FLIR	MVDAC	SGEC	DCAC
Enabling the network to integrate users with new requirements						
1	Facilitate connections at all voltages/locations for all existing and future devices with SG solutions through the availability of technical data and additional grid information to: • simplify and reduce the cost of the connection process subject to maintaining network integrity/safety • facilitate an 'open platform' approach – close to 'plug & play' • make connection options transparent • facilitate connection of new load types, particularly EV ensure that the most efficient DER connection strategies can be pursued from a total system perspective			🟩	🟩	
2	Better use of the grid for users at all voltages/locations, including in particular renewable generators			🟩	🟩	🟩
3	Registers of the technical capabilities of connected users/devices with an improved network control system, to be used for network purposes (ancillary services)				🟩	🟩
Enhancing efficiency in day-to-day grid operation						
5	Improved automated fault identification and optimal grid reconfiguration after faults reducing outage times: • using dynamic protection and automation schemes with additional information • where distributed generation is present • strengthening Distribution Management Systems of distribution grids.		🟩	🟩		
6	Enhance monitoring and control of power flows and voltages			🟩		🟩
7	Enhance monitoring and observability of grids down to low voltage levels, potentially using smart metering infrastructure					🟩
Ensuring network security, system control and quality of supply						
11	Solutions to allow grid users and aggregators to participate in an ancillary services market to enhance network operation				🟩	🟩
12	Improved operation schemes for voltage/current control taking into account ancillary services					🟩
13	Solutions to allow intermittent generation sources to contribute to system security through automation and control					🟩
14	System security assessment and management of remedies, including actions against terrorist attacks, cyber threats, actions during emergencies, exceptional weather events and force majeure events		▨			
16	Solutions for demand response for system security purposes in required response times				🟩	🟩

🟩	Relevant
▨	Optional relevant
□	No relevant

5. Distribution Network Building blocks (UC) Description

5.1 Mobile Work Force Management (MWFM) building block (UC)

5.1.1 Descriptions of Function

5.1.1.1 Function Name

Mobile Work Force Management

5.1.1.2 Function ID

MWFM

5.1.1.3 Brief Description – UC Summary

This building block (UC) covers the ability for the field crew to have access to work orders from the field. The main issue about this UC is pervasive means of communication options especially in case of regular communication disturbance. This UC deals with mobile Internet access to the central IS with automatic handover between communication media.

5.1.1.4 Narrative

Work orders from network applications (Outage call centers, SCADA …) are collected in a central system for scheduling and assignments. GIS asset system and gears management are integrated with the dispatch system in order to provide a real time updated overview of the scheduled works and allows supervisor to affect work orders efficiently.

Orders flow in real time from/to central IS to/from field mobile devices (SmartPhone or/and laptop).

Office supervisors and field crews are continuously updated on work progress and work planning evolution.

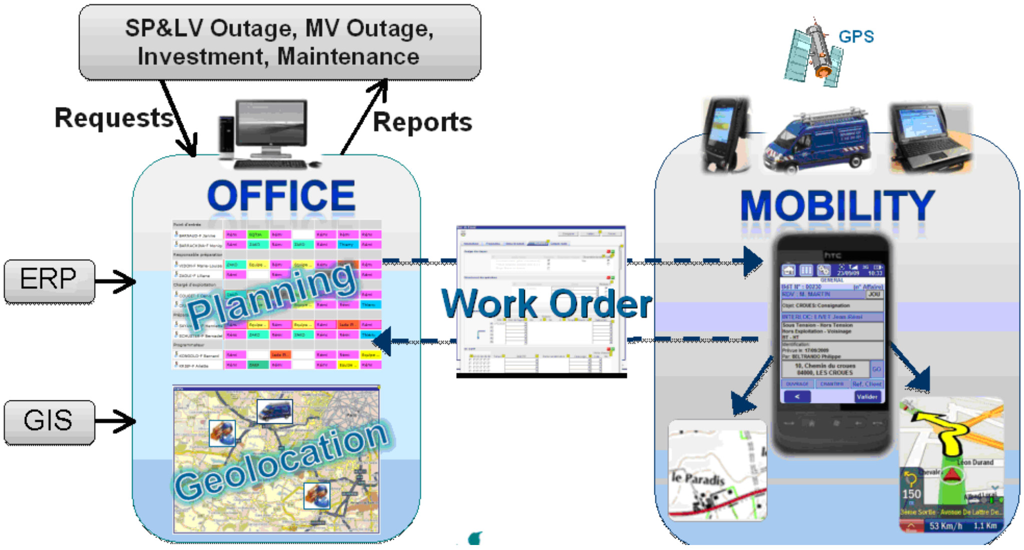


Figure 7 - MWFM building block (UC)

Workers on the field must have the ability to have access to work orders:

- Whatever the location (inside the operation truck, 300 meters away from his truck, in a urban area, in a rural area where no high speed medium available, inside a building, at home, into the customers' premises, in a public hotspot, …)
- Whatever the type of work the worker is doing : planned or emergency

- Whatever the situation: “normal” situation, or “crisis” situation (after a big disaster such as a tempest).

We can distinguish several kinds of crisis situation:

- Environmental such as a tempest, a tsunami, a snow storm, …
- Terrorism: cyber attack on smart grid system, massive disaster on production system
- Major breakout that affects the electrical system (for instance peak overload during winter that produces a massive breakout) or the communication system

Depending on the situation, the electrical system can be partially or totally affected. The communication system can also be partially or totally affected. We can find a great diversity of situations:

- Electrical system is OK but regular communication system is out of order (a major breakdown in a public communication infrastructure)
- Electrical system is out of order and regular communication system is out of order
- Electrical system is out of order but some crisis communication system is still operating

From the worker’s point of view:

- The communication system must be able to select the best medium among the media available taking into account the QoS required by the application (latency, jitter, packet loss, throughput).
- In case of “crisis” situation the communication system must switch automatically (handover) to a “crisis” medium in a transparent way for the end-user.

From the central IS point of view:

- The communication system must be able to “push” data to the worker handset whatever the telecommunication medium the worker is currently using (even if its IP address has changed).
- Workers identity has to be proven and secure communication has to be guaranteed
- The data sent to the worker must be adapted to the throughput available from the workers ‘point of view`: for instance attached files mustn’t be sent if only narrow bandwidth medium is available (crisis situation in case of regular communication disturbance).

The media used in the communication system can be sorted in several categories:

- Regular communication (normal situation when a cellular radio communication system is used). In this category we can find : 2G/GPRS, 3G and 4G
- Crisis communication (crisis situation such as a tempest when regular communication systems aren’t available). In this category we find private communication systems: satellite and narrow band radio system such as DMR (Digital Mobile Radio) or TETRA.
- AMI (Automated Metering Infrastructure) communication system. In this situation, the field worker is using the AMI communication system in order to connect to the central IS. In this category we can find : 2G/GPRS, PLC, DSL, Fiber, Ethernet
- Public communication system. In this situation, the field worker is using a public communication system such as a Wifi Hotspot, a DSL line, Ethernet, Fiber. In this situation a Secure VPN (like IPSEC) should be used to connect to the central IS

5.1.1.5 Actor (Stakeholder) Roles

Grouping (Community) ’		*Group Description*
MWFM		*Mobile Work Force Management*
Actor Name	*Actor Type (person, organization, device, system, or subsystem)*	*Actor Description*
Field_Worker	Person	Worker on the field
Dispatch_System	System	Central Dispatch System containing work orders

5.1.1.6 Information exchanged

Information Object Name	*Information Object Description*
Task_information	Information related to the task: location, type, severity, skills needed (Prioritization of tasks, e.g. Faults, Maintenance
Worker_information	Information related to worker: location, availability, skills, planning
Worker_ID	The ID of the worker
Medium_BW	The telecom network bandwidth available when requesting the work order details or when sending back the report
Medium_Description	Description of the communication media that is used. For instance name of the media (GPRS, 3G, Satellite, DSL, …), Operator, …
Medium_type	Type of the communication according to the following categories : • Regular communication system • Crisis communication system • AMI communication system Public communication system
Work_order_ID	ID of a work order
Work_order_data	The main data of the work order: type of intervention, tasks to do, asset location, asset type, …
Work_order_Attached_file	Attached file containing additional information such as forms, photography,…

5.1.1.7 Activities/Services

5.1.1.8 Contracts/Regulations

5.1.2 Step by Step Analysis of Function

5.1.2.1 Steps to implement function – Mobile Work Force Management

5.1.2.1.1 Preconditions and Assumptions

5.1.2.1.2 Steps – Sequence 1

Describe the normal sequence of events, focusing on steps that identify new types of information or new information exchanges or new interface issues to address. Should the sequence require detailed steps that are also used by other functions, consider creating a new “sub” function, then referring to that “subroutine” in this function. Remember that the focus should be less on the algorithms of the applications and more on the interactions and information flows between “entities”, e.g. people, systems, applications, data bases, etc. There should be a direct link between the narrative and these steps.

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot ‘.’. Within a level, the sequence number comprises an optional letter and an integer number. The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

Sequence 1:

1.1 - Do step 1
1.2A.1 - In parallel to activity 2 B do step 1
1.2A.2 - In parallel to activity 2 B do step 2
1.2B.1 - In parallel to activity 2 A do step 1
1.2B.2 - In parallel to activity 2 A do step 2
1.3 - Do step 3
1.3.1 - nested step 3.1
1.3.2 - nested step 3.2

Sequence 2:

2.1 - Do step 1
2.2 – Do step 2

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	*Triggering event? Identify the name of the event.*[4]	*What other actors are primarily responsible for the Process/Activity? Actors are defined in section5.4.1.5.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information? Actors are defined in section5.4.1.5.*	*What other actors are primarily responsible for Receiving the information? Actors are defined in section5.4.1.5.* *(Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 5.4.1.6*
1.1	Fault detection	Dispatch System	Insert-work-order	A fault that requires a human operation as been detected.	Source of fault detection can be customers, the DN Management System, field crew, …	Dispatch system	Fault_information
1.2	A new work order has been inserted to the dispatch system. This work order has to be assigned to a worker.	Dispatch system	Assign_Work_order	Upon a fault detection, the dispatch system assign a work order to the most suitable worker taking into account: the type of work, the skills required, the location of the asset, the location of the workers, their skills and availability. And the end of the process	Dispatch system		Worker_ID Work_order_ID

---

[4] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
				a Work_order_ID is assigned to a Worker_ID			
1.3	New work order assignment	Dispatch system	Conf_REQ	The dispatch system sends to the worker that a new work order has been assigned to him	Dispatch system	Field_Worker	Worker_ID
1.4	Conf_REQ is received by the worker	Field_Worker	Check_availibilty	The worker receives the information that a new work order has been assigned to him. The worker checks his availability. In case of unavailability of the worker (after a timeout triggered in the central Dispatch system), the task is sent to another worker	Field_Worker	Dispatch_System	Worker_ID Work_order_ID
1.5	Availibilty is OK	Field_Worker	Handover (medium selection)	In case the worker can handle the work order, the worker's handset select (handover) the relevant communication medium to connect to the Dispatch_System	Field_Worker	Field_Worker	Medium_description Medium_BW Medium_type
1.6	Medium is	Field_Worker	Conf_ACK	Once the communication	Field_Worker	Dispatch_System	Work_order_ID

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
	selected			medium is selected, the worker sends a CONF_ACK to the dispatch system			Worker_ID Medium_BW Medium_description Medium_type
1.7	Conf_ACK reception	Dispatch_System	Compute_Req	The dispatch center receives a Conf_ACK. In accordance to Worker_ID and Work_order_ID , the dispatch center selects the data to transmit to the worker.	Dispatch_System	Dispatch_System	Worker_ID Work_order_ID
1.8	Request_computed	Dispatch_System	Work_order_details	The dispatch center send the work order's details to the worker. Depending on Medium_BW, Medium-Description and medium_type, the Work_order_Attached_file are sent or not.	Dispatch_System	Field_Worker	Work_order_ID Work_order_data Work_order_Attached_file

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
				As soon as the necessary bandwidth is available, the complete work order is sent to the worker.			
1.9	Work order's details received	Field_Worker	Do_the_job	The worker do the tasks according to the work order he has received	Field_Worker		
1.10	Job_done	Field_Worker	Make report	Once the job is done, the worker makes the report.	Field_Worker		Work_order_ID Work_order_report Work_order_report _attached_file
1.11	Report_made	Field_Worker	Handover (medium selection)	The worker's handset select (handover) the relevant communication medium to connect to the Dispatch_System	Field_Worker	Field_Worker	Medium_description Medium_BW Medium_type
1.12	Medium is selected	Field_Worker	Send_report	According to the Medium_BW, the Work_order_report _attached_file are sent or not. As soon as the necessary bandwidth is available, the complete report is sent back the Central Dispatch	Field_Worker	Dispatch_System	Work_order_ID Work_order_report Work_order_report _attached_file Medium_BW Medium_description Medium_type

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
1.13	Report_received	Dispatch_System	Compute report	The dispatch system receives a work order report and stores it.	Dispatch_System	Dispatch_System	Work_order_ID Work_order_report Work_order_report_attached_file

5.1.2.1.3 Post-conditions and Significant Results

Actor/Activity	*Post-conditions Description and Results*

5.1.2.2 Architectural Issues in Interactions

5.1.2.3 Diagram

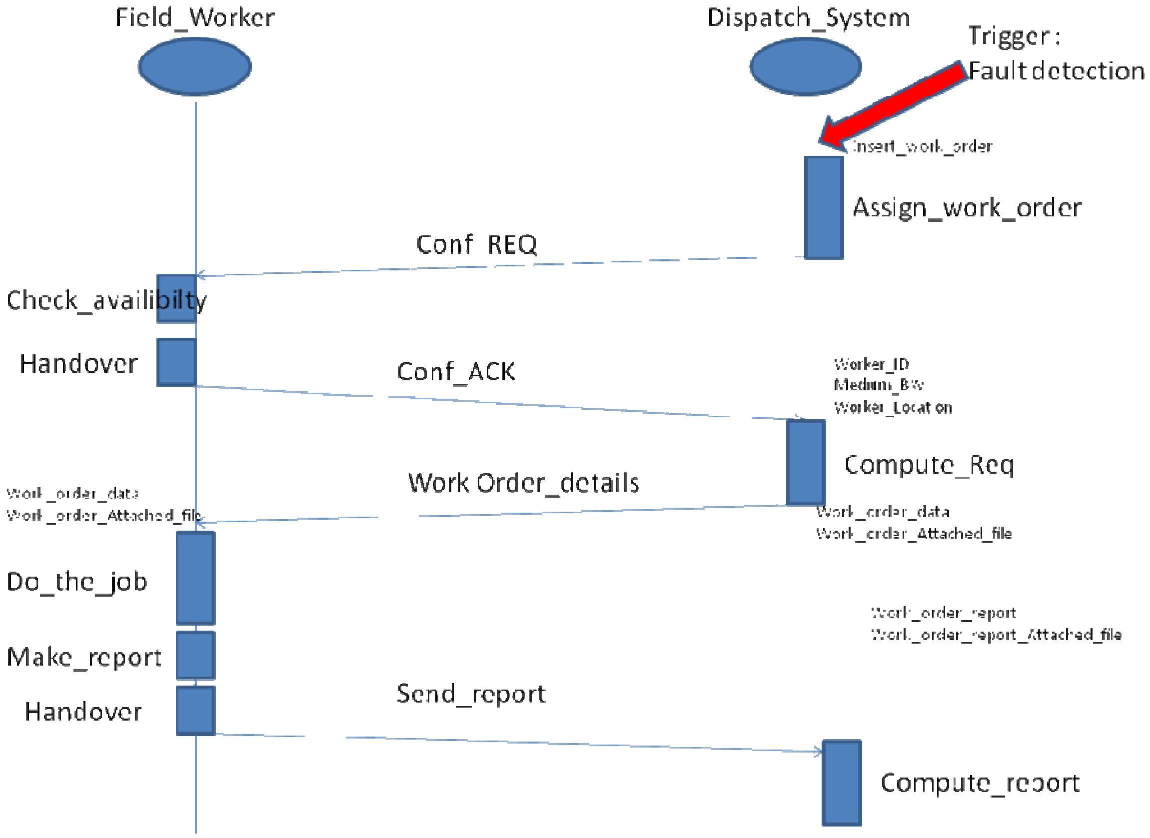


Figure 8 - MWFM diagram

5.2 Fault Location, Isolation and Service Restoration (FLIR) building block (UC)

5.2.1 Descriptions of Function

5.2.1.1 Function Name

Fault Location, Isolation and Service Restoration (based on the Intelligrid use case "Advanced Auto Restoration" http://www.smartgridipedia.org/index.php/IntelliGrid_Use_Cases)

5.2.1.2 Function ID

FLIR

5.2.1.3 Brief Description

This building block(UC) describes the procedures after a fault until the service is restored. It includes the identification of a fault, determining its location, isolating the faulty section and reconfiguring the grid to re-energize these sections as quickly as possible. Depending on the distribution network's degree of automation, these activities can be carried out by an operator in the control center supported by near real time information or fully automated (either at the control center level or in a distributed way). FLIR is a second step after the self defense of the grid. In this building block(UC) the network is in an emergency operating mode (in contrast to the building block(UC) DCAC and MV DAC).

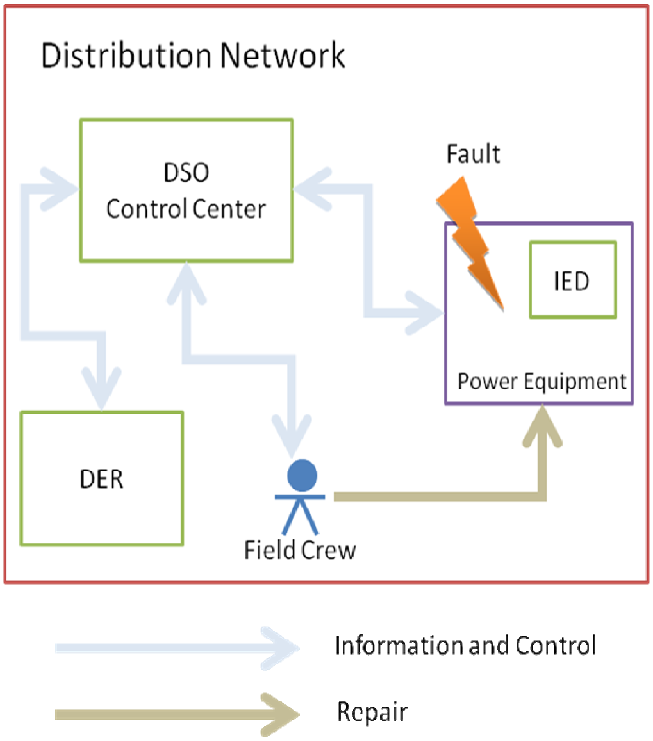


Figure 9 - FLIR Architecture (running at control center level)

5.2.1.4 Narrative

Depending on the degree of automation the necessary decisions are taken by a system operator or by the application itself. FLIR actions are determined based on data collected from the substation and feeder levels. This application can be run at control center level or in a decentralized way by a Multi Agent System, without human interference , e.g., as proposed in the INTEGRAL project, Deliverable D9.4, http://www.integral-eu.com/fileadmin/user_upload/downloads/Deliverables/D9.4_Final.pdf.

Many utilities offer performance-based rates (PBR). Essentially PBR penalizes utilities for service unavailability, e.g. via SAIDI (System Average Interruption Duration Index) and SAIFI (System Average

Interruption Frequency Index). Automation can help to reduce the outage duration and facilitate the operator's tasks. These indexes are related to the grid code or the considered standard CENELEC EN 50-160 (3 minutes for SAIDI), and CEI 61000-2-1 or IEEE 1159 (1 minute for SAIFI).

In order to minimize the outage time and frequency, the grid is constantly monitored with IEDs, split between protective relays and remotely controlled switches, which are responsible for topology modification, and between fault passage indicators, which are responsible for sensing. These IEDs notify the FLIR application in case of a fault (e.g., a tree falling on a power line). Using this information the faulty segments can be identified. As a next step either the system operator or the application selects the best switching procedure to open the nearest remotely controlled switches on each side of the fault location to isolate the fault. By operating other switches feeding the non-faulted de-energized feeder segments, the service in the non-faulted sections is restored. Subsequently actions of the active components of the distribution system are coordinated (load shedding, DER control, multi-level feeder reconfiguration) to enable a smooth operation of the network. E.g., in order to perform FLIR efficiently and effectively, a Multi-level Feeder Reconfiguration application that dynamically optimizes the connectivity of the distribution systems is helpful. This application recommends an optimal selection of feeder(s) connectivity for different objectives and requests confirmation from the operator or it acts automatically (running at control center or substation level). In its closed-loop mode, it determines a switching order for remotely controlled switching devices to restore service to the non-faulted sections by using multi-level load transfers, DER starts, and intentional islanding. In addition the Multi-level Feeder Reconfiguration application can unload an overloaded segment optimally, triggered by alarms that are generated by overloads of substation transformer or segments of distribution circuits or by operator demand (see section on related applications).
If necessary, the field crew is sent to the faulty section and repairs the fault. Afterwards the grid is reset to its original state.

Regarding the high-level SG functionalities described in Chapter 4.2.1, this building block(UC) is related to the following functionality:

SG Functionality		**FLIR**
B. Enhancing Efficiency in day to day grid operation	5. Improved automated fault identification and optimal grid reconfiguration after faults reducing outage times.	Using dynamic protection and automation schemes with additional information, strengthening Distribution Management Systems of distribution grids.

In the following we consider a simple FLIR building block(UC) example with two neighboring substations and a common control center running FLIR with an operator taking switching decisions.

5.2.1.4.1 Initial State

As shown in Figure 10, two neighboring substations are connected in a manner to make auto-restoration possible, in other words:

- Per typical utility operation, there is breaker located in the substation connected to each feeder, provided with an automatic reclosing function. These are labeled 1A1, 1B1, 2A1, and 2B1 in the figure, following the naming convention <substation1/2><feederA/B><switch/breaker#>.
- Normally-closed switches are located at intervals along each feeder to permit auto-sectionalizing around a fault. (e.g. 1B2, 1B3, 1B4). These switches are typically of the "no-load break" variety, for economic reasons. They can open only when there is no load on the line. Some may be of the "load break" variety, which can open under normal current. Usually only those devices at the head of the feeder (such as 1A1, 1B1 etc.) will be "fault interrupting" breakers capable of opening under fault current.
- A normally-open switch is located at the end of adjacent feeders. (e.g. 1C or 2C). This switch can be closed to share load or restore power from one feeder to the other.
- Each breaker and switch is monitored and controlled by an Intelligent Electronic Device (IED).

- Fault recorders in substations or in the field avoid false location due to distributed sources interaction with the detection process.
- In this example, the two adjacent sets of feeders can also be connected to each other (if necessary) using a number of normally-open switches (1X, 1Y and 1Z).
- The FLIR application running in the control center gathers information and controls the IEDs connected to its feeders. It reports to the Operator. (FLIR can also be run in a distributed way, the necessary modifications are not described in this example)

The scenario begins with each IED reporting its downstream load and switch status to the FLIR application.

From the current data reported by each IED (shown in italics with arrows in Figure 10), the load on each individual section of the feeders can be calculated. This example assumes that the maximum capacity limit on each feeder is 100A. Feeder 1B, in that case, is operating near capacity, while the other feeders are about 50% loaded.

5.2.1.4.2 Fault Detection

A fault occurs on feeder 1B between switches 1B2 and 1B3. Breaker 1B1 trips and de-energizes 90A of load, including 60A that is downstream from the fault.

All IEDs on feeder 1B report the fault and the loss of current to the FLIR application. The IEDs that saw the fault current (1B1 and 1B2) may send an estimated distance to the fault. IED 1B1 reports that it has tripped and has started reclosure timers.

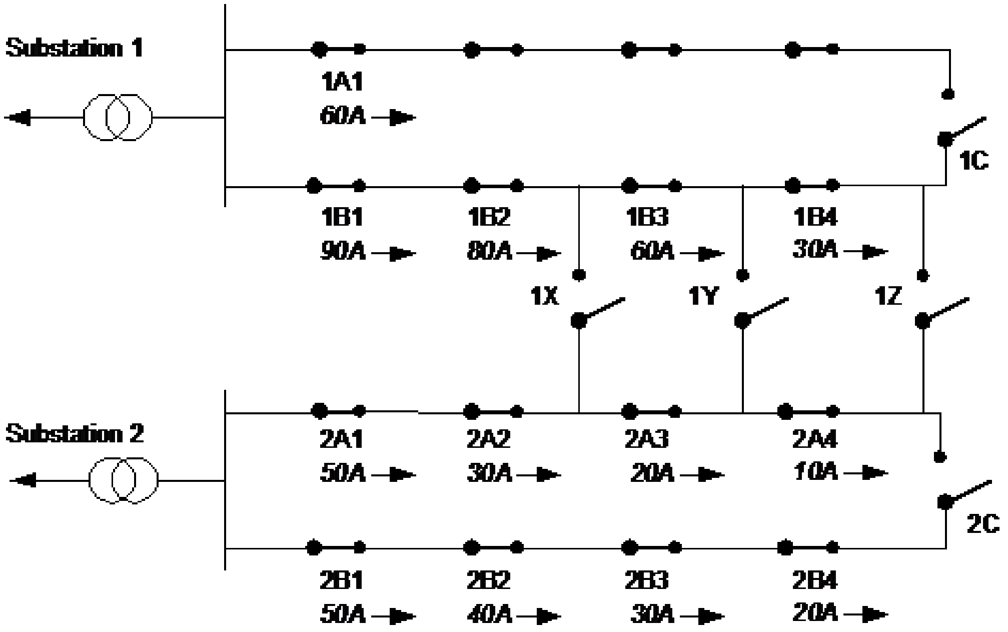


Figure 10: Initial State

5.2.1.4.3 Auto-Sectionalization

The IEDs on feeder 1B take action to isolate, or auto-sectionalize, the fault. There are two possible methods for doing so, with different communications requirements.

- With High-Speed Communication:
  One possible method is that the FLIR application determines which two switches (1B2 and 1B3) to open using fault direction and distance information provided by the IEDs. This method requires fast communication between the 1B IEDs and FLIR, in order to open the switches between reclosings of the breaker (measured in seconds). It also requires the IEDs to provide a specialized communications service, i.e. “open the next time you see zero current”. As high-

speed communication is needed, this requirement is also be linked to breakers capabilities and switches capabilities to isolate quickly the fault, without reclosure at all.

- Without High-Speed Communication:
  By Fault-Interruption Counting. A more robust and distributed method is for each IED to be programmed to open its switch after a pre-configured reclosure attempt. Each IED opens its switch under the following conditions:
  - The IED has observed fault current
  - The IED has seen the fault current drop to zero or the voltage is low, indicating the breaker has tripped.
  - These two conditions have occurred a pre-configured number of times. The number is different for each IED on the feeder.

  No IED is permitted to open its switch between the initial fault and the first reclosure attempt, in case the fault is transient. 1B4 is permitted to open its switch between the first and second reclosure attempts, but does not do so. Because 1B4 is downstream from the fault and has no other source of current, it does not observe the fault current and its opening conditions are therefore not met. Similarly, 1B3 does not observe fault current and so does not open in its time window if there are no sources downstream feeding the fault (i.e., DG feeding two phase or three phase faults).

  IED 1B2, however, has seen the same current as 1B1, and has been counting the fault interruptions. After the third reclosure attempt, 1B2 opens its switch, isolating the fault from any source of current. When 1B1 recloses the fourth time, it is successful, and 10A of load is restored to that section of feeder 1B.

5.2.1.4.4 Isolating the Fault

The final step in auto-sectionalization, is to isolate the fault. The FLIR application observes that 1B3 and 1B4 have reported zero current and voltage without having reported fault current. It therefore determines (possibly with the assistance of distance-to-fault data from 1B1 and 1B2) that the fault is between 1B2 and 1B3. FLIR application recommends to the operator that switch 1B3 be opened in order to isolate the fault. The operator confirms this operation, and the FLIR application sends the message to 1B3 causing it to open. In highly automated scenario the operator does not have to confirm this operation, it is executed automatically.

5.2.1.4.5 Load Splitting

Whichever auto-sectionalizing method is used, the fault is now isolated and auto-restoration can begin. The FLIR application reviews the data provided prior to the fault. It calculates the loading on each segment of each feeder and determines that there is 60A of load that can be restored.

However, the “traditional” solution, to close switch 1C, will not solve the whole problem. Feeder 1A is already loaded at 60A. If it accepts the whole downstream load of 60A, it will be overloaded, since the example began with the assumption of 100A maximum limit per feeder. As an alternative the loads and the sources can be modulated.

The FLIR application determines that it will be necessary to do a load transfer of the downstream load and re-energize it from multiple sources. The FLIR application recommends to Operator that switch 1B4 be opened, receives confirmation from Operator 1, and opens the switch by sending a message to 1B4.

5.2.1.4.6 Auto-Restoration and Load Balancing

The restoration of loads disconnected by the FLIR application is coordinated with the dynamically changing availabilities provided by the transmission, generation and distribution systems. This includes the re-synchronization of Distributed Energy Resources and micro-grids based on the post-contingency operating conditions.

This requires the optimal allocation and prioritization of controllable equipment in the distribution system (automated switching devices, controllable capacitors, voltage regulators, demand response installations, etc.). These activities cannot be accomplished without knowing what is expected from the application, because different stakeholders may have different dominant objectives and other requirements for these applications (compare with DCAC building block(UC)).

In our simple example without DERs, the FLIR application recommends that switch 1C be closed. Operator confirms this operation and FLIR application sends the message to IED 1C, restoring 30A of service.

The FLIR application recommends that switch 1Y be closed to restore the remaining un-faulted section of feeder between 1B3 and 1B4. The operator confirms the operation with the FLIR application, which sends the message to 1Y and restores the remaining 30A of service.

Following auto-restoration, feeder 1A is loaded at 90A and 2A is loaded at 80A, while 2B is only loaded at 50A. Operator may choose to close switch 2C in order to lighten the load on feeder 2A.

In theory, the whole system could be more efficiently loaded by also closing switch 1Z. However, the FLIR application would not make this recommendation because:

- The power on the two feeders is likely incompatible due to differences in frequency, voltage, and phase angle. Therefore, it would be necessary to open 1C before closing 1Z.
- Opening 1C would cause a momentary outage downstream of 1B4. Furthermore, if 1C was not a "load break" switch, it would be necessary to first break the load at 1A1, meaning that the outage would occur for all of feeder 1A.

After these steps, FLIR has completed, i.e.,the network is fully restored and can be operated in normal mode again.

5.2.1.5 Related Applications for the Coordination of Critical and Emergency Actions (CCEA)

Not only faults, but other critical emergency situations need to be handled by the distribution system operator. Examples include overloading and under-frequency protection. Such an application recognizes critical and emergency situation based on changes of the operating conditions and coordinates the objectives, modes of operation, and constraints of the system. While the other building blocks (UCs), e.g., DCAC and MV DAC treat the normal operation, applications for critical situations try to prevent an emergency situation by coordinating actions when the network is unstable or under stress, and applications for emergency situations help the network to recover once a fault has occurred or another event has happened that interrupts the operation of the network. Thus CCEA applications have to act faster than DCAC and MV DAC.

For example, Under-frequency Load Shedding Schemes trigger emergency load reduction mode of Volt/VAr/Watt control, or the under-frequency protection of Distributed Energy Resources triggers the pre-armed intentional islanding. Another application helps to optimally unload an overloaded segment. This objective is pursued if the application is triggered by the overload alarm from SCADA/DMS. To protect the distribution system from damages, these applications cover actions such as

- shedding load under conditions of low frequency, based on pre-defined settings, modes of operations, and priorities of connected groups of customers
- shedding load under conditions of low voltage, based on pre-defined settings, modes of operations, and priorities of connected groups of customers
- shed or reduce generation to preserve load balance over the lines and increase network stability
- control of load tap changers and shunts to prevent voltage instability
- control of series compensation devices to prevent system instability and critical overloads changes the modes of operation, the settings, and the priorities of remedial action schemes (RAS), Volt/VAr control and feeder reconfiguration, based on evaluation of the developing or expected emergency conditions.

In contrast to similar applications in the building block (UC) DCAC, CCEA applications have to delivery urgent messages and react fast as they serve the purpose of mitigating difficult situations instead of optimizing the normal operation.

To meet the Smart Grid requirements such applications include coordinating actions between SCADA/DMS, Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids analogously to FLIR. External actors, such as aggregators and retailers are not included in these coordinative actions, they are updated by MV DAC and DCAC on the new status once the network is in normal operation again.

As in the FLIR building block (UC), depending on the degree of automation, an operator person is involved and some actions can even be executed without interaction with the control center. As a consequence the resulting ICT requirements for such applications are almost identical to the building block (UC) presented in this section and hence we omit a detailed analysis of such applications for the coordination of actions in critical and emergency situations.

Regarding the high-level SG functionalities described in Chapter 4.2.1, this building block (UC) is related to the following functionalities:

SG Functionality		CCEA
C. Ensuring network security, system control and quality of supply	12. Improved operation schemes for voltage/current control taking into account ancillary services.	Supporting the operator with more information, possibly using automation schemes with additional information, strengthening Distribution Management Systems of distribution grids.
	13. Solutions to allow intermittent generation sources to contribute to system security through automation and control.	DER are included in the applications for critical and emergency situations and help to stabilize the system quickly.
	14. System security assessment and management of remedies, including actions against terrorist attacks, cyber threats, actions during emergencies, exceptional weather events and force majeure events.	During emergencies this applications either recommend actions to the operator or control the available components automatically.

5.2.1.6 Summary

Performing advanced FLIR will require the following measures beyond those required for existing FLIR mechanisms:

- Calculation of loads on each feeder or line section, and storing these values.
- More advanced logic in FLIR application to evaluate each possible switching action, perhaps on the order of the Contingency Analysis programs currently used by EMS stations.
- One of the following features:
    - Full breakers and protection relays on each section, or “load break” or “fault-interrupting” switches. Utilities are unlikely to do this because of the significantly higher cost.
    - Fault-Interruption counting, as discussed in this example. Fault-interruption counting has one major drawback: Ideally, it requires the same number of reclosures as there are switches on the feeder. Typically, utilities do not use a high number of reclosures because it causes excessive wear on the breaker and it annoys the customers, who see multiple small outages within a short period of time. Therefore it is rare to see more than two or three reclosures. This example, with four reclosures, would be extremely rare. This limits the granularity with which load can be restored, and increases the number of subscribers affected by a fault.
    - High-speed communications between remote IEDs and FLIR. In this example, it would permit the FLIR application to immediately determine that 1B2 and 1B3 switches should open, and do so quickly, between the first and second reclosings of breaker1B1 (not discussed in the step by step analysis).

5.2.1.7 Actor (Stakeholder) Roles

Grouping Community		Group Description
FLIR		This function collects all the activities after a fault until the service is restored
Actor Name	Actor Type (person, device, system)	Actor Description
IED	Device	IED: Gather data from feeders and operate switches based on control commands from FLIR application Includes a fault recorder to avoid blinding or undesired tripping of several non-directional IEDs
Fault Identification, Location, Isolation and Service Restoration Application (FLIR)	System	System that uses automation to aid and increase speed of recovery of fault events. Involved during entire fault process from identification to system restoration. • Network operation monitoring (substation- and network state supervision, logging) • Network control (remote or local through field crew) • Fault management (supports fault occurrence diagnosis and provides field information) Typically, this application is part of a Distribution Management System (DMS) run at a control center, but FLIR can also be run in a decentralized way.
DER	Device	Provide services of load/source modulation to support the restorative actions.
System Operator	Person	Monitors network and identifies the need for and performs required switching using the FLIR Application
Field Crew	Person	Repairs faulty lines

5.2.1.8 Information exchanged

Information Object Name	Information Object Description
Switch State	Digital Input with value Open or Closed. The change of state of a switch. Includes: a point number, the quality of the point (online/offline or valid/invalid), the new state, the time the state changed, typically accurate to millisecond resolution.
Current	Analog value in Amperes. Often a twelve-bit or sixteen-bit integer that must be scaled for display in engineering units. Includes: a point number, the quality of the point, and the value. May or may not include a millisecond timestamp.
Voltage	Analog value in Volts. Often a twelve-bit or sixteen-bit integer that must be scaled for display

	in engineering units. Includes: a point number, the quality of the point, and the value. May or may not include a millisecond timestamp.
Trip	Digital Input with value Trip. A particular type of Switch State change that indicates through its point number that a breaker has tripped and is now open. Includes all the same data as for a Switch State change.
Fault Detected	Digital Input with value True or False. Indicates an IED has observed fault current. Includes: a point number, the quality of the point, the new state, millisecond timestamp. May also include an analog value indicating a calculated Distance to Fault.
No Current Detected	Digital Input with value True or False. Indicates an IED cannot detect any current. Includes: a point number, the quality of the point, the new state, millisecond timestamp. May not be sent as a separate indication because it can be determined from the Current transmitted.
No Voltage Detected	Digital Input with value True or False. Includes: a point number, the quality of the point, the new state, millisecond timestamp. May not be sent as a separate indication because it can be determined from the Voltage transmitted.
Switch Control	Digital Output with value Open or Close. Sent by FLIR to change the state of a switch. Includes a point number and the requested switch state.
DER Control	Digital Output with values to order a concrete action, e.g. start/stop consuming/producing. Sent by FLIR to change the state of a DER.
Request	Message to an Operator, requesting that a particular action be taken, e.g. opening a particular switch. Includes: the operation to be taken (e.g. trip, close), and the location (e.g. the device name or feeder location). May be graphical, text, or voice.
Confirm	Confirmation from an Operator to the FLIR application that the requested operation can proceed.
Full record of the fault (pre and during the fault at a given sampling) or three estimated impedances (positive negative and zero sequence)	Data needed for the FLIR function to “locate” (in kilometer or in Ohm the distance to the fault) the fault and estimate it’s impedance.

5.2.1.9 Activities/Services

Activity/Service Name	Activity/Service provided
Fault Detection	Identify that a fault has occurred and where it is located. (filters and summarizes multiple alarms into a conclusive message about the core cause of the contingency, using alarm reduction based on events from multiple sources)
Auto-Sectionalization	Open switch(es) upstream of a fault to permit restoration of service
Fault Isolation	Open switch(es) downstream of a fault to prevent a repeated fault when service is restored. May be considered a sub-function of auto-sectionalization.
Load Splitting	Open switch(es) within a de-energized area, permitting some of the load in that area to be re-energized from different sources.
Auto-Restoration	Close switch(es) to re-apply power to a de-energized area.
Load Balancing	Open or close switch(es) to divide load between different sources and reduce load on any one source.
DER Modulation and Control	Automatically shed/reduce/increase generation and loads to preserve load balance and system stability (load curtailment and source support to diminish a given congestion)

5.2.2 Step by step analysis of function

5.2.2.1 Steps (Scenario with Operator in Control Center)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A	Fault	External	Report Fault	IEDs upstream from the fault report seeing fault current	IED 1B1, IED 1B2	FLIR application	Fault Detected
1B	Loss of current and voltage	External	Report Loss of Service	IEDs downstream from the fault report loss of current and voltage	IED 1B3, IED 1B4	FLIR application	No Current Detected, No Voltage Detected
2.1		IED 1B1	Initial Trip	First feeder IED (relay) trips breaker and reports the action. Starts reclosure timer.	IED 1B1	FLIR application	Trip
2.2	Recloser timer expires	IED 1B1	First Reclose Attempt	Upon expiry of reclosure timer, first IED recloses the breaker. Reports the action.	IED 1B1	FLIR application	Switch State (close)
2.3	Fault	External	Report Fault	IEDs upstream from the fault report seeing fault current again. This message indicates that the fault was not intermittent and that the FLIR should attempt to auto-sectionalize.	IED 1B1, IED 1B2	FLIR application	Fault Detected

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
2.4		IED 1B1	2nd Trip	First IED trips breaker and reports the action. Starts reclosure timer. This message indicates that the FLIR application can now attempt to open a switch for auto-sectionalization.	IED 1B1	FLIR application	Trip
2.5		FLIR application	Auto-sectionalize	Compute the correct switch to open based on the fact that the upstream switches reported fault current, while the downstream switches reported no current or voltage. Directs the correct switch to open between reclosures of the breaker.	FLIR application	IED 1B2	Switch Control (open)
2.6	Reclosure timer expires	IED 1B1	Report Upstream Power Restored	Upon expiry of the reclosure timer, first feeder IED recloses the breaker. Reports the action. Power is now restored from the substation to switch 1B1.	IED 1B1	FLIR application	Switch State (close), Current, Voltage
3.1	Logic timer expires	FLIR application	Request Isolation	Detects (using a timer) that no fault has occurred since 1B1 reclosed the breaker. Determines that switch 1B3 is the first switch downstream from the fault and should be opened. Requests confirmation from Operator.	FLIR application	Operator	Request (open 1B1)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
3.2		Operator	Confirm Isolation	Tells the FLIR application it is permitted to open the first downstream switch (1B3).	Operator	FLIR application	Confirm
3.3		FLIR application	Isolate Fault	Requests that the first downstream switch (1B3) open.	FLIR application	IED 1B3	Switch Control (open)
3.4		IED 1B3	Report Isolation Complete	The IED controlling the first downstream switch reports that the switch is open.	IED 1B3	FLIR application	Switch State (open)
4.1		FLIR application	Request Load Split	Determines from the Current and Voltage information stored prior to the fault that service cannot be restored from a single source. Determines which switch to operate (1B4) and requests confirmation from the Operator.	FLIR application	Operator	Request (open 1B4)
4.2		Operator	Confirm Load Split	Operator confirms that the switch to split the load (1B4) be opened	Operator	FLIR application	Confirm
4.3		FLIR application	Split Load	Opens the switch to split the load (1B4)	FLIR application	IED 1B4	Switch Control (open)
4.4		IED 1B4	Report Load Split Complete	IED (1B4) reports that the switch is open and the load is split.	IED 1B4	FLIR application	Switch State

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
5.1		FLIR application	Request Local Restoration	Determines that half the load can be restored by closing the local normally open switch (1C), and requests permission from operator.	FLIR application	Operator	Request (close 1C)
5.2		Operator	Confirm Local Restoration	Operator confirms that the normally open switch (1C) be closed	Operator	FLIR application	Confirm
5.3		FLIR application	Restore from Local Source	Closes the switch to restore power from the local source (1C).	FLIR application	IED 1C	Switch Control (close)
5.4		IED 1B4	Local Restoration Complete	IED (1C) reports that the switch is closed and current is restored to half the load.	IED 1B4	FLIR application	Switch State (close), Current
6.1	Local Restoration completed	FLIR application	Load Balancing and DER Modulation and Control	Determine optimal allocation and prioritization of controllable equipment (switches, capacitors, voltage regulators, DERs, etc).	IEDs	FLIR Application	Switch state, Current, Voltage
6.2		FLIR application	Request Inter-Substation Restoration	Based on decision reached in previous step the other half of the load is to be restored by closing the inter-substation switch (1Y). FLIR requests permission from operator.	FLIR application	Operator	Request (close 1Y)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
6.3		Operator	Confirm Inter-Substation Restoration	Operator confirms that the normally open switch (1Y) be closed	Operator	FLIR application	Confirm
6.4		FLIR application	Restore from Inter-Substation Source	Closes the switch to restore power from the other utility source (1Y).	FLIR application	IED 1Y	Switch Control (close)
6.5		IED 1Y	Inter-Substation Restoration Complete	IED (1Y) reports that the switch is closed and current is restored to the remaining load.	IED 1Y	FLIR application	Switch State (close), Current

5.2.2.2 Steps (Scenario without Operator)

In this scenario, the FLIR application is either running at the control center or at substation level. The following steps differ from the scenario with an operator.

Isolation: In Step 3.1 no request to the operator is generated and hence Step 3.2. is unnecessary. As soon as the appropriate switching action has been computed the corresponding control command is issued.

Load Split: In Step 4.1 no request to the operator is generated and hence Step 4.2. is unnecessary. As soon as the appropriate switching action has been computed the corresponding control command is issued.

Local Restoration: In Step 5.1 no request to the operator is generated and hence Step 5.2. is unnecessary. As soon as the appropriate switching action has been computed the corresponding control command is issued.

Inter-substation Restoration: Running at control center level, fully automated without operator: In Step 6.2 no request to the operator is generated and hence Step 6.3. is unnecessary. As soon as the appropriate switching action has been computed the corresponding control command is issued.

If the FLIR application is running at the substation level, then messages need to be exchanged between the involved substations and DERs in order to allow FLIR to reach the correct conclusions and control commands in Step 6.1. In Step 6.2 no request to the operator is generated and hence Step 6.3. is unnecessary. As soon as the appropriate switching action has been computed the corresponding control command is issued.

5.3 MV DAC from utility control centre (MVDAC) building block (UC)

5.3.1 Descriptions of Function

5.3.1.1 Function Name

MV Data Acquisition and Control from the utility control center.

5.3.1.2 Function ID

MVDAC

5.3.1.3 Brief Description

This building block (UC) covers data acquisition and control of MV network from the utility control center. The following figure presents the scope of this building block.

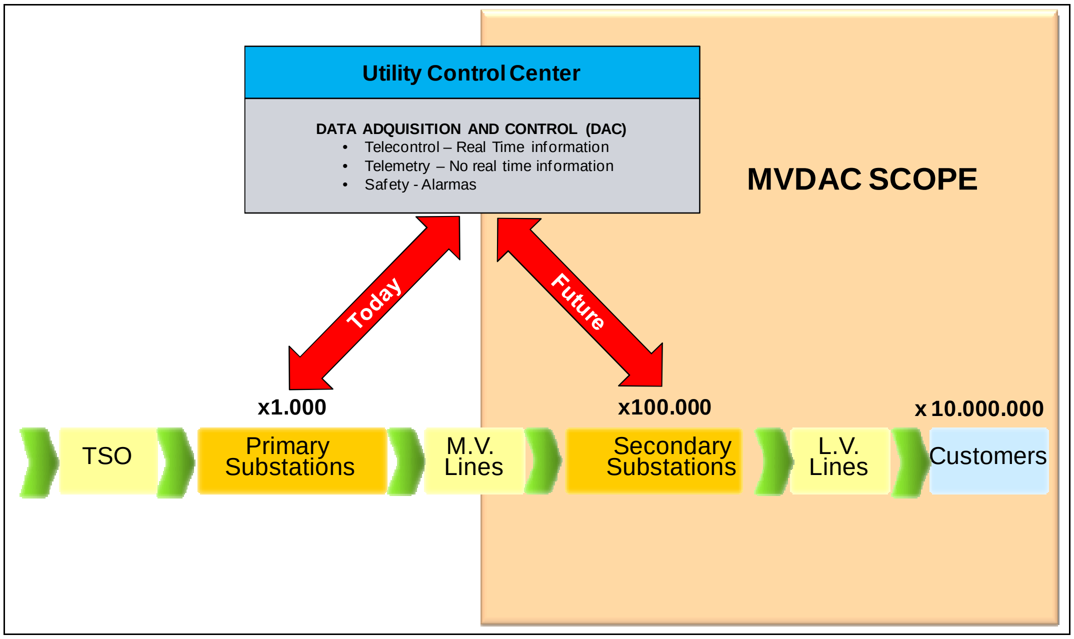


Figure 11 - MV DAC Building bloc (UC)

This function has already been deployed widely in VHV and HV networks. Future smart grid will require the deployment of this function also in MV network, due to the better management of power flow and customer service level.

This uses case does not cover ADA (Advanced Distribution Automation). It must to be taken into account that even in a distributed and automated control environment, aimed by future smart grid, the responsibility of network stability resides in DSOs. So, electrical network must be visible and controllable in last instance from them being the utility control center the selected location for doing that.

Three different categories of data are considered:

- Real Time information. Managed by Telecontrol function.
- Non-Real Time information. Managed by Telemetry function.
- Safety Alarms. Managed by Safety function.

5.3.1.4 Narrative

DAC from the utility Control has been already deployed widely in VHV and HV network. In concrete, Primary substations (those which transform from VHV/HV to HV/MV) for voltage transformation or for connecting centralized generators have been until now the locations in which DAC has been required.

Beside, DAC has been also deployed in some poles of the VHV or HV to manage OCR (Over Current Reclosers).

Future smart grid requirements will force to deploy DAC in the MV network. It is expected that secondary substations (those which transform from MV to LV) and DERs will be the main elements of the network that concentrate DAC functionality.

MV network has the following differences from the HV/VHV network which suggest that the DAC solution will not be the same in both of them:

- There are 100 times more secondary substations than primary substations. And more or less 100 times more LV energy supplies than secondary substations.
- Secondary substation location is closest to the customers (in urban areas mainly) and primary substations are normally in rural areas.
- Due to growing number of Distributed Energy Resources (DER) in MV and LV networks more power monitoring is needed on those levels (e.g. due to increasing dynamical behavior…)

The solution for DAC in VHV and HV has been deployed using mainly the utility own private network by means initially of dedicated point to point or multipoint connections at 9600 bps (employing telecommunication technologies like PDH, Point to Multipoint Radio) and recently by means of Ethernet connections (employing MPLS networks).

DAC in MV will force to establish communications with much more sites. So, economical advantages of using an existing network and services of public network will be much greater and its viability has to be analyzed.

Within DAC functionality in MV and DERs, several functions could be identified:

- Telecontrol function: Retrieve real time information from the Power System and control it through a centralized location by operators. For doing this function, very complex power equipment has to be installed inside secondary substations for controlling purposes (circuit breakers, switches…). For this reason, it is expected that no more that 10% of MV secondary substations (strategically selected) will be automated in future Smart Grid. On the others hand, it is expected that 100% of DER installations will require this function.
- Telemetry function: Collect measurements (non-real time information) from meters through a centralized location. For doing this function, very simple power equipment (meters) has to be installed inside secondary substations or DERs. It is expected that 100% of MV secondary substations and DERs will be measured remotely. Additionally, it is expected that secondary substations concentrates telemetry information from the LV energy supply meters.
- Safety function: This function covers the collection of alarms from Power System shelters through a centralized location.

ADA (Advance Distribution Automation) function is out of the scope of this building block (UC).

This MV DAC from the utility control centre building block (UC) will be fundamental for the smart grid development for the following reasons:

- Actual Roll out of LV meters in Europe e.g. by means of PLC technology, where the telemetry information is collected from the secondary substation. This also encourages the deployment of MV SG functionalities in these shelters.
- Even in a distributed and automated control environment, aimed at by the future smart grid, the responsibility of network stability resides in DSOs. In the last instance electrical networks must be visible and controllable from the utility control center which is the selected location for doing that.

Regarding SG Functionalities described in chapter 4.2.1.2, this building block (UC) is related to the following ones:

SG Functionality		MV DAC from the utility control center
A. Enabling the network to integrate users with new functionalities	1. Facilitate connections at all voltages/locations for all existing and future devices with SG solutions through the availability of technical data and additional grid information	Visibility and control of some parameters of existing and future devices from the utility control center, allows their widely deployment
	2.Better use of the grid for users at all voltages/locations, including in particular renewable generators	Visibility and control from the utility control center avoids risk of instability caused by removable generators
B. Enhancing Efficiency in day to day grid operation	5. Improved automated fault identification and optimal grid reconfiguration after faults reducing outage times	Visibility and control of the MV grid from the utility control centre reduces the field workers implication to solve a fault and so reduce the outage time.
	6. Enhance monitoring and control of power flows and voltages	Visibility and control from the utility control center must be a requirement even in a distributed control environment

In the following figure, the main actors (stakeholder) roles of this building block (UC) are presented.

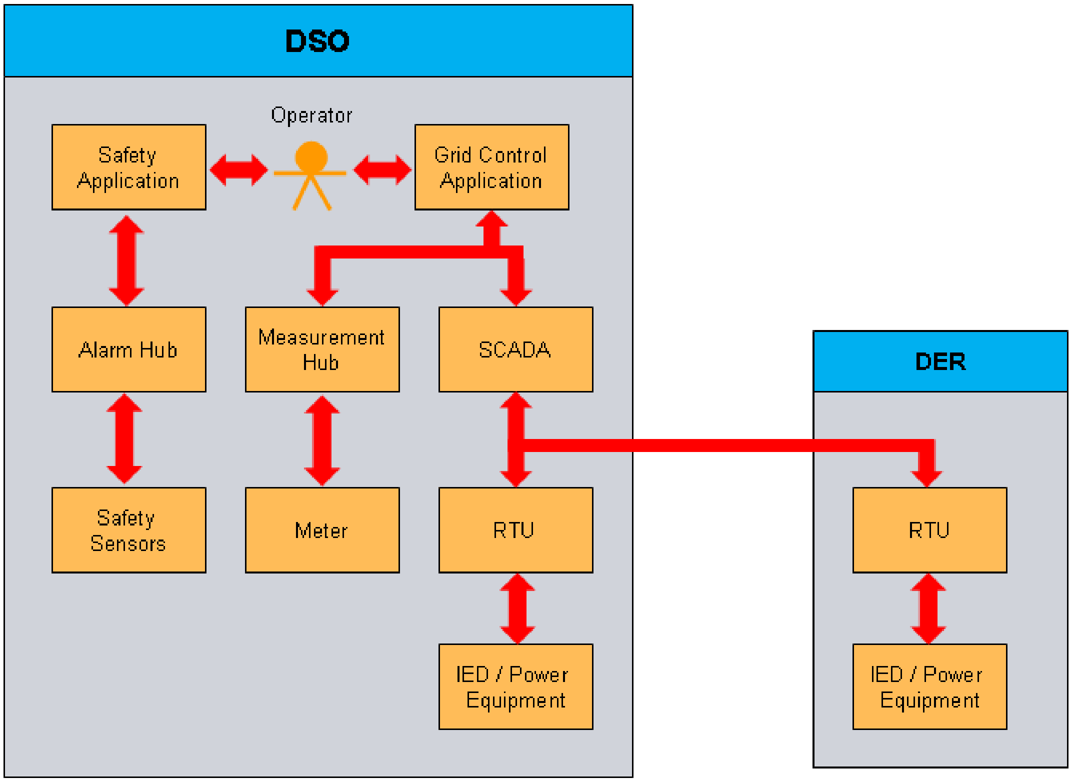


Figure 12 – MVDAC actor (stakeholder) roles

5.3.1.4.1 Telecontrol function

The difference of this function from others is the kind of information it manages, which is Real Time Information. This information is critical in delay of its retrieval. This could be due to an error or a loss. It has to be understood that this kind of information must have the very first priority in any QoS policy. Comparing it for example with Voice RTP traffic, delayed Real Time Information can not be regenerated from the previous or next samples.

There are two main systems involved in the execution of this function:

- The SCADA System that is in charge of updating real time information of RTUs (Remote Terminal Units) from a centralized data base.
- The Grid Control Application that is in charge of presenting information to the grid operator with a visual interface in order to facilitate the visibility and decision making.

The SCADA System updates real time information cyclically (every 2 seconds) from the RTUs. If the information is delayed later than these 2 seconds, an error is produced and the request is repeated. This kind of error has the same effect, when interference causes an error in the transmission or when a packet is lost. The percentage of errors in the SCADA system must be limited.

The Grid Control Application interfaces with the SCADA System to retrieve real time information and presents it to the grid operator in a GIS graphically.

The Grid Operator is allowed to introduce orders, like for example to open switches. Their state must be updated instantaneously in the visual interface, once they are executed in the electrical grid, .

The SCADA System is also in charge to send orders received from the Grid Control Application through RTUs to the Power equipment.

5.3.1.4.2 Telemetry function

This function retrieves non-real time information from meters. In the future smart grid it is expected that 100% of secondary substations and 100% of DERs will have meters that could be measured remotely from a control center.

There are two main systems involved in the execution of this function:

- The Measurement Hub that is in charge of updating non-real time information from meters from a centralized data base.
- The Grid Control Application that is in charge of presenting this information to the grid operator with a visual interface in order to facilitate the visibility.

The Measurement Hub updates non-real time information periodically with the configured frequency (daily, hourly, monthly) from meters. Meters could store measurements in different periods (quarter of hour, hour, day…).

The Grid control Application interfaces with the Measurement Hub to retrieve non-real time information and presents it to the grid operator graphically.

5.3.1.4.3 Safety function

This function manages safety alarms that could arise in Power System shelters.

There are two main systems involved in the execution of this function:

- The Alarm Hub that is in charge of collecting safety alarms from safety sensors in a centralized data base. Safety sensors detect, digitalize and send safety alarms to the Alarm Hub.
- The Safety Application that is in charge of presenting this information to the safety operator with a visual interface in order to facilitate the visibility.

5.3.1.5 Actor (Stakeholder) Roles

Grouping Community		Group Description
Telecontrol Function		This function collects all the activities related to retrieve real time information from the Power System and to control it through a centralized location by operators.
Actor Name	Actor Type (person, device, system)	Actor Description
SCADA System	System	The Supervisory Control and Data Acquisition (SCADA) System updates in its databases, real time information (Measurements and states) of the Power System in order to assist operators to control (operate) it.
RTU	Device	A Remote Terminal Unit (RTU) is generalist equipment which acts as a middleware between the SCADA System and Power Equipments for DAC. For monitoring and controlling a Secondary Substation, one RTU is installed inside the shelter: • It has one or two WAN interfaces that interconnect it to the SCADA System • It has several digital/analog inputs/outputs that allows it to: o Collect information from sensors of Power Equipments o Send commands to actuators to Power Equipments
Power Equipment	Device	Equipment which directly operates on the Power System. Typical Power system Equipment examples are: o Circuit Breakers o Load tap changers o Capacitor banks o Switches o Voltage Regulator Controller o Potential transformers (PTs) o Current transformers (CTs), meters...
Grouping Community		Group Description

Telemetry Function		This function covers the collection of measurements (non real time information) from meters through a centralized location
Actor Name	Actor Type (person, device, system)	Actor Description
Measurement Hub	System	System which is in charge to update data bases, with non-real time measurements from meters. Depending on the final usage of this information this update could be performed with a certain frequency (daily, hourly, monthly)
Meters	Device	Power equipments which stores different measurements (active/reactive power consumed in different periods) in order to send them to a Measurement Hub. It has a local interface to interconnect it to the Measurement Hub.
Grouping Community		Group Description
Safety Function		This function covers the collection of alarms from Power System shelters through a centralized location
Actor Name	Actor Type (person, device, system)	Actor Description
Alarms Hub	System	System which is in charge of collecting all alarms that are currently actives from a Central Location.
Safety Sensors	Device	Sensors that collect safety alarms (intrusion, fire…). They usually have a local connection to interconnect to the Alarm Hub.
Grouping Community		Group Description
Control Center		Systems and persons that are in a centralized location for controlling (operating) or supervising alarms of the Power System
Actor Name	Actor Type (person, device, system)	Actor Description
Safety Application	System	Application which interacts with safety operators and presents them Power System alarms with a visual interface. It collects alarms from the alarm hub.
Grid Control Application	System	Application which interacts with grid operators presents every real time information graphically in a GIS and allows introducing orders like for example open switches that are executed in the grid. It collects real time information and send real time orders trough the SCADA System. This application could also include non real time information from Measure hub to assist operators in their work.
Grid Operator	Person	Person who operates the electrical grid.
Safety Operator	Person	Person who supervises safety alarms of the Power shelters.

5.3.1.6 Information exchanged

Information Object Name	Information Object Description
RTU Analog & Digital inputs	Analog and Digital information from the Power Equipment that are digitalized by the RTU
RTU Analog & Digital Outputs	Analog and Digital managed from the RTU to perform orders (like opening a switch, circuit breaker…) in the power equipment.
Real Time States	Digitalized information of states.
Real Time Measurements	Digitalized information of measurements.
Non-Real Time Measurement	Digitalized information with different measurements in different periods.
Real Time Orders	Digitalized orders which are sent from the SCADA system to the RTU
Safety Alarm	Digitalized information of alarms from a safety sensor to the alarms hub.

5.3.1.7 Activities/Services

Activity/Service Name	Activity/Service provided
Real Time Data Acquisition	SCADA System
Non-Real Time Data Acquisition	Measurement Hub
Control	SCADA System
Alarms Reception	Alarm Hub
Grid Operation	Manual Procedures
Safety Supervisión	Manual Procedures

5.3.2 Step by step Analysis of Function

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot '.'. Within a level, the sequence number comprises an optional letter and an integer number.

The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

5.3.2.1 Steps for Telecontrol Function

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1A	Periodical acquisition	SCADA System	Real Time Data Acquisition	SCADA System updates real time information from the RTU by means of continuous polling.	RTU, Power Equipment	SCADA System	Real Time States Real Time Measurements
1A.1A.1A	Change in RTU Inputs	RTU	Digitalization of Changes	The RTU is monitoring continuously Power Equipment through its Analog and Digital Inputs. When a change occurs is some of the inputs, the RTU takes note of it in order to send it in the next request from the SCADA System	Power Equipment	RTU	RTU Analog & Digital Inputs
1A.1A.1B.1	Periodical every 2 seconds	SCADA System	State or Measurement Change Data Request	SCADA System requests every 2 seconds for any change of state or measurements detected in the RTU	SCADA System	RTU	There is no information exchanged.
1A.1A.1B.2	Reception of a Change Data Request	RTU	State or Measurement Changes Sending	When a request of state or measurement change is received, RTU sends all these changes to the SCADA System	RTU	SCADA System	Real Time States Real Time Measurements

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1A.1B.3	Periodical every 10 minutes	SCADA System	Every State and Measurement Data Request	SCADA System requests every 10 minutes information of states and measurements in the RTU	SCADA System	RTU	There is no information exchanged.
1A.1A.1B.4	Reception of every Data Request	RTU	Every State and Measurement Sending	When a request of every state and measurement change is received, RTU sends all of them to the SCADA System	RTU	SCADA System	Real Time States Real Time Measurements
1A.1B	Periodical Operation	Grid Operator	Grid Operation	Grid Operator is continuously operating the Grid with the aid of the Grid Control Application that usually presents every real time information graphically in a GIS and allows to introduce orders like for example open switches that are executed in the grid and therefore produces change of states that are represented interactively in the Grid Control Application.	Grid Control Application SCADA System	Grid Control Application SCADA System	Real Time Measurements Real Time States Real Time Orders
1A.1C	Request of Order from the Grid Operator	SCADA System	Control Order	SCADA System is responsible to send orders to the Power Equipments through the RTU	Grip Operator Grid Control Application SCADA System	RTU Power Equipment	Real Time Orders

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1C.1	Request of order from the Grid Control Application	SCADA System	Sporadic Order Request	SCADA System transmits an order to the RTU	SCADA System	RTU	Real Time Order
1A.1C.2A	Reception of order from the SCADA System	RTU	Sporadic Order Execution	RTU execute the order through the Digital outputs	RTU	Power Equipment	RTU Digital Outputs
1A.1C.2B	Reception of order from the SCADA System	RTU	Order Reception Confirmation	RTU confirms the reception of one order	RTU	SCADA System	There is no information exchanged.

5.3.2.2 Steps for Telemetry Function

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.1A	Periodical acquisition	Measurement Hub	Non Real Time Data Acquisition	Measurement Hub updates non real time information from the meters by means of a periodical polling.	Meter	Measurement Hub	Non-Real Time Measurements
1B.1A.1A	Change in Measurement	Meter	Digitalization of Measurements	Meter is measuring and digitalizing some parameters (for example active power or reactive power) of the electrical network. The meter could store measurements for different periods (days, hours…).	Electrical Network	Meter	Non-Real Time Measurements
1B.1A.1B.1	Periodical every configured period (1 day, 1 hour, 1 month…)	Measurement Hub	Request Measurement	Measurement Hub requests every configured period (1 day, 1 hour, 1 month…) measurements from a meter.	Measurement Hub	Meter	There is no information exchanged.
1B.1A.1B.2	Reception of Measurement Request	Meter	Send Measurement	When a measurement request is received, meters sends all these measurements to the Measurement Hub	Meter	Measurement Hub	Non-Real Time Measurements

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.1B	Periodical Operation	Grid Operator	Grid Operation	Grid Operator is continuously operating the Grid with the aid of the Grid Control Application that presents non-real time information graphically in a GIS.	Grid Control Application Measurement Hub	Grid Control Application	Non-Real Time Measurement

5.3.2.3 Steps for Safety Function

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1C.1A	Safety Alarm	Alarm Hub	Receive Alarms	Safety sensors send any safety alarm that could arise in the electrical shelter to the Alarm Hub.	Safety Sensors	Alarm Hub	Safety Alarms
1C.1A.1	Safety Alarm	Safety Sensors	Send Alarms	Safety sensors detect, digitalize and send safety alarms in electrical shelters to alarm Hub	Electrical Shelter	Alarm Hub	Safety Alarms
1C.1A.2	Alarm reception	Alarm Hub	Confirm Alarms	Alarm Hub sends a confirmation for the reception of an alarm.	Alarm Hub	Safety sensors	There is no information exchanged.
1C.1B	Periodical Safety supervision	Safety Operator	Safety Monitoring	Safety Operator is continuously supervising alarms with the aid of the Safety Application that presents safety alarms graphically.	Safety Application Alarm Hub	Safety Application	Safety Alarms

5.4 SG Energy Control of Power Inverter (SGEC) building block (UC)

5.4.1 Descriptions of Function

In future the number of intelligent power devices running directly in context of a smart grid will increase. This is due to voltage and frequency stabilization, infeed of storage systems, electric car supply, windpower, photovoltaic systems, etc. Today, the number of devices which can act as a consumer or a prosumer (e.g. storage devices) is small and there are limited mechanisms to actively control it. Nowadays, a first approach will be done in photovoltaic plants. This is due to increasing installed power which is fed into the grid could cause the problem of over voltages and frequency instability and thus need to be prevented. Therefore, an active control of high power inverters is necessary. But there are limited communication means available, today, in order to achieve a set of control, information and identification functions esp. for bigger windfarms and photo voltaic plants.

5.4.1.1 Function Name

The set of power inverter related smart grid functions is named **Smart Grid Energy Control** of Power Inverter Functions **(SGEC).**

5.4.1.2 Function ID

SGEG

5.4.1.3 Brief Description

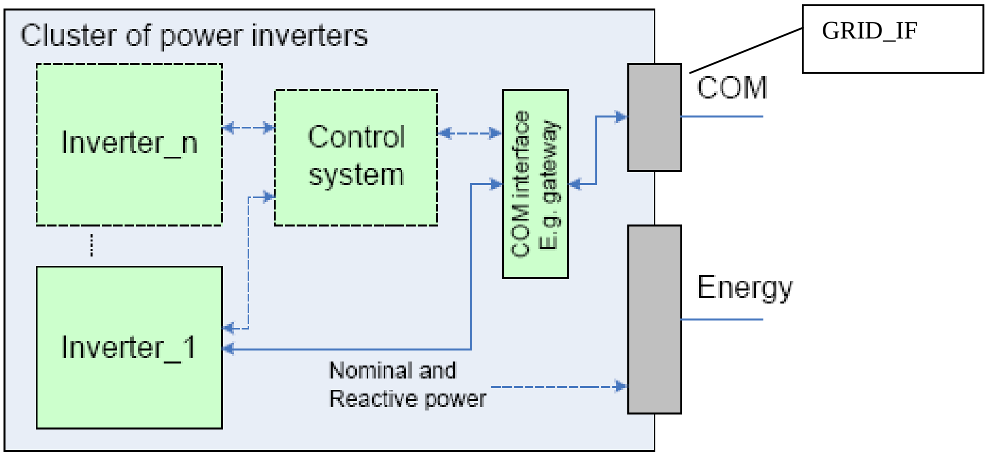


Figure 13 - SGEC building block (UC)

Objective: The power inverter is a necessary component within smart grids. The objective of (high) power inverters in smart grids is to perform various tasks which require an active energy control element. These tasks can be consumer related and/or generator related. Thus, the inverter can handle energy in both directions. Typical tasks are drive applications like a (pipeline) compressor, power conditioning (active filter), building a storage interface to the grid (bi-directional interface to battery, pumped water storage, fly wheel), static power generation infeed (fuel cell), variable energy generation (wind turbines, photovoltaic). It is possible to connect a single power inverter to the grid or a cluster of several power converters controlled by a built-in control system (see picture above). In any cases the power inverter (cluster) needs to be fully controlled by the grid and in general the power inverter (or cluster) will only show one communication interface and just one energy interface to the grid.

Scope: Inverters can be excellently controlled in a highly dynamic manner. This is true especially for the voltages at the inverter terminals (grid energy interface) and the current driven by the inverter. From this it is intended to use inverters in a grid e.g. for reactive power compensation and reduction of mains voltage distortions. In HVDC applications inverters are essential to convert DC current to alternating current and vice versa.

Inverters are necessary for islanding operations and uninterruptible power supplies. In that context it can be used for peak shaping and help to reduce losses within the grid (by reduction of harmonics and improvement of power quality).

Moreover, inverters are suitable for metering tasks. Any kind of pre-processing can be performed.

Rational: The communication between grid administration / control and a single inverter or a cluster of inverters will take place using non-real-time frames as well as fast real-time frames. The latter are necessary to e.g. inform the inverter about critical mains conditions which could end-up in an immediately ramp-down resp. disconnection from mains or can lead to the activation of other appropriate protection functions.

5.4.1.4 Narrative

A power inverter consists of a power stack build up with power transistors, thyristors, etc. and a control unit which generates the control signals for the power stack. The control unit also contains the process control, e.g. voltage and/or current control.

The inverter needs to be protected against damages. This is due to overload conditions (over-voltage, over-current, short circuit conditions, ...), but also over-temperature. There are various protection mechanisms implemented to react on such situations. In case of emergency conditions the inverter will inform the outside world by alarms or warning messages.

Moreover the inverter is in principle able to generate voltages of various shapes and of various frequencies and phase angles.

From this a synchronization with the mains and adaptation onto the mains voltage is given. The current fed to the mains or retrieved from the mains is managed by a closed loop control.

In general inverters are equipped with a lot of so called parameters which are used to tune the various functions implemented in the inverter, e.g. the current controller.

Because the implemented measurement system is always needed for the various control tasks, the inverter can take over metering tasks as well in context of a smart grid. Moreover, a pre-processing of the sampled data is possible and the data could be delivered with a time-stamp, if a synchronized real-time-clock is available.

Thus, also history data could be provided on demand to the outside world.

Finally, also downtimes like maintenance, repair, etc. must be taken into account, especially for energy production planning

All the communication between the inverter and the smart grid controller is intended to be done using just one interface. However, communication to different “controllers” would be still possible. However, in order to prevent conflicts in case of contradictory commands are sent to the inverter from different controllers, a coherent set of control commands (such as commercial aspects or voltage-control, etc.) should be sent by just one “controller” i.e. one (external) controlling instance.

The following functionalities are seen to be necessary for this building block (UC) according to chapter 5.4.1.3:

- Basic Control of Inverter Functions (Connect / Disconnect to/from grid, Adjust Maximum Generation Level, Adjust Power Factor, ...)
- Reporting Functions (Event Logging, Status Reporting, Error Messages, Load conditions, ...)
- Act as metering device (actual electrical data, e.g. voltage, current, distortion, ...)
- Scheduled Actions based on time, temperature, power pricing
- Periodic commands, like clock time synchronization
- VAr modes for VAr support from PV/Storage inverters (Modes PV1…PV5)

- Advanced functions (Watt/Frequency or Watt/Voltage mode, advanced schedules, low voltage fault ride through (FRT), separate Watt and VAr management, harmonic cancellation)
- Submitting characteristic identification parameters of the inverter driven equipment (e.g. active power rating, reactive power rating, time to shut down, overload capability, max. time of mains voltage loss, necessary quality of energy service, flexibility, handling of peak power, ...)
- Historical data collection, pre-processing and storage
- Conditional and event based maintenance

5.4.1.5 Actor (Stakeholder) Roles

Grouping (Community) ’		*Group Description*
Power Inverter		
Actor Name	*Actor Type (person, organization, device, system, or subsystem)*	*Actor Description*
GRID_IF	Communication Interface	The grid controller (CONTR) defines a clear data interface (GRID_IF) within the smart grid in order to communicate with the power inverter using well defined telegrams running in real-time and non-real-time. In case several power inverters are clustered, e.g. in larger production plants, the data interface towards the grid (GRID_IF) has now moved from the individual power inverter to a central control system. In that case the communication inside the inverter cluster could be done using the Grid IF protocol definition too, but also other protocols are possible
PI	Device	The Power-Inverter (PI) builds up the energy interface between the grid and an e.g. DER.
CONTR_#	Device, Person, (Sub)-System	Operates the smart grid and controls the PI (e.g. DER) using the GRID_IF and its agreed functionality. There can be more than just one controller which communicates with the inverter, but on different aspect levels (commercial, voltage control, etc....). It is intended that just one logical controller is available for each aspect. CONTR_1: Voltage / Power Controller, Alarms, Warnings CONTR_2: Commercial aspects CONTR_3: Metering data CONTR_4: Maintenance

5.4.1.6 Information exchanged

Information Object Name	*Information Object Description*
Identification	Inverter provides an identification data-set: active power rating

Information Object Name	*Information Object Description*
	reactive power rating overload capability storage capacity / storage energy peak power capability type of provided metering data type of implemented functions / commands
Command	Commands are used to activate, tune or deactivate certain functions implemented inside the inverter resp. inverter cluster. In general the functions will require specific data for parameterization, which is intended to be provided as parameters of the command.
Alarm Data / Warning Data/ Information Data	Alarm data is published by transferring an alarm-number only. In order to explore the reason for the alarm, history data need to be read. In case of an alarm, normally the inverter will protect itself. Warning data can be provided at any time, and will not lead to further actions within the inverter. Informational data is used to inform about general conditions (maybe in a regular intervals) (e.g. about energy production reduction).
History Data	History Data consists of long term data measurement and short term data acquisition. The short term history data also contains the history of the latest alarms.
Metering Data	There are accurate sensors built in the inverter for measuring voltages and currents with fast sampling rates (< 1 ms). From this metering data will be provided which consists of the original (smoothed) measurement values but also calculated values from that measurement values. Only pre-defined data is available.
Commercial	Offer / Order Energy to / from smart grid
Time	In case of synchronized clocks, time stamped data could be provided
Energy Indexes	Indexes of previous time-period are calculated for energy production forecast purposes
Maintenance	Information (begin, end) about maintenance downtimes are to be announced to the controller.

5.4.1.7 Activities/Services

In general the inverter will not do any action without having received an appropriate command. An appropriate command is necessary for changing data and/or receiving data as well as activation of specific functions. However, it should be possible to activate scheduled functions which, e.g., provide pre-defined data automatically in the chosen time-raster.

In a clustered system the central control system provides more processing power and intelligence than a single power inverter. In this case the controller can perform balancing actions without having received any external commands in order to be able to deliver the agreed amount of power.

In case an unknown command is received, an according (negative) acknowledge will be sent back.

In case of offering and/or ordering energy to/from grid the inverter is allowed to send sporadic telegrams. Furthermore there will be functions which will automatically be activated in certain fault conditions (if these functions are set in standby mode by an according command). One such fault-driven function is the “Voltage_Fault_Ride_Through” which is (automatically) activated in case of short voltage dips and forces the inverter to deliver an amount of reactive power in order to support the normal mains voltage level.

Maintenance caused downtimes must be announced to the controller, too, for energy forecast purposes. This aspect also relates to chap. 5.4.1.8 of this document.

Activity/Service Name	*Activities/Services Provided*
Command	Get_Data (e.g. Energy Indexes, Metering data, ...) Set _Data Get_Identification_Data Set_Operation_Mode (consumer, provider) Connect_to_grid Disconnect_from_grid Define_Metering_Dataset Set_Reactive_Power Set_Active_Power Set_Power_Factor Set_Limits Set_Characteristic_Curve_of_Control_Action Set_Short_Time_Overload_Behaviour Activate/Release_Voltage_Control Activate/Release_Power_Factor_Control Activate/Release_Peak_Shaping Activate/Release_Voltage_Fault_Ride_Through Activate/Release_General_Fault_Ride_Through Activate/Release_Scheduled_Data_Response Clock/Time_Synchronization
Command_Response	Positive Acknowledge Negative Acknowledge Requested Data
Alarm	Overload Condition Over-Temperature General Error_Condition
Warnings	Warning-Level Temperature reached bad weather conditions
Commercial	Offer_Energy Order_Energy
Commercial_Response	Accept_Reply Refuse_Reply
Maintenance	Announce_Maintenance_Interval Announce_Planned_Downtime

5.4.1.8 Contracts/Regulations

Contract/Regulation	*Impact of Contract/Regulation on Function*
Contracts between Smart Grid and Operator and Prosumer	**Schedules.** Defines amount of kW generated by e.g. DER at different times and constraints for power flow. Deviation from schedules will be timely detected and announced to the distribution system. **Volt/VAr control agreement.** Defines modes of e.g. DER operation and setting for Volt/VAr control. Defines rules for changes of modes of operation and setting (e.g. local/remote). Deviation from agreement will be timely detected and announced to the distribution system. **IEEE Standard 1547.** Defines interconnection rules between e.g. DER and Supplier. Deviation from the rules may result in violation of power quality limits, delays in service restoration, damage of DER equipment. Deviation from the standard must be timely detected and fast informations are to be sent out.

Policy	*From Actor*	*May*	*Shall Not*	*Shall*	*Description (verb)*	*To Actor*

Constraint	*Type*	*Description*	*Applies to*

5.4.2 Step by Step Analysis of Function

5.4.2.1 Steps to implement function – Name of Sequence

5.4.2.1.1 Preconditions and Assumptions

Preconditions and assumptions are already covered within the description above.

Actor/System/Information/Contract	*Preconditions or Assumptions*
	Preconditions and assumptions are already covered within the description above.

5.4.2.1.2 *Steps – Name of Sequence*

Describe the normal sequence of events, focusing on steps that identify new types of information or new information exchanges or new interface issues to address. Should the sequence require detailed steps that are also used by other functions, consider creating a new “sub” function, then referring to that “subroutine” in this function. Remember that the focus should be less on the algorithms of the applications and more on the interactions and information flows between “entities”, e.g. people, systems, applications, data bases, etc. There should be a direct link between the narrative and these steps.

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot ‘.’. Within a level, the sequence number comprises an optional letter and an integer number. The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

Sequence 1:

```
1.1 - Do step 1
1.2A.1 - In parallel to activity 2 B do step 1
1.2A.2 - In parallel to activity 2 B do step 2
1.2B.1 - In parallel to activity 2 A do step 1
1.2B.2 - In parallel to activity 2 A do step 2
1.3 - Do step 3
1.3.1 - nested step 3.1
1.3.2 - nested step 3.2
```

Sequence 2:

2.1 - Do step 1
2.2 – Do step 2

There is no sequence of parallel working communication paths. It is just a request and reply communication system. The only exceptions are alarms and warnings which are submitted in an asynchronous and sporadic manner on demand.

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	*Triggering event? Identify the name of the event.*[5]	*What other actors are primarily responsible for the Process/Activity? Actors are defined in section5.4.1.5.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information? Actors are defined in section5.4.1.5.*	*What other actors are primarily responsible for Receiving the information? Actors are defined in section5.4.1.5.* *(Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 5.4.1.6*
#1	Alarm	PI	Name of Inverter and Alarm-Number (Should be defined by the grid controller in case of parameter setting)	Inverter will disconnect from mains	PI	CONTR_1	Real-time message
#2	Warning	PI	Name of Inverter and Warning Number	Inverter will continue	PI	CONTR_1	Non-Real-time message
#3	Command	CONTR_1	-----	Configuration, Setpoint values, etc.	CONTR_1	PI	Real-time or non-real-time message

---

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#4	Command confirmation	PI	Acknowledge	actual values, metering data, etc.	PI	CONTR_1	Real-time or non real-time messages
#5	Periodical data acquisition	PI	Metering	pre-defined data-set which is sent in equidistant time instances	PI	CONTR_3	Real-time or non real-time messages
#6	Offering energy	PI	Sporadic offering execution	Send offer	PI	CONTR_2	non real-time message
#7	Reply to offer	CONTR_2	Offer reception confirmation	Send Reply	CONTR_2	PI	non real-time message
#8	Order energy	PI	Sporadic ordering execution	Send order	PI	CONTR_2	non real-time message
#9	Reply of order	CONTR_2	Order reception confirmation	Send Reply	CONTR_2	PI	non real-time message
#10	Maintenance	PI	Sporadic Maintenance Announcement	Send Maintenance Information	PI	CONTR_4	non real-time message
#11	Reply to Maintenance	CONTR_4	Information reception confirmation	Send Reply	CONTR_4	PI	non real-time message

5.4.2.1.3 Post-conditions and Significant Results

Actor/Activity	*Post-conditions Description and Results*
	See description above

5.4.2.2 Architectural Issues in Interactions

Future use

5.4.2.3 Diagram

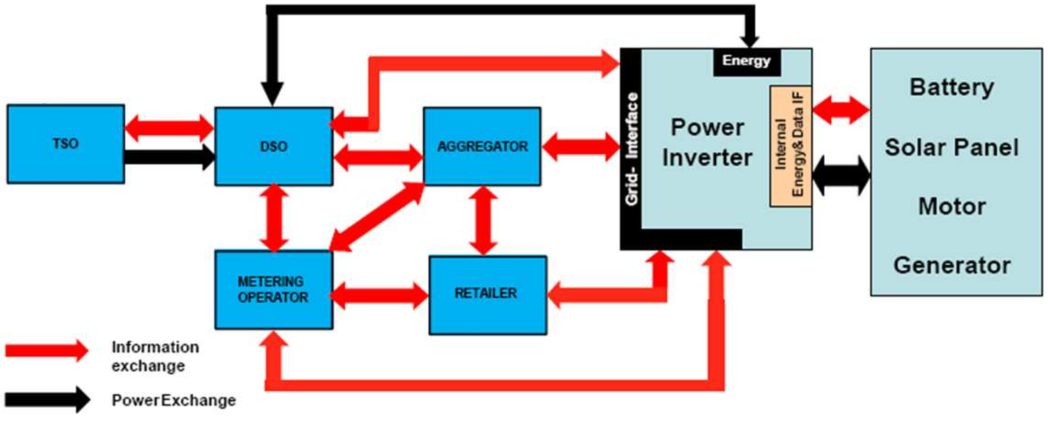


Figure 14 - SGEC architecture

<u>Note:</u> In general all the shown information paths exist. However, in case of a concrete application (power, farm-technology...) and under consideration of country specific legal situations only one relevant communication path is selected and used for controlling the power inverter, resp. the inverter cluster. Acknowledgements and information can be sent to multiple recipients.

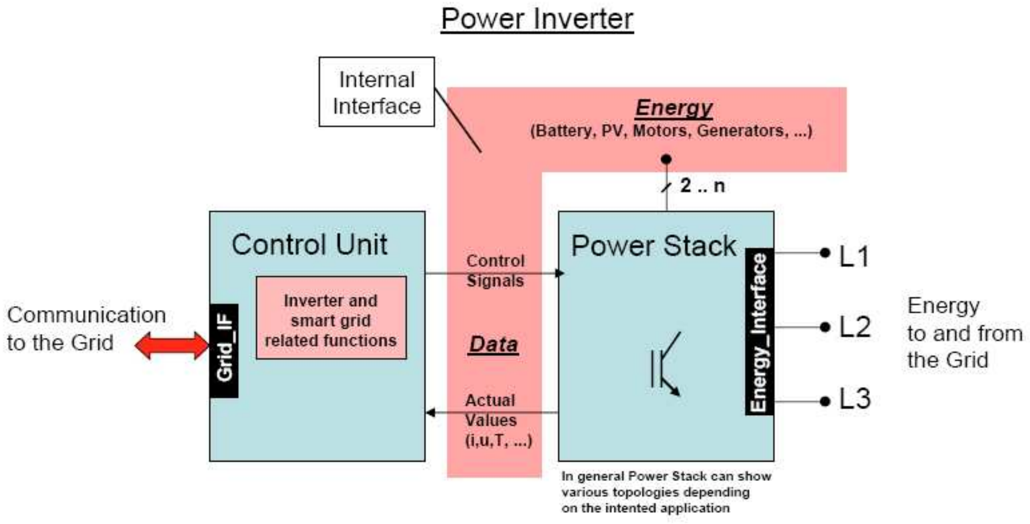


Figure 15 - High Power Inverter architecture

5.5 Dynamic Control of Active Components (DCAC) building block (UC)

5.5.1 Descriptions of Function

5.5.1.1 Function Name

Dynamic Control of Active Components

5.5.1.2 Function ID

DCAC

5.5.1.3 Brief Description

This building block (UC) covers the dynamic control (performed automatically) of distributed active network components on substation level.

Distributed Energy Resources (DER), including Distributed Generation (DG), storage and Demand Side Management (DSM), as well as controllable power system equipment such as load tap changers, switched capacitor banks and FACTS devices represent Active Components within a Distribution Network.

The dynamic control to be applied at substation level shall ensure stable and energy efficient network operation. The substation/DSO shall communicate the grid service requirements to the Aggregator. Negotiation takes place between the Aggregator and the DER regarding the current capabilities for services as part of already agreed contracts. After negotiating the applicable conditions, the substation shall be informed and may control the (controllable) distributed units so they provide the agreed service or, as in case of DSM, request the Aggregator to send incentive signals to the building's energy management system in order to motivate a shift of energy usage.

In summary, the following main actions are involved:

- The substation/DSO communicates the grid service requirements to the Aggregator.
- In order to fulfill these requirements, dynamic control of the distributed active network components is performed. Depending on the equipment to be controlled, this is done either directly by the DSO or via the Aggregator.

5.5.1.4 Narrative

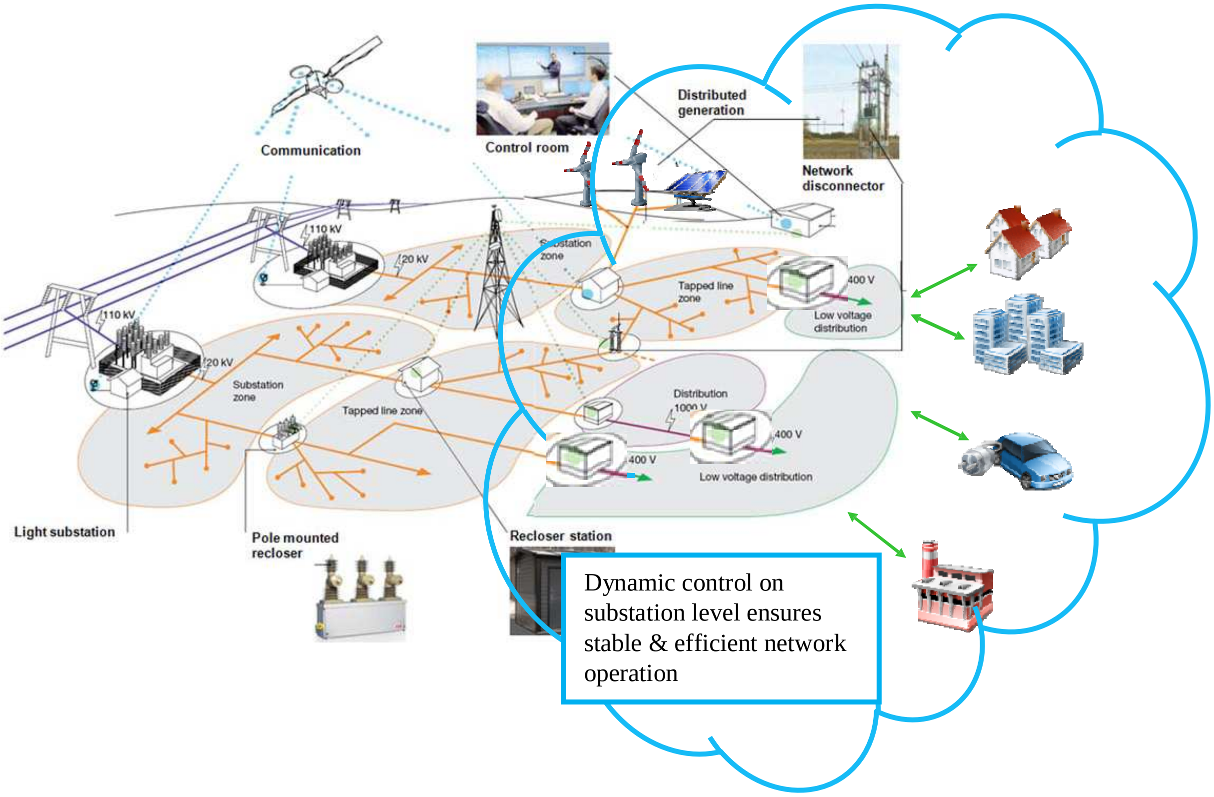
Increasing deployment of distributed generation – often with stochastic generation patterns – results in a need for coordinated control of the distribution network, capable of dealing with the arising dynamics of the network.

Since the stochastic generation cannot follow the load demand, coordinated methods to store energy as well as demand side management techniques like load shifting will lead to more efficient and stable network operation.

In addition, voltage profile changes arising due to the dispersed generation need to be addressed by locally coordinated voltage and VAr control. The DG entities shall be able to inject real as well as reactive power, which is based on the assumption that they are equipped with controllable inverters.

Also applications enabling a self-healing grid are taken into consideration, with the goal to automatically return to stable operation after critical and emergency situations.

The dynamic control of the above methods shall be performed automatically on substation level in order to balance the power flow at the lowest possible level and minimize communication (including delays and risk of data loss) to and dependence on higher network levels. Both hierarchical as well as flat (e.g. agent-based) communication architectures can be investigated for the control actions within the substation area.



Dynamic control on substation level ensures stable & efficient network operation

From FINSENY Annex I part B, Original source: ABB

Figure 16 - DCAC building block outline

As prerequisite for this building block (UC), it is assumed that the DSO has up-to-date knowledge of current and expected power flow for each substation based on both measurements and forecasts.

To obtain the current system condition, state estimation is performed on substation basis based on real-time data received from the distribution network. The data is gathered from distribution network SCADA, power inverters at DERs and complemented by data from other sources like AMI (Advanced Metering Infrastructure) devices as well as PMUs (Phasor Measurement Unit) where available.

The required monitoring to achieve this information is out of the scope of this building block (UC).

The analysis of the measurement data leading to control actions is assumed to take place within the substation and is also out of the scope of this building block (UC).

The interfaces for information and power exchange are sketched in the following figure, with the orange highlighted boxes representing the main actors of this building block (UC).

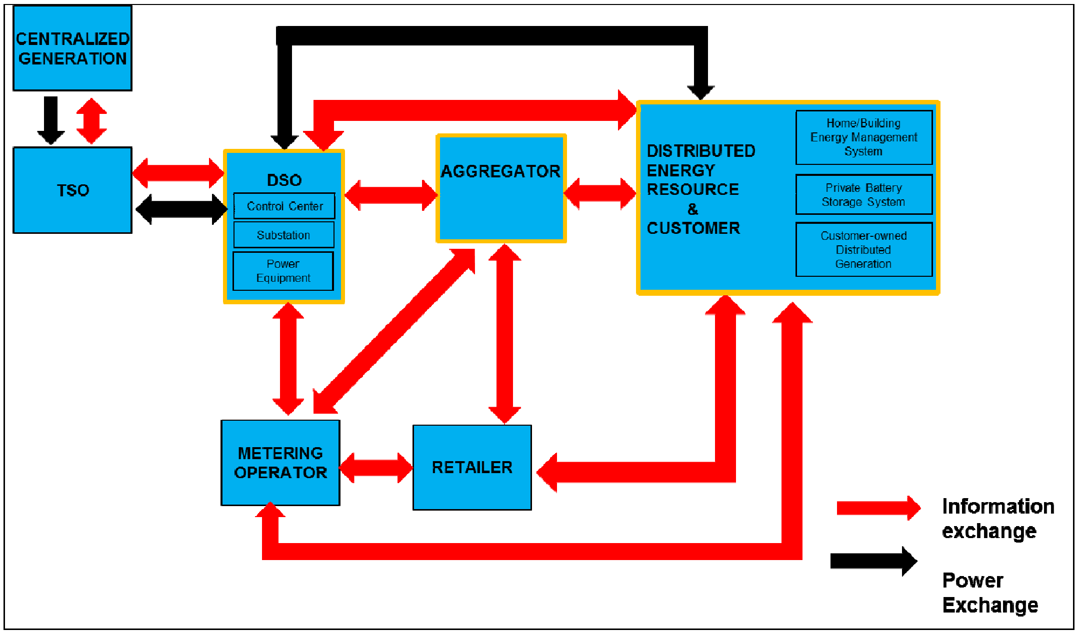


Figure 17 - Overview of roles, actors and interfaces of the building block (UC)

The customers participating in DSM services as well as the DER owners are assumed to have agreed contracts with the Aggregator to be able to offer these services to the network. This is coupled to certain incentives for the customer and DER owner. These incentives can be of very different nature, e.g. flexible tariffs for energy consumption – communicated via price signals - with the goal to achieve load shifting or compensation for active and reactive power provisioning and V2G services. For this it is assumed that metering of the consumed and produced energy is performed where required.

The feedback loop for the control function is based on continuously analyzing the monitored data.
Both the monitoring function and the analysis function are important prerequisites for this building block (UC).

Regarding SG Functionalities described in chapter 4.3, this building block (UC) is related to the following ones:

SG Functionality		Dynamic Control of Active Components
A. Enabling the network to integrate users with new functionalities	2. Better use of the grid for users at all voltages/locations, including in particular renewable generators	Coordinated integration of renewable generation. Control actions for stable network operation and ancillary services provisioning.
	3. Registers of the technical capabilities of connected users/devices with an improved network control system, to be used for network purposes (ancillary services)	Reporting of charging/discharging capabilities by distributed storage.
B. Enhancing Efficiency in day to day grid operation	6. Enhance monitoring and control of power flows and voltages	Monitoring is assumed as prerequisite for this building block (UC). Control actions are done in order to locally support stable network operation.

C. Ensuring network security, system control and quality of supply	11. Solutions to allow grid users and aggregators to participate in an ancillary services market to enhance network operation	Coordinated integration of renewable generation including demand response actions. Supporting stable network operation including provision of ancillary services.
	12. Improved operation schemes for voltage/current control taking into account ancillary services	
	13. Solutions to allow intermittent generation sources to contribute to system security through automation and control	
	16. Solutions for demand response for system security purposes in required response times	

5.5.1.4.1 Balance variations of renewable energy production

The balancing of the variations of renewable energy production due to its stochastic nature with the load demand shall be performed as much as possible by the following mechanisms:

- Use of dispatchable distributed storage, including plug-in electric vehicles (PEV)
- Load shifting as DSM method to influence the amount and time of energy usage

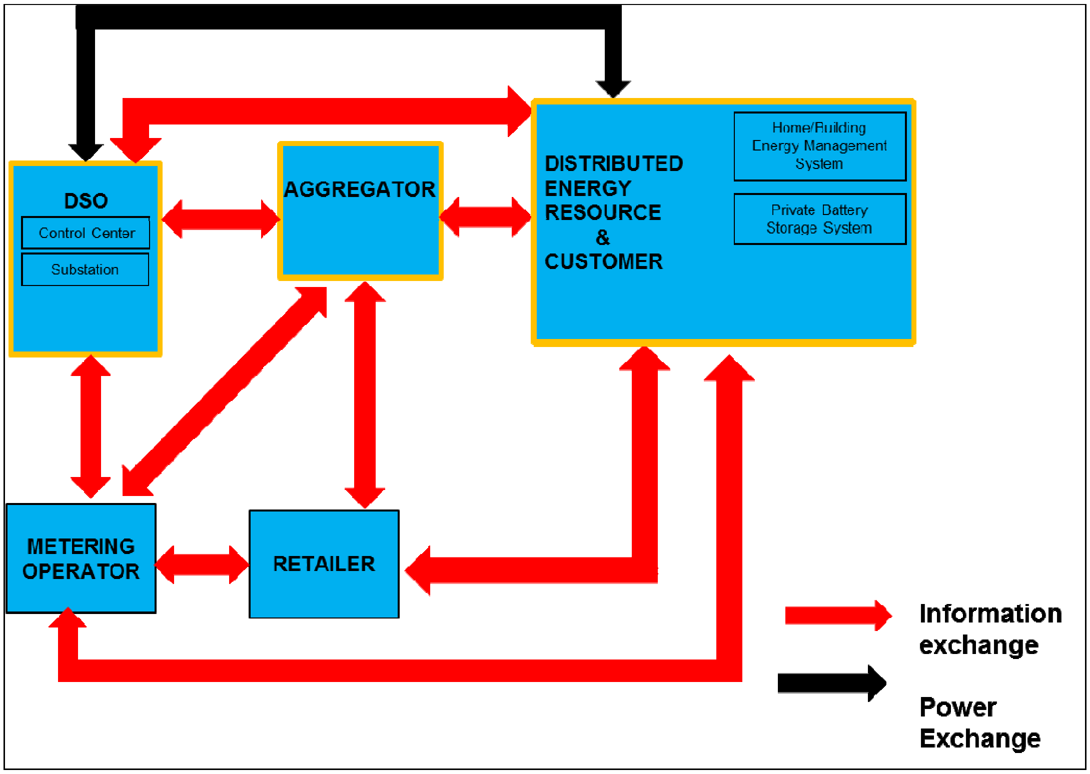


Figure 18 - Actors and interfaces of "Balance variations of renewable energy production"

The Aggregator receives information from the distributed storage systems about their current charging/discharging capabilities, triggered by either connection to the grid or certain State of Charge (SoC) thresholds being crossed. Upon request from the substation, the Aggregator sends a list of possible contributors to system services to the substation.

Based on this, the substation selects units to control either directly or via the Aggregator.

Plug-in electric vehicles can either use *immediate charging* or *smart charging/V2G*.

Immediate charging is started right away without negotiation involving the substation and is not considered in this building block (UC).

Smart charging/V2G allows for a wider timeframe depending on customer requirements. This timeframe can be used for charging and discharging according to the grid situation. V2G or charging in time-deferred or interrupted mode or at different rates is possible as long as at the end of the specified time period the battery is charged according to the user requirements.

The PEV user has an energy services contract with the Aggregator with a subscription to a special tariff scheme for grid services. Based on the time of day and duration of the grid connection, different charging tariffs (lower compared to immediate charging) and V2G compensations will apply.

Other battery storage units like e.g. batteries located at roof-top PV systems send their charging/discharging capabilities either regularly or threshold-driven to the Aggregator in order to be taken into account as storage resource.

The load shifting DSM method is assumed to run on voluntary basis, encouraged by price signals sent to the Home/Building Energy Management System at the customers' premises. Direct control DSM methods are not covered in this building block (UC). Therefore the described DSM method – purely based on price signals – is a rather soft method of control. Its results will be visible by the continuous analysis of the monitoring data.

The Aggregator will negotiate energy prices with the market for provision of ancillary services.

Requests from the DSO have higher priority compared to triggers from the market. Based on these triggers, the Aggregator can forward respective price signals to the Home/Building Energy Management

System. Both the Metering Operator and the Retailer then have to be informed about the current tariff class in order to perform proper metering and billing.

The price signals indicate a switch to a higher or lower tariff class, but do not represent a concrete energy price. The tariff classes (levels of energy prices) for the customer are assumed to be pre-agreed with the Retailer.

Upon reception of a price signal, load shifting at the customers' premises can either be performed manually or automatically in case a building energy management system is present. The required decisions and actions for the building internal handling are out of the scope of this building block (UC).

5.5.1.4.2 Local Volt/VAr/Watt optimization

Within the substation area, the voltage profile – dynamically changing due to the stochastic production of the distributed renewable energy generators – shall be optimized locally.

- Reactive and active power injection by distributed renewable generators. The (or parts of the) distributed generators are assumed to be able to control their reactive power injection.
- Control of deployed power equipment like load tap changers, voltage regulators, switched capacitor banks and FACTS devices.

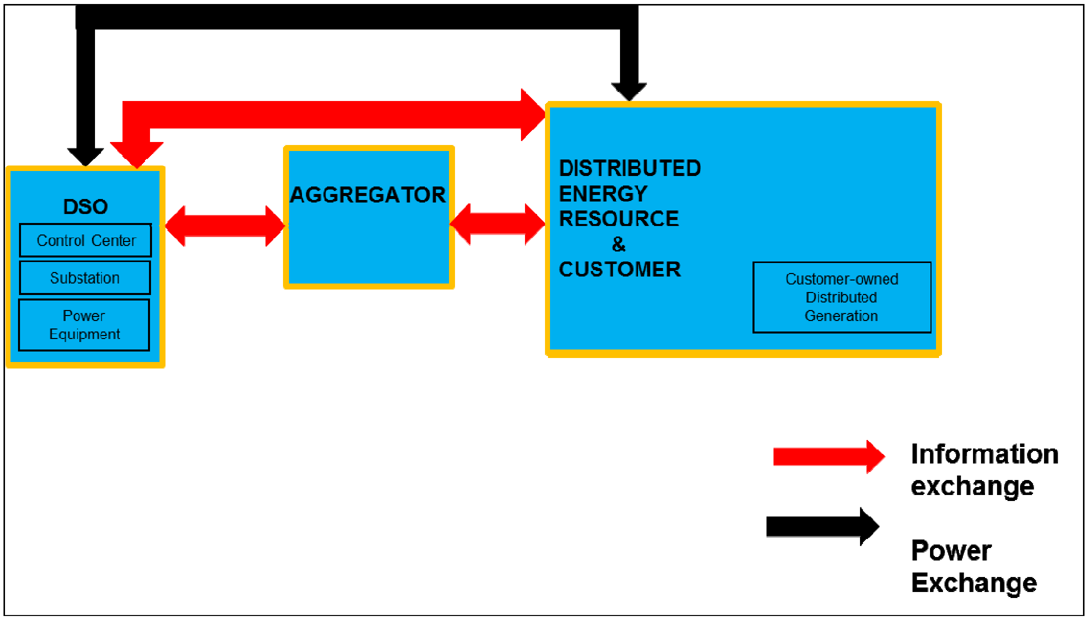


Figure 19 - Actors and interfaces of "Local Volt/VAr/Watt optimization"

Also for the case of DERs, information about the current capabilities is provided to the Aggregator before offering a list of potential contributors to the substation.

The Local Volt/VAr/Watt optimization application as presented here is an adapted version of the function described in reference [4], The application is capable of supporting the following objectives, which can be changed at different times following present scenarios, operator requests, or other application triggers:

- Minimize kWh consumption at voltages beyond given voltage quality limits (i.e., ensure standard voltages at customer terminals)
- Minimize feeder segment(s) overload
- Reduce load by a given value while respecting given voltage tolerance (either normal, or emergency)
- Conserve energy

- Provide reactive power support for distribution bus
- Minimize cost of energy
- Reduce energy losses
- Provide compatible combinations of above objectives

This application is constraint by the following limits:

- Loading limits of model elements
- Voltage limits at the equivalent customer terminals
- Voltage limits in selected point of distribution primaries, including the distribution bus of the substation
- Reactive power or power factor limits at selected busses
- Capability limits of distributed energy resources
- Operating reserve limits
- Limits of controllable devices: Load Tap Changer (LTC) limits, Voltage regulator limits, Capacitor control limits, Distributed generation control limits, Power electronics limits

This Local Volt/VAr/Watt optimization application calculates in a coordinated manner across the substation area the optimal states of the following controllable devices: Voltage controller of LTCs, Voltage regulators, DG controllers, Switched Capacitor controllers.

In general, the application can support three modes of operation as presented in reference [4] :

1. Closed-loop mode, in which the application runs periodically (e.g., every 15 min) or is triggered by an event (i.e., topology or objective change or alarm message), based on real-time information. The application's recommendations are executed automatically via control commands.
2. Study mode, in which the application performs "what-if" studies, and provides recommended actions to the user.
3. Look-ahead mode, in which conditions expected in the near future can be studied (from one hour through one week) by the user.

However, for the purpose of this building block (UC), only the closed-loop mode is considered, having the most impact on ICT requirements. The feedback loop is realized by the continuous analysis of monitored field data.

The application shall be based on dynamically changed behavioral models of the real and reactive load and power flow models derived from measurements.

The application shall be able to include the controllable power equipment and DG variables and issue corresponding signals to these variables in the closed-loop control sequences.

If during optimization or execution of the solution, the circuit status changes, the application is interrupted and the solution is re-optimized. If, during execution, some operations are unsuccessful, solution is re-optimized without involving the malfunctioning devices. If some of the controllable devices are unavailable for remote control, solution does not involve these devices but takes into account their reaction to changes in operating conditions.

The analysis part of this function is not detailed in this building block (UC) and is assumed as prerequisite to take place locally within the substation. This building block (UC) elaborates on the control actions derived from the analysis function.

As part of the coordinated analysis within the substation, suitable devices for control actions are selected. After any change of equipment state, whether due to substation request or due to local automatic action, the substation is notified about the new state or operating point, including the information on available regulation range.

5.5.1.4.3 Distribution Network Control for the Self-healing Grid (SHG)

The objective of the SHG applications is to evaluate distribution network behavior in real-time, prepare the distribution network for withstanding credible combinations of contingencies, prevent potential wide-area blackouts, and accommodate fast recovery from emergency state to normal state.

The Self-healing Grid function presented here is based upon reference [4], adapted to fit the needs of the distribution network.

The SHG function comprises a set of computing applications for information gathering, modeling, decision-making, and controlling actions. These applications reside mostly in distributed systems, such as relay protection, remedial automation schemes (RAS), local controllers, and other distributed intelligence systems. All these applications and system components operate in a coordinated manner and adapt to the actual situations.

The conventional methodology for emergency control is based on off-line studies for selection of the local emergency automation schemes, their locations, and their settings. Such off-line studies are usually performed for selected operating conditions based on typical cases and on previous emergencies. However, the design of remedial actions and emergency automation schemes based on previous emergencies may be ineffective for the future emergencies. In reality, the emergency situations often occur under conditions that are quite different from the study cases. With the advent of deregulation, the energy schedules are derived from financial considerations rather than strictly power operations considerations. Therefore, the types of possible contingencies increase substantially, and it would be very difficult to study with purely off-line analysis. Not only are there increased pressures from deregulation, there are new challenges imposed by the involvement of distributed devices and customers in preventing and responding to distribution network emergencies. For instance, with the increased number of distributed energy resource (DER) devices connected to the distribution system, distribution operations have to expand to monitor and manage (if not actually control) these DER devices. The advances of Distribution Management Systems (DMS) and Advanced Distribution Automation (ADA) make these systems available for real-time coordination of operations in normal, emergency, and restorative states of the system.

The SHG will be supported by fast data acquisition systems and will include fast simulation and decision-making applications. These distributed applications will coordinate the behavior of distributed control systems (distributed Control Centers, DMS, DER Control system, RAS, and relay protection). These distributed systems and actuators will perform adequately fast after critical and emergency situations following the rules and settings preset by the simulation and decision-making applications. Local actuators can be integrated into distributed intelligence schemes and can communicate among themselves in a peer-to-peer manner. The rules of behavior of the distributed intelligence schemes can be preset by the DSO control system.

The future control system for the self-healing grid will differ from the current approaches by implementing significantly more automated controls instead of supervisory controls by the operators and by aiming at preservation of adequate integrity of the future distribution system instead of self-protection of equipment only.

ICT requirements for such applications are almost identical to the building block (UC) presented in this section and hence we omit a detailed analysis of such applications.

5.5.1.5 Actor (Stakeholder) Roles

Grouping Community		Group Description
Balance variations of renewable energy production		This function collects all the activities related to the balancing of (stochastically) distributed energy production and load.
Actor Name	Actor Type (person, device, system)	Actor Description
Substation	System	Primary or secondary substation. Performs state estimation based on real-time measurement data. Derives control actions from analysis of power flow situation.

DSO	System	Distribution System Operator, owns Substations.
Control Center	System	Distribution System Control Center, participates in price negotiations with Aggregator and/or market
Customer	Person	Residential or small business energy user that has a contract with the Aggregator and Retailer for price-signal based provision of energy. (Can also be DER owner).
DER owner	Person	Owner of Distributed Energy Resource (generation and/or storage). (Can also be Customer).
Private Battery Storage System	System	Customer-owned storage and charging system that allows control by the DSO (as per contractual agreements). Examples: - Batteries installed at roof-top PV systems - Plug-in electric vehicles (PEV) when connected to a charging station
Home/Building Energy Management System	Device	Communication interface at the customer home network to allow for use of price signals for customer to decide on load shifting.
Aggregator	System	Aggregators offer (sell) energy and flexibilities for the use of the other electricity system players. There can be contract agreements between aggregators and Distributed Energy resources & Customers.
Market	System	Following market rules, energy price is calculated and physical and financial transactions are made. Owing specific issues of Energy, normally, there are day-ahead transactions and then a several intraday transactions in order to maintain stability.
Metering Operator	System	Role which offers services to provide, install and maintain metering equipment as well as services to measure consumption and generation of energy.
Retailer	System	Entity selling electrical energy to consumers.
Grouping Community		Group Description
Local Volt/VAr optimization		This function collects all the activities related to the local optimization of the voltage profile.
Actor Name	Actor Type (person, device, system)	Actor Description
Substation	System	Primary or secondary substation. Performs state estimation based on real-time measurement data. Derives control actions from analysis of power flow situation.

Control Center	System	Distribution System Control Center: Monitoring and performing the optimization for the overall distribution network
Aggregator	System	Aggregators offer (sell) energy and flexibilities for the use of the other electricity system players. There can be contract agreements between aggregators and Distributed Energy resources & Customers.
DER owner	Person	Owner of Distributed Energy Resource (generation and/or storage). (Can also be Customer).
Customer owned Distributed Generation System	System	Distributed Generation System at customer premise. Includes inverters for controllable reactive power injection.
Power Equipment	Device	Equipment which directly operates on the Power System, including e.g.: - Load tap changers (LTC) - Switched Capacitor banks - FACTS devices - Voltage Regulator Controllers

5.5.1.6 Information exchanged

Information Object Name	Information Object Description
Notification	Digitalized information that can be a list of information items or an event notification, e.g. - Charging and storage capabilities - Price signal update - PEV disconnection
Request	Digitalized message requesting a particular task, e.g. - Smart charging - Price signal update - Market price negotiation
Answer	Digitalized message answering a request, e.g. - Charging and V2G capabilities - Market price negotiation
Command	Digitalized message to order a concrete action, e.g. - Start/stop charging - Start/stop discharging

5.5.1.7 Activities/Services

Activity/Service Name	Activity/Service provided
Availability of contribution to network services	Identify what entities can contribute to network services including their constraints.
Energy storage	Energy is stored in a distributed battery system.
Energy retrieval	Energy is retrieved from a distributed battery system.
DSM triggering	Upon request by DSO or triggered by price negotiation with the Market, a price signal is sent from the Aggregator to the Home/Building Energy Management System to encourage shifted power consumption.
Price negotiation	Price negotiation takes place between Market and Aggregator.
Voltage adjustment	Voltage regulating devices are triggered to adjust to requested set points.
VAr adjustment	VAr regulating devices are triggered to adjust to requested set points and modes.
DG control	Distributed Generation Systems are controlled with respect to requested active and reactive power injection.

5.5.1.8 Contracts/Regulations

Contract/Regulation	Impact of the Contract/Regulation on Function
Contracts regarding provision of ancillary services	Required contracts between the following actors: • DER Owner of Private Battery Storage System – Aggregator • Customer with Home/Building Energy Management System – Aggregator
Contracts regarding provision of active & reactive power	Required contracts between the following actors: • DER Owner of Distributed Generation – Aggregator
Standard contract for energy delivery	Required contracts between the following actors: • Customer – Retailer • Retailer – Metering Operator • Customer – Metering Operator
Market involvement	Negotiations to take place between: • Aggregator –Market • Retailer - Market
DSO regulation	The DSO is a regulated entity that is paid (following regulated basis) for the distribution services it delivers.

5.5.2 Step by step Analysis of Function

The numbering of the sequence steps conveys the order and concurrency and iteration of the steps occur. Using a Dewey Decimal scheme, each level of nested procedure call is separated by a dot '.'. Within a level, the sequence number comprises an optional letter and an integer number.

The letter specifies a concurrent sequence within the next higher level; all letter sequences are concurrent with other letter sequences. The number specifies the sequencing of messages in a given letter sequence. The absence of a letter is treated as a default 'main sequence' in parallel with the lettered sequences.

5.5.2.1 Steps for Function “Balance variations of renewable energy production”

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1A	Battery available for grid use, triggered by SoC threshold crossed	Private Battery Storage System	Battery Charging and Discharging availability	The Aggregator is informed about the current capabilities of the battery system, either for charging or discharging use for the network. The information includes the offered timeframe and required SoC at the end of this timeframe.	Customer	Aggregator	Notification (Charging and Storage Capabilities)
1A.1B	PEV plugged in at charging station	Private Battery Storage System	PEV Charging and V2G availability	Via the charging station, the information on charging and/or V2G availability is submitted. The information includes current capabilities in terms of charging rate, maximum storable/retrievable energy as well as time constraints.	Customer	Aggregator	Notification (PEV availability with charging and storage capabilities)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1B.1A	PEV requests smart charging	Private Battery Storage System	Smart charging request	Via the charging station, the request for smart charging is submitted. This includes the time constraints as well as the required SoC at the end of the time interval.	Customer	Aggregator	Request (smart charging)
1A.1B.2A	Plugged-in PEV requested smart charging	Aggregator	Smart charging required	The DSO/substation is informed that charging of an individual PEV has to be scheduled within given conditions. (When scheduled, continue with 1A.1C.2A.1A)	Private Battery Storage System	Substation	Request (PEV charge request)
1A.1B.1B	PEV disconnected from charging station	Private Battery Storage System	Disconnection of PEV	Via the charging station, the information on disconnection of a PEV is submitted.	Customer	Aggregator	Notification (PEV disconnection)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1C.1A	Requirement for energy storage or delivery detected	Substation	Request charging and storage candidates	The substation requests information on connected charging systems including their charging and storage capabilities.		Aggregator	Request (Charging and storage candidates list)
1A.1C.2A		Aggregator	Forward charge and storage capabilities	The Aggregator compiles a list of charging systems with their current capabilities and forwards to Substation. Examples of capabilities: E.g. information that charging of an individual PEV has to be scheduled within given conditions. Or information on V2G capabilities incl. timeframe.		Substation	Answer (Charging and V2G capabilities)
1A.1C.2A.1A		Substation	Start Charging Command	The Substation selects an available Private Battery Storage System and sends charging command to this unit.		Private Battery Storage System	Command (Start Charging)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1C.2A.1A.1A	PEV is disconnected during charging or highest allowed SoC is reached	Private Battery Storage System	Stop Charging by storage system	Charging is stopped automatically by Storage system when highest allowed SoC is reached or in case of PEVs also when PEV is disconnected.	Customer	Substation	Notification (Stop Charging by storage system)
1A.1C.1B	Requirement for energy storage cancelled	Substation	Stop Charging by Substation	Charging is stopped by Substation		Private Battery Storage System	Command (Stop Charging)
1A.1C.2A.2A	Charging process stopped	Substation	Inform about completed charging process	The Substation informs the Aggregator about the total kWh delivered to storage system including the time of day.		Aggregator	Notification (Charging information)
1A.1C.2A.1B		Substation	Start Discharging Command	The Substation selects an available Private Battery Storage System and sends discharging command to this unit.		Private Battery Storage System	Command (Start Discharging)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1C.2A.1B.1A	PEV is disconnected during discharging or lowest allowed SoC is reached	Private Battery Storage System	Stop Discharging by PEV	Charging is stopped automatically by Storage system when lowest allowed SoC is reached or in case of PEV also when PEV is disconnected.	Customer	Substation	Notification (Stop Discharging by PEV)
1A.1C.2A.1B.1B	Requirement for energy retrieval cancelled	Substation	Stop Discharging by Substation	Discharging is stopped by Substation		Private Battery Storage System	Command (Stop Discharging)
1A.1C.2A.2B	Discharging process stopped	Substation	Inform about completed discharging process	The Substation informs the Aggregator about the total kWh retrieved from storage system including the time of day.		Aggregator	Notification (Discharging information)
1A.1D.1A		Aggregator	Market price negotiation	The prices for provision of balancing services are negotiated between Market and Aggregator		Market	Request (Market Price Negotiation – bid)
1A.1D.2A		Market	Market price negotiation	The prices for provision of balancing services are negotiated between Market and Aggregator		Aggregator	Answer (Market Price Negotiation - answer)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1C.1B	Requirement for energy consumption or conservation detected	Substation	Request DSM triggering	The Aggregator is requested to pass on price signals to the customer. These price signals shall either encourage or discourage energy consumption depending on DSO requirement.		Aggregator	Request (price signal update)
1A.1C.2B		Aggregator	Acknowledge reception of DSM request	The Aggregator acknowledges the reception of the request for DSM triggering.		Substation	Notification (ACK)
1A.1C.3B		Aggregator	Send price signal	The Home/Building Energy Management System receives an updated price signal from Aggregator. (Based on either request from DSO or result of market price negotiation.)	Substation	Home/Building Energy Management System	Notification (Price Signal Update)
1A.1C.4B		Home/Building Energy Management System	Acknowledge price signal	The Home/Building Energy Management System acknowledges reception of price signal.		Aggregator	Notification (ACK)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1A.1C.5B		Aggregator	Send price signal information	The Aggregator informs the Retailer about the sent price signal.	Substation	Retailer	Notification (Price Signal Update)
1A.1C.5B		Retailer	Acknowledge price signal information	The Retailer acknowledges reception of price signal information.		Aggregator	Notification (ACK)
1A.1C.6B		Retailer	Send tariff information	The Retailer informs Metering Operator about the current tariff.	Substation	Metering Operator	Notification (Tariff Update)
1A.1C.7B		Metering Operator	Acknowledge tariff information	The Metering Operator acknowledges reception of tariff information.		Retailer	Notification (ACK)

5.5.2.2 Steps for Function Local Volt/VAr optimization

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.1A	Periodic event	Control Center	Measurement information	Provide periodic information on collected measurements to be used for optimization process within substation		Substation	Notification (Measurement results)
1B.2A	Periodic event	Substation	Device state information	Provide periodic information on states and set points of the power equipment		Control Center	Notification (Device state information)
1B.1B	Voltage change requirement as result of analysis	Substation	Voltage change request	Request to selected load tap changer or voltage regulator to disable local automatic regulation and switch to new set point.		Power equipment (LTC, voltage regulator)	Command (disable local automation, new set point)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.2B		Power equipment (LTC, voltage regulator)	State and set point information	Inform about changed state and new set point. Includes information on available regulation range. This notification is sent both after changes upon substation request or due to local automatic regulation. In case of unsuccessful control attempt, this is reported.		Substation	Notification (state change, new set point or unsuccessful attempt)
1B.3B		Substation	Enable local automatic regulation	When analysis function determines that local automatic regulation of the power equipment shall be used again, it is enabled.		Power equipment (LTC, voltage regulator)	Command (enable local automation)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.1C	Reactive power change requirement as result of analysis	Substation	VAr change request	Request to selected Switched Capacitor Banks or FACTS devices to disable local automatic regulation and switch to new set point. For FACTS devices a different mode of operation can be requested.		Power equipment (Switched Capacitor Banks,, FACTS devices)	Command (disable local automation, new set point and mode)
1B.2C		Power equipment (Switched Capacitor Banks,, FACTS devices)	State and set point information	Inform about changed state and new set point and mode. Includes information on available regulation range. Required both after changes upon substation request or due to local automatic regulation. In case of unsuccessful control attempt, this is reported.		Substation	Notification (state change, new set point and mode)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.3C		Substation	Enable local automatic regulation	When analysis function determines that local automatic regulation of the power equipment shall be used again, it is enabled. FACTS devices are returned to steady-state mode.		Power equipment (Switched Capacitor Banks,, FACTS devices)	Command (enable local automation)
1B.1D	Periodic event	Customer owned Distributed Generation System		The Aggregator is informed about the current capabilities of the distributed generation system with regards to active and reactive power injection.		Aggregator	Notification (DG power capability)
1B.1E	Active and reactive power change requirement as result of analysis	Substation	Request DG power injection capabilities	The substation requests information on active/reactive power injection capabilities of connected distributed generation.		Aggregator	Request (DG power capability)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.2E		Aggregator	Forward DG power injection capabilities	The Aggregator compiles a list of distributed generation systems with their current capabilities and forwards to Substation. The information provided reflects the current capabilities of active and reactive power injection.		Substation	Answer (DG power capability)
1B.3E		Substation	Request DG power injection	The Substation selects a distributed generation system and sends power command to this unit indicating requested level of active and reactive power injection.		Customer owned Distributed Generation System	Command (power injection)

#	Event	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
#	Triggering event? Identify the name of the event	What other actors are primarily responsible for the process/Activity	Label that would appear in a process diagram. Use action verbs when naming activity	Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step	What other actors are primarily responsible for Producing the information?	What other actors are primarily responsible for Receiving the information?	Name of the information object.
1B.4E		Customer owned Distributed Generation System	Acknowledge DG power injection	The Distributed Generation System acknowledges reception of power injection command and controls the power injection accordingly. The adapted power injection values are included in the notification.		Substation	Notification (power injection)

6. References

[0] General FINSENY Glossary of Terms v2.2

[1] EU Commission Task Force for Smart Grid. Expert Group 1: Functionalities of Smart Grids and Smart Meters

[2] Smart Grid Mandate M/490

[3] Intelligrid Use Case Template. http://www.smartgrid.epri.com/doc/IntelliGrid_Use_Case_Template.doc

[4] Distribution Grid Management (Advanced Distribution Automation) Functions Building block (UC) Description, EPRI, Intelligrid Project, February 2010

7. Glossary

This document uses the terms included in the general FINSENY Glossary and Terms [0].