Distributed Intelligence in Critical Infrastructures for Sustainable Power

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Requirements Specifications of Intelligent ICT Simulation Tools for Power Applications

Business, application and ICT technology requirements for tools

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Overview:	**From business, application and ICT dimensions, the requirements for tools for supply and demand matching, intelligent load shedding and fault detection are described.**

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Acronyms and Abbreviations

APX	Amsterdam Power Exchange
CHP	Combined Heat Power
CRISP	Distributed Intelligence in Critical Infrastructures for Sustainable Power
DG	Distributed Generation
DNO	Distribution Network Operator
DSM	Demand Side Management
ESCO	Energy Service Company
EPS	Electric Power System
FDD	Fault Detection and Diagnostics
FPI	Fault Path Indicator
HV	High Voltage
ICT	Information and Communication Technology
ILS	Intelligent Load Shedding
J2EE	Java® 2 Platform, Enterprise Edition
J2ME	Java® 2 Platform, Micro Edition
MV	Medium Voltage
OCL	Object Constraint Language
OSGi	Open Services Gateway initiative
PS	Power System / Power Supply
RES	Renewable Energy Systems
SCADA	Supervisory Control and Data Acquisition
SDM	Supply and Demand Matching
SO	Service Oriented
TSO	Transmission System Operator
UML	Unified Modeling Language

Executive summary

This report, deliverable D2.1 in the CRISP project, serves as a preparation report for the development of simulation tools and prototype software which will be developed in forthcoming stages of the CRISP project. Application areas for these simulations are: fault detection and diagnosis, supply and demand matching and intelligent load shedding. The context in which these applications function is the power network with a high degree of distributed generation, including renewables.

In order to control a so called distributed grid we can benefit from a high level of distributed control and intelligence. This requires, on top of the power system network, an information and communication network.. We argue that such a network should be seen as an enabler of distributed control and intelligence. The applications, through which control and intelligence is implemented, then form a third network layer, the service oriented network.

Building upon this three-layered network model we derive in this report the requirements for a simulation tool and experiments which study new techniques for fault detection and diagnostics and for simulation tools and experiments implementing intelligent load shedding and supply and demand matching scenarios. We also look at future implementation of these services within the three-layered network model and the requirements that follow for the core information and communication network and for the service oriented network. These requirements, supported by the studies performed in the CRISP Workpackage 1, serve as a basis for development of the simulation tools in the tasks 2.2 to 2.4.

1. Introduction

The following descriptions from the CRISP Annex I - "Description of Work" give the general scope and goal of workpackage 2 and the task to be performed in workpackage 2.1 of the CRISP project on Distributed Intelligence in Critical Infrastructures for Sustainable Power.

"WP2: Intelligent distributed ICT developments and tools for power application" focuses on development of distributed intelligence ICT requirements, specifications, simulation tools and prototype software for the scenarios and strategies of the WP1 and the associated experiments and tests of WP3. Business, application and ICT requirements are defined, a multi-agent based simulation tool for market-oriented distributed demand-supply matching is developed as well as a simulation tool for fault detection and diagnostics and for decision support for network security models. Electronic markets and intelligent agent algorithms and architectures for power applications will be investigated and defined.

The objective of the total work package WP2 can be formulated as follows:
To develop the distributed intelligence ICT requirements, specifications, simulation tools and prototype software for the scenarios and strategies of WP1 and the associated experiments and tests of WP3.

In **WP 2.1 Business, application and ICT technology requirements for tools**, from dimensions business, application and ICT technology dimensions, the requirements for tools are derived. The ICT-node network and the power delivery node network have different requirements for distributing data and exchanging messages optimally. The tools to develop do have to be able to deal with handling dynamically configuration settings as needed in case of self-healing when facing a failure and when reconfiguration is needed for cost optimisation or for favouring the usage of renewables.

ICT-enabled solutions require a change in focus from the power network to the information and communication (ICT) network and the application area, which is represented by a service network through which distributed and intelligent applications can be deployed. Chapter 2 gives an introduction on this three-layered network approach.
Chapter 3 gives a characterisation of the three application areas to be studied: Fault Detection and Diagnosis, Supply and Demand Matching and Intelligent Load Shedding. Although the scenarios in Workpackage 1 and the experiments in Workpackage 3 are not completely worked out yet at the time of delivery of this report, the main characteristics of these scenarios and experiments have been described in order to derive the basic requirements for the simulation software.
Chapters 4 to 6 go into more detail on the three-layered network and describe the consequences for the power network when large scale distributed generation comes into play, and the way in which the ICT network and the service network could and should be utilised in order to enable intelligent and distributed control of the power network. This leads to requirements for the ICT and the service networks.
The report concludes with a short resume of the main requirements and some remarks on architectural implementation issues for distributed applications, which are not directly of concern in the simulations and experiments, but may be of use in a follow-up project.
In the Annexes 2 and 3 some background can be found on typical ICT-related issues: standardisation efforts within the distributed information network and the Model Specification Methodology UML.

2. Setting the scene

ICT services and ICT networks are essential for operating the future power grid with a high penetration of distributed generation units. In order to discriminate between the different areas we distinguish the following three network layers: the Power System (PS) Node network, the Information and Communication (ICT) node network and the Service Oriented (SO) Node network. Figure 1 depicts these three different system layers in our approach.

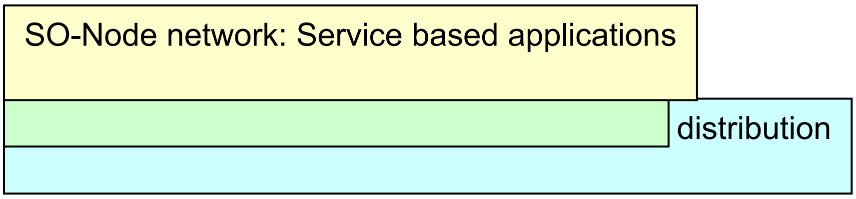

Figure 1 The different system layers of our approach

The PS-node network consists of the power delivery infrastructure, including producers and consumers. The network consists of hardware, including existing dedicated ICT systems for operation and control.
The ICT-node network is also a hardware network, which enables free information flows between the network nodes, supports local intelligence at each node, and is built upon the PS-node network. The ICT-node network is an enhancement of the dedicated operation and control systems within the PS-node network.
The SO-node network is a functional network, which consists of the software components which together constitute one or more services or applications that control the PS-node network through the ICT-node network. The location of these processes in the network is of later concern.

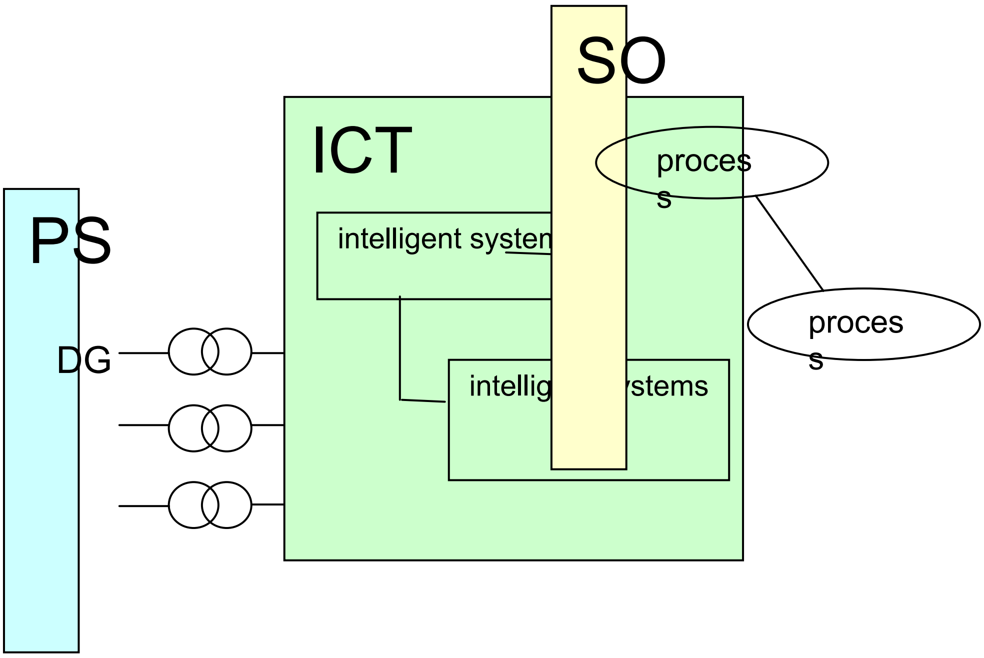

Figure 2 Three network layers from different point of views

In Figure 2 these three layers are shown with their own 'processes'.

Figure 3 , Figure 4 and Figure 5, adapted from a CRIS[1] presentation, capture different views of the future Power grid – ICT systems referred to in the introduction above. The main characteristics addressed are future cell-based distribution networks, a transition diagram from passive networks towards active networks, and a system view on the dependability between the ICT-node and the SO-node networks.

The power grid itself can be organised as a cell-based distribution network, which consists of hierarchies (Middle Voltage or MV and High Voltage or HV) of generation-distribution cells (Figure 3). This network of generation-distribution cells constitutes the Power System Node network, or PS-Node network. Supporting the necessary information flow to facilitate the proper operations of the PS-Node network we have a communication infrastructure, the ICT-Node network. The interaction between the cells within the PS-Node network is handled by a collection of service based applications, the SO-Node network. The SO-Node network is further described in Section 5.

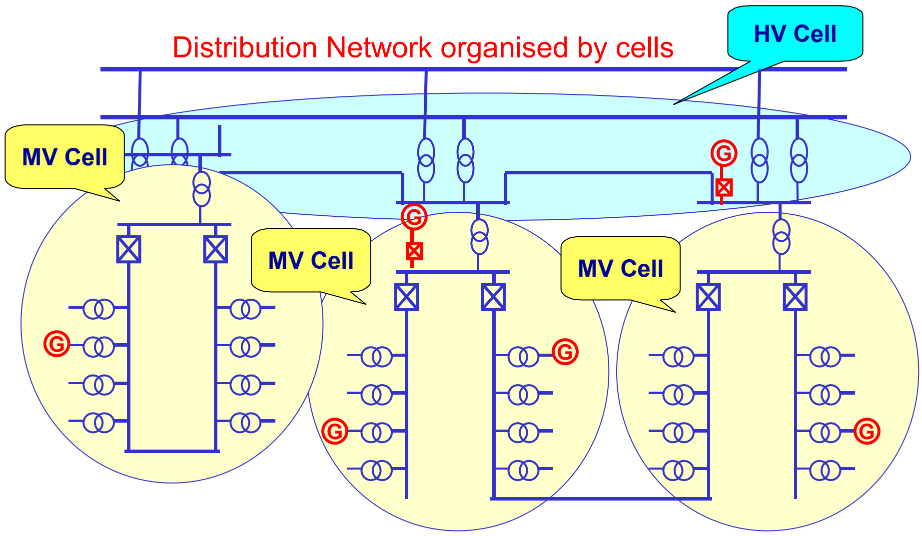

Figure 3. A cell-oriented view of next generation generation-distribution PS-Node networks

The successful operation of a future cell-based power grid, as depicted in Figure 3, poses several challenges, technical as well as economical. Figure 4 indicates some of these challenges involved in the transition from a 'Passive network' towards an 'Active network'. Through this transition we are able to organise the generation-distribution cells such that they interact in an optimal way to meet supply-demand conditions

[1] CRIS AB The International Institute for Critical Infrastructures: www.cris-inst.com

A key transition of focus, in Figure 4, is from 'energy value/kWh' towards 'Information value/ kWh'. That is, an increasing dependence on information collection, distribution, processing and management. This explicit utilisation of information is a corner stone to meet the requirements for the services under study in this report.

The transition in Figure 4 is based on the shift in the power system due to introduction of distributed generation. The shift is from 'emphasis on a capacity distribution grid' towards 'emphasis on flexible control of the distribution grid'. The shift is not initiated or imposed on the market by the utility companies but is necessary as a reaction upon the introduction on a large scale of small capacity generation, a.o. by renewable sources.
Utilities and network operators are forced to respond to this shift. A more flexible distribution network control is needed. Thus a shift is also made from 'value / kWh' towards 'value / information'. For energy trading the value will mainly be financial profit. For utilities and network operators the value is more complex: energy quality, network operation and control, and maintenance efficiency.
The issues captured in Figure 3 and Figure 4 will be further addressed in Chapter 4, especially in paragraphs 4.3 and 4.5.

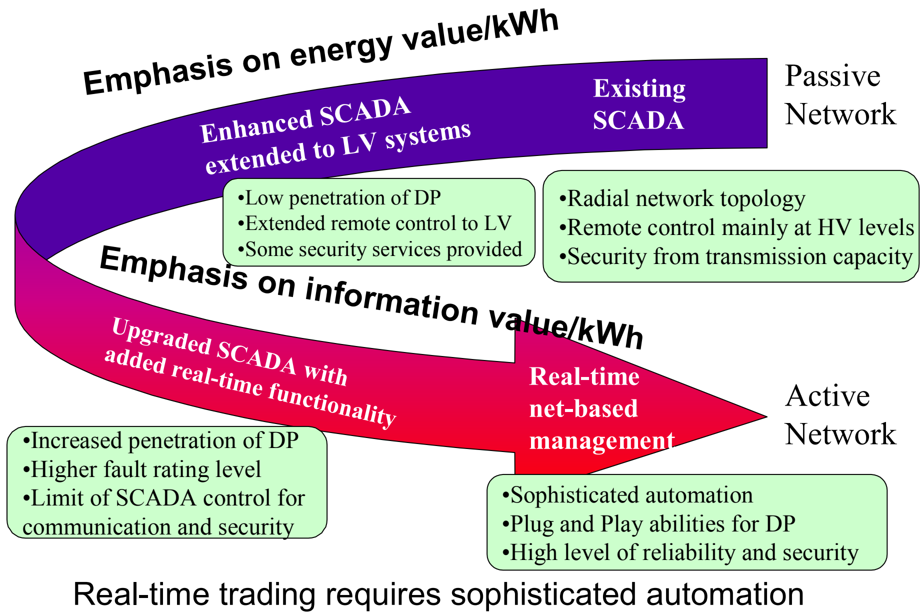

Figure 4. Next generation of cell based generation and distribution networks. A transition from passive networks towards active networks

The increased openness of the systems and their associated information flow also poses new challenges related to security and resilience, i.e., dependability issues. The structure of the information systems and its interactions with the power systems have to be addressed in an appropriate way. Figure 5, captures some major issues to that end. It also captures the dependencies between the ICT-Node and SO-Node networks.

We have in Figure 5 *dependable components* and *dependable interactions* between components. Historically, most efforts have been devoted to dependable hardware components. Due to the increasing importance of embedded *Ambient Intelligent* systems efforts on validation/verification of software components have gained momentum in efforts on dependable systems (EU FP6, proposals DeSIRE and DeFINE[1])). However, equally important is to ensure dependable interactions between software-software and software-hardware components. In Figure 5 we have indicated three levels of interactions in complex systems. Firstly, we have interaction models based on the distribution network (communication and connectivity). Secondly, we have interactions between software components and hardware components (e.g. embedded systems). Thirdly, we have co-ordinations on the system levels between software components. As a matter of fact, arguably most vulnerabilities in systems stems from vulnerabilities in the models and implementations of interactions. Furthermore these kinds of vulnerabilities are difficult to detect with classical off-line methods.

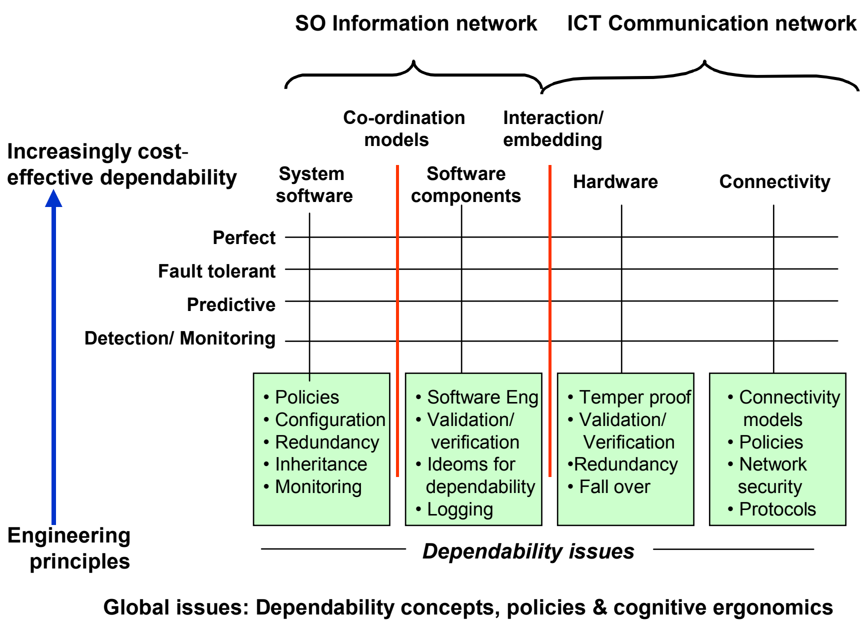

Figure 5. A system view on dependable intelligent power systems supported by the ICT-Node and SO-Node networks

In this report we start with a description of the simulation scenarios and experiments for fault detection and diagnosis, intelligent load shedding and supply and demand matching. We also look at future implementation within the three-layered network model and the requirements that follow for the core ICT-network and for the SO-network. This distinction enables a separation of concerns and hence clearer frameworks in which the tools and experiments eventually will operate.

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[1] http://www.laas.fr/DeSIRE&DeFINE/Introduction.html

3. Simulations and experiments

3.1 Supply and demand matching

3.1.1 Characterisation of supply and demand matching

Supply and demand matching allows for management of electricity use where supply may intrinsically be subject to uncertainty (such as in the case of RES) and certain supply and demand loads can be shifted in time without affecting the basic functionality of use. Shifting of supply may be established by changing the operation time of certain types of generators. In the case of hybrid generation such as CHP a characterisation has to be made of the generation devices and the underlying application area (e.g. heating). Also energy storage devices may be used, esp. for non-controllable RES generation. Shifting demand requires a characterisation of the types of underlying applications which can be subjected to a shift over time. Heating and cooling processes and certain types of industrial processes are included in this category. Turning on lights or watching television typically are not. In the experimental and simulation scenarios several cases will be studied.

Certain types of load management and demand side management are already well-known in the power industry. In the traditional setting the planning of the amount of electricity consumption is done based on time-of-year, meteorological prospects and feedback of historical consumption data. This base load is supplied for by the market, which consists of long-term contracts and day ahead trading, including import. One hour before delivery of the electricity, program changes are accounted for in view of the present situation. Thus the uncertainty in supply of electricity approaches zero at the time of delivery. Ancillary services at the background provide capacity for spinning reserve or for balancing. An independent grid operator, the TSO, manages the process.

The introduction of large scale distributed generation based on small units and RES calls for a change in this approach. Not only information has to be known on consumption patterns, but also generation information is needed for planning and balancing of the grid. Also traditional demand side management (DSM) will need inclusion of supply side management, and hence a call for supply and demand matching (SDM) tools is to be expected. Another term for SDM in this context may be *distributed balancing services*.

What do we want to solve with SDM?
The following reasons can be found to apply SDM:

- System balancing is traditionally performed at a central level. Due to larger amounts of local supply the system balancing process will change. Not only the central balancing process needs adaptation, also the need for system balancing at the local level becomes apparent. Electricity prices may be used as one instrument to control the balance.
- Due to fluctuating energy prices over time cost effectiveness can be obtained by supplying electricity at periods with high prices and consuming load at periods with low prices. The main actor in these scenarios is not the Transmission System Operator (TSO), but the local consumer and generator, or the Energy Service Company (ESCO) as a representative for these parties.

In contrast with load shedding, which is in principle applied as an emergency measure, SDM is applied for strategic reasons. It does not just pick the loads to be shed, but it looks at shifting loads for both generation and consumption units. A similarity with intelligent load shedding is that it takes into account the functionality behind the supply and demand: SDM shifts supply and demand loads that are shiftable, based upon rules; ILS sheds demand loads based on rules.

Which parties may benefit from SDM?
As mentioned, supply and demand matching might be beneficial to local consumers and owners of generators, since they can shift (part of) their energy use to cheap periods and they can shift or increase their production to periods with high prices. Another cost effective measure which can be achieved by supply and demand matching is the matching of local generation and consumption within the MV-network, thus avoiding transmission fees and transmission energy losses.

Clusters of parties with shared interest may arise, such as building corporations. Trading services can be offered by ESCO's, in which supply and demand matching is coupled to an external power market. The ESCO acts as an intermediate between local generators and consumers and the market.

The ESCO, offering matching services to local generators and consumers based on electricity prices, can also offer services for balancing and stabilisation of local subnetworks, thus taking the responsibilities out of the hands of local generators and consumers and supporting the tasks of the transmission system operator. This allows for freedom of contracts in a liberalised market.

What do we need for SDM?
Since SDM requires information and control of a large number of generation and consumption nodes, traditional SCADA is difficult to use and expensive to apply. In stead an inexpensive ICT-infrastructure is needed with two-way communication facilities. The SDM market will more resemble e-commerce, where real-time price developments are common. Hence the control system can benefit from a high level of distributed intelligence, where each node has been provided with some intelligence. In order to facilitate the control of such a 'granular' system different levels of (virtual) clustering of devices can be established. Energy Service Companies (ESCO) may offer these services to private consumers and generators. In chapter 0 different options for the ICT architecture will be discussed. ESCO's may also be involved in operation and maintenance of the ICT-layer introduced in chapter 6.

In the following paragraphs the simulations and experiments will be described, which are planned in the CRISP project. From there a list of requirements will be derived for the simulation tools to be developed.

3.1.2 Short description of simulations

In D1.2 [2] a number of scenarios will be developed which form the basis for the SDM simulations to be performed. Also the experiments to be described and performed in workpackage 3 will lead to several scenarios. The basic scenario for supply and demand matching handles the following:

> *The Energy Service Company (ESCO) delivers a supply and demand contract to its Selling Customers (Suppliers) and Purchasing Customers (Consumers). This contract offers the following:*

The ESCO delivers demand shifting services to the Consumer in return for device diagnostics and a management fee.
The ESCO delivers Supply Shifting services to the Supplier in return for a management fee.
The Supplier delivers real-time energy tariff data to the ESCO in return for money for this data.
The Supplier delivers energy to the Consumer in return for money for kWh.

In this scenario the distribution costs are considered fixed. Also it is assumed that the Supplier is responsible for the delivery of energy.
Note that the roles of Supplier and Consumer can be played by one single Customer. Consumption of own generated energy however is not taken into account in the scenario, since no money transfer will occur in this case.

3.1.2.1 Individual control – the E-box concept

The E-box concept enables energy management services in a household environment. The E-box gateway functions as an intermediate between a household (including the user and its devices) and the outside world, preferably through an ESCO offering different energy services. Basic services include metering and maintenance. Supply and demand matching can be implemented at an E-box architecture in order to achieve cost benefit for the household. A complete description of the E-box concept can be found in D1.2 [2].

In the E-box concept scenarios will more or less follow the basic scenario described above. In these scenarios a choice will be made for certain types of private generation of electricity which are either prone to uncertainty (PV, wind), or are – within constraints – shiftable over time. We also need to take into account in this scenario hybrid systems, such as CHP, where the heat can be used to satisfy a demand articulation, and which produces as a by-product power to be used privately or sold in a market. Another scenario might be a power-driven heat pump for hot water supply.
Also a choice will be made for certain types of private consumption based on different demand articulations, such as heating or cooling processes. A coupling exists between supply and demand, which might be more complex than just a direct transfer of supply to demand. Examples of such are application of CHP and the electric heat pump.

The matching process consists of optimisation based on cost, where the private supply and demand loads will be coupled to a number of different market scenarios among which a real-time electricity price market, where optimisation is based on a cost-benefit. The market will be a typical day or hour ahead market. User input and weather forecasts will be put in use for planning of private energy generation and consumption.

3.1.2.2 Distributed balancing with clusters of generators and consumers

In these scenarios the private point of view for optimisation is upgraded to a higher level. The ESCO can be seen as taking over the role of supplier. The ESCO is responsible for the control of clusters of distributed small scale generators and hence responsible for the delivery of energy to its customers. The ESCO controls each generator based on a contract and trades surplus electricity to small scale consumers.
SDM can solve the problem of aggregated cost optimisation based on clusters of local generation and consumption in a liberalised environment, typically in a day ahead market. Cost benefit will be for the local generators / consumers by subscribing to ESCO commercial services.

We can look at two different angles in the clustering of generation:

- A net-coupled control SDM-cluster is the DG-variant of a large central control cluster, used on a nation or region-wide basis at the moment. Operation of this type of SDM-cluster, due to its size has an effect on market prices. This means, that the control strategy is driven by the behaviour of other similar SDM-clusters. Power grid requirements, of course, constrain this mechanism and optimal use of the infrastructure can be made by using the power lines for PLC-communication.
- A "commercial" control cluster can be compared to an extension of a virtual power plant [P1547,2003]. A commercial control cluster may react on price variations on the market, but also may be involved in price formation itself. Currently, in the US, spare diesel power aggregates in buildings are combined to fulfil such functionality in periods of sparse electricity. In the following sections, the four above-mentioned types will be discussed in more detail. In this chapter these four types of SDM-clusters are discussed. One of the concepts, the E-Box, is discussed further to further illustrate the SDM-concept.

In Figure 6 these two subcases of clustered control are put into context together with the individual control case from section 3.1.2.1 and with the case of central control, based on the current situation, which can be seen as a reference case for the three novel approaches.

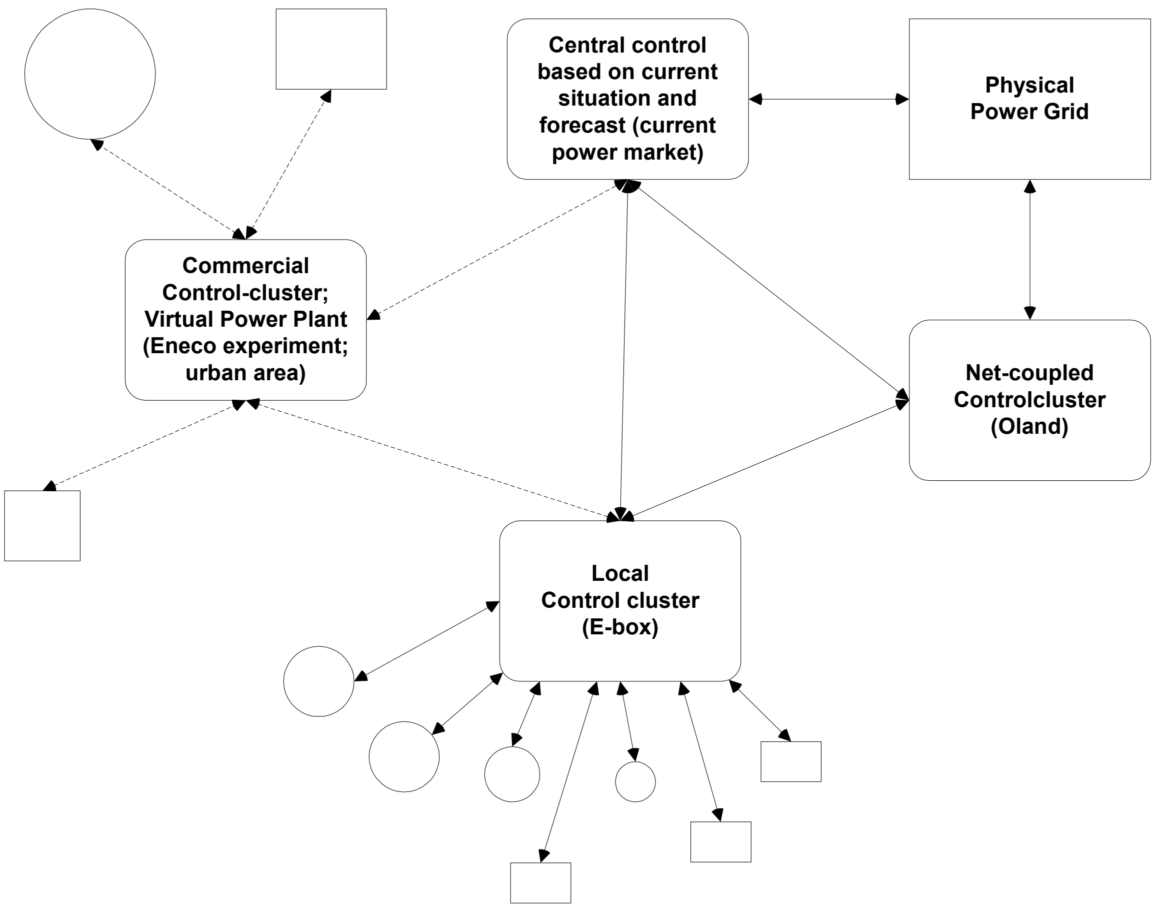

Figure 6 Types of SDM-agent clusters; simulation cases

3.1.3 Short description of experiments

In this paragraph we will focus on experiment A of workpackage 3 and the experiments on the isle of Öland.
One of the goals we intend to establish in WP3 is the support of the supply and demand matching experiments by simulations. Therefore we also take the experiments description as an input for deriving the tool requirements.

3.1.3.1 WP 3A – The ENECO experiment

The ENECO experiment refers to scenarios and strategies concerning local market-oriented demand-supply matching and associated highly distributed architectures. A field test is being prepared in which several types of distributed generation and consumption are installed within one controllable environment. Electricity generation will consist of several types of micro-CHP units at a residential level, such as Stirling motor, PEM Fuel Cell engine and SteamCell™, several existing large CHP systems (100-1000 MW_{el}) in a horticulture environment and an operational windmill (2 MW_{el}). The horticulture CHP's are driven by heat demand, which can be controlled using the dependence between energy-profile (i.c. heat) and weather forecasts, thus allowing demand side management. Also 2 large industrial cooling installations are part of the system, which allow shift on demand side due to dependence between energy (i.c. cold) profile and weather forecasts and mutations in stored products.

ICT provides always on connections using common ADSL-technology and standardised distributed intelligence. Agents, representing the generation and consumption units, take care of communication between units and with an outside world, represented by a dedicated server. The ICT tools developed in the CRISP project are used for monitoring and dispatching purposes, in order to create an efficient balance between generation and demand without causing local overload of the electricity distribution infrastructure. Particular attention will be given to the fact that customers must perceive this as a service and not as intrusion into their private life or industrial processes. The field test is being prepared, testing local market-oriented demand-supply matching and associated highly distributed architectures.

The system uses a real-time connection of the subsystems and works on a time scale of a number of hours maximally. Further inputs include weather model forecasts, energy contract information and horticultural process operating conditions. Clusters may be defined of generators and consumers transparently. The use of agent algorithms in the experiments should be defined as well as the goals for optimisation in terms of the conditions to be agreed with the customers. This is related to the role that the retailer wants to play in relation to the customers on one hand and the producers on the other hand.

Apart from conduction the ENECO experiment as such, the experimental case will be supported by deriving scenarios as input for simulations as described in 3.1.2.1 and 3.1.2.2

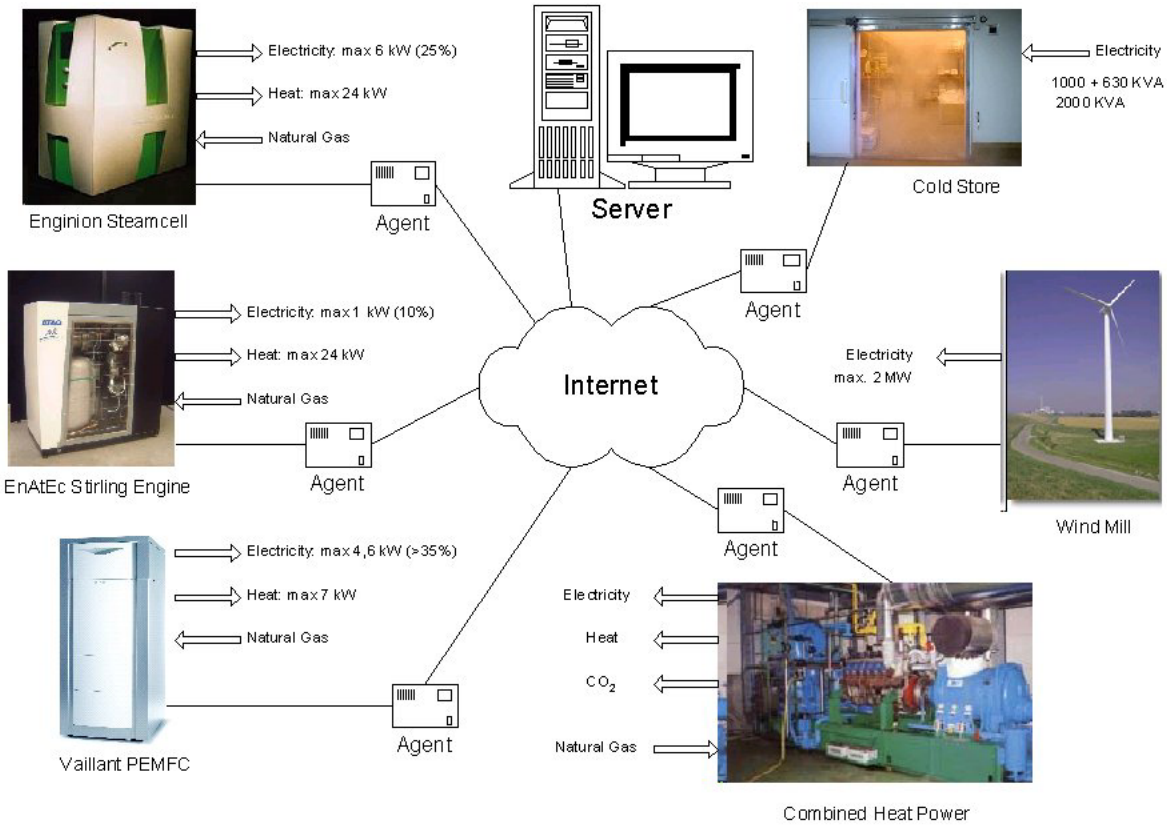

Figure 7 The ENECO experiment - WP3A

3.1.3.2 WP 3C – The Isle of Öland

The Isle of Öland, located in the Baltic Sea in the south of Sweden, is a prime place to observe the patterns of supply and demand due to several factors. The island is a popular place to spend summer holidays on but is much less populated during the winter. On and around Öland the amount of installed DG lies in the order of 30 MW. The load varies from 15 to 85 MW approximately. The patterns of demand are such that there is a peak during Easter (when people start heating their holiday houses) and lowest during the autumn. The power generation on Öland is unable to supply enough during the spring so import from the mainland is necessary. However, in the autumn there is a surplus of energy generated so export to the mainland is possible. A single power cable connects Öland to the mainland.

The Isle of Öland provides a unique opportunity to introduce new technologies and accurately measure their efficiency. An experiment is scheduled in which field measurements are performed with the aim of capturing the load responses due to changes in the supply voltage and capturing the voltage responses due to load changes. More on this experiment can be found in paragraph 3.2.2 and in D1.5. The Isle of Öland and the results of these measurements may be used as an input for development of scenarios for supply and demand matching simulations as described in paragraph 3.1.2. This will be further evaluated in D1.2 [2].

The tools supporting research on supply and demand matching shall support cell-oriented generation-distribution at regional levels.

3.1.4 Requirements for supply and demand matching

In the supply and demand experiments, based on expected loads and generation capacities, optimal strategies (in the economical sense) are determined for tuning of supply and demand of energy in (part of) the PS-node network over an extended period of time (up to 24 hours). Strategies should be flexible and adaptable to stimuli from the grid. In forthcoming subparagraphs we come up with a requirements list for the simulation tool in the context of supply and demand matching:

3.1.4.1 Context for supply and demand matching

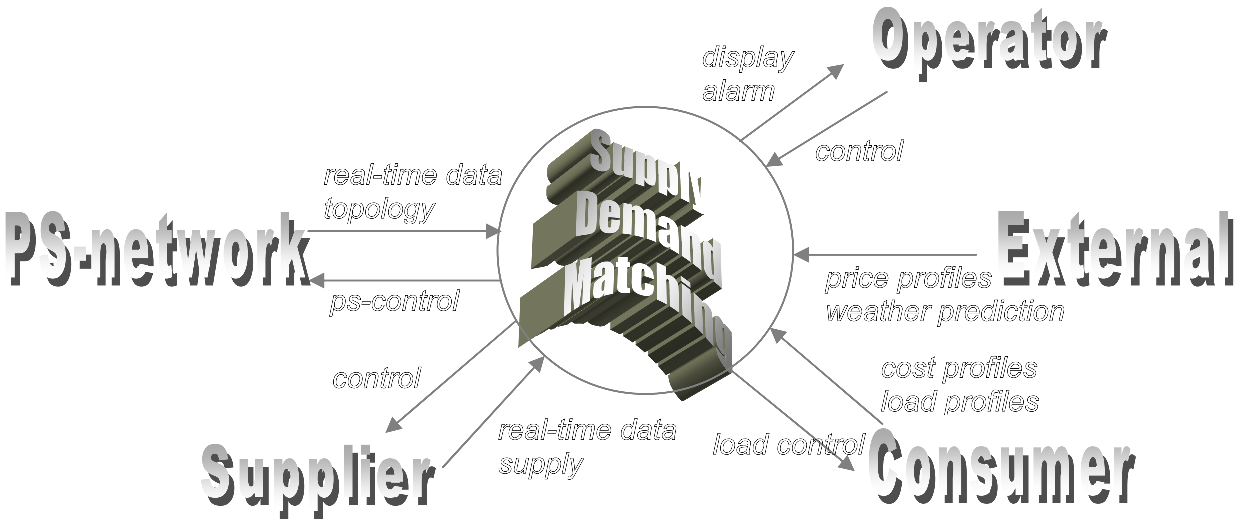

Figure 8 Demand-Supply Matching Context Diagram

load profiles:	individual load priority tables
load control:	dynamic load priority tables
real-time data:	network performance, generation, loading, configuration & position
ps-control:	Voltage and Reactive power Control; Active power Control; Transformer LTC Control; Shunt Compensation Control; Series Compensation Control; Switching Capacitor Control; Load Shed Control

It is important to differentiate between requirements for simulation tools and requirements for experiments. The latter will eventually be reflected in practice and a.o. deal with time scale aspects.

3.1.4.2 Requirements for simulations and experiments

Functional requirements

- Scenarios, specifying test sets in several normal and abnormal events should be specified.
- Deriving utility functions for SDM
  The utility a.o. expresses an economic value for decision to be made and depends on the underlying market model. Utility functions will be developed in D1.2 [2]

Data flows

- Input data requirements

  Generators should be able to specify their supply articulation in terms of maximum/minimum load for each period, the uncertainty of delivery, the cost, depending on the load.

  Note that the supply articulation can be dependent on a primary process at the customer site, with a given demand. E.g. CHP-units in agriculture primarily have a demand articulation of heat; on producing the heat, as a 'by-product' electricity can be supplied.

  Consumer devices also must be able to specify their demand articulation. This articulation can vary from fixed load for each period to a total required load for a longer timeframe (typically a day) and a weighing function for spread of the load over this timeframe.

3.1.4.3 Requirements with emphasis on simulations

Functional requirements

- Network characteristics
  In D1.1 [1] different layouts of the distribution network are given: a radial layout, an open loop layout and a double shunt layout. We shall restrict ourselves to the first two. Behaviour of the distribution network may depend on the type of layout and therefore it should be possible to implement different transmission and distribution network layouts in the tools. This includes network topology, transmission and distribution capacity, generated load and power.
- Device characteristics
  Specific characteristics for devices, such as reaction time for starting or stopping the device, the minimum required running time, etc. must be specified. Devices can be generating devices, consuming devices or energy storage devices. For hybrid installations both electricity and gas or heat specifications must be defined.
- Fluctuations and uncertainties
  The simulation tools should be able to deal with fluctuations and uncertainties in the supply and demand articulation. The uncertainties may be used at the algorithmic level or to perform sensitivity or risk analysis on the outcome of a scenario.

Data flows

External information, such as weather forecasts and pricing information should be specified. In the simulations the price information can be provided by implementing different market models.

- Output data requirements
  These follow from the goals defined for the simulations and experiments: which questions does one want to answer. Typically generated and consumed loads and (direct and indirect) costs and proceeds are part of the output data.

3.1.4.4 Requirements with emphasis on experiments

Communication requirements

- Polling and interrupt latencies must not exceed the timeframe of tens of seconds. Billing is based on 15 minutes' intervals. Communication can be further reduced by using semi-

autonomous operation of local systems (autonomous operation during ‘normal conditions’.).
NOTE: This requirement is less strict than the requirement for the protection-fault or load-shedding ICT-networks.

- Individual nodes should be able to run apart from the rest of the network without interference to the higher priority protection-fault and load-shedding networks. Other parts of the network should find a "healing" strategy to let the remainder of the network function with maximum intact functionality.
- An always-on communication connection has to be present during execution of the experiments.
- An interoperability interface should be defined to establish communication between the ENECO experimental environment and the CRISP-experiment trial software. In the test the CRISP-infrastructure must be able to operate in read-only, shadowing mode with respect to the experimental environment. Control signals are only emitted by the former system. Physically the experimental environment and the CRISP-trial software may share the same infrastructure; logically the infrastructures may be entirely different.

Functional requirements

- A controlled testing environment should be established in which several versions of the algorithms are executed under well-defined circumstances before actually using them in operational circumstances. The involved scopes are module, integration, one-node and multi-node respectively.
- A data-collection strategy has to be defined to monitor the behaviour of the PS- and ICT-network and the individual components during the test period. Variables to monitor are status reports, yields of generators and loads of consumers over time. Furthermore the dynamic responses of the system on external events have to be monitored.
- Supply and demand matching is about taking control of equipment. Control decisions should be communicated to generators and consumers which should obey these commands or – when overruled by local autonomy – should communicate the refusal with the originating control centre.
- A configuration management scheme for distributing and installing basic software components should be implemented. Basic software components include drivers, primary tools and software utilities.
- One of the distributed nodes should function as a data collection, control and management node. Hierarchically however, this node should use the same primitives as those available to all other peer-nodes to query the network.
- A "portal" software structure should be defined to get access to real-time external information. This portal should be available to the network from every node in the network.
- To give access to external operational information a similar "portal" has to be defined to the distribution, protection and load shedding network infrastructure.

Infrastructure requirements

- Reliability and security issues
  We are aiming at dependable systems, i.e., systems supporting robust, secure, and safe operations. Robust and safe operations are typically the focus of current grid systems. Issues of security enter as we will have a network-centric view of the operations. Of

course, we have to develop and use increasingly reliable components to start with, but we have also to develop methods and tools for on-line maintenance and support. These tools are supporting protection, detection and response of unwanted events. We have also to address issues of secure execution of unreliable software components. These issues will be further addressed in D1.6 [5].

- Internal and external communication requirements
  Communication in the ENECO experiment is based on agents, representing the generation and consumption units. The requirements for agents are described further in 5.3

Data flows

- Output data requirements
  The experimental conditions should be monitored and logged, such as: network status and operational conditions, generated and consumed loads and (direct and indirect) costs and proceeds, control decisions, etc.

3.1.5 Architectural implications

It is proposed to separate in the software architecture the functional supply and demand model and the market model as much as possible. The tool to be developed will facilitate future developments in this way, since different price or market models can be studied using the same basic supply and demand structures, and different grid solutions can be studied without disturbing a market model. Also experimental data in stead of the supply and demand tool can be linked to different market models.
Main importance will be the interfaces between the two subsystems.

3.2 Intelligent load shedding

In WP 3 load shedding is planned as an experimental package. Although the experiments will be supported by simulation studies, there is no simulation tool planned, and hence we do not need a complete list of requirements for it. In this paragraph we will focus on a number of main characteristics for load shedding.

3.2.1 Context for intelligent load shedding

A main characteristic of intelligent load shedding is to keep track of individual load available to shed at each moment in time, to establish the cost related with each load shedding and to find an "optimal" combination of amount, location and costs for the load shedding, with respect to a certain disturbance.
A second challenge in intelligent load shedding is to identify disturbances in the network that require load shedding.

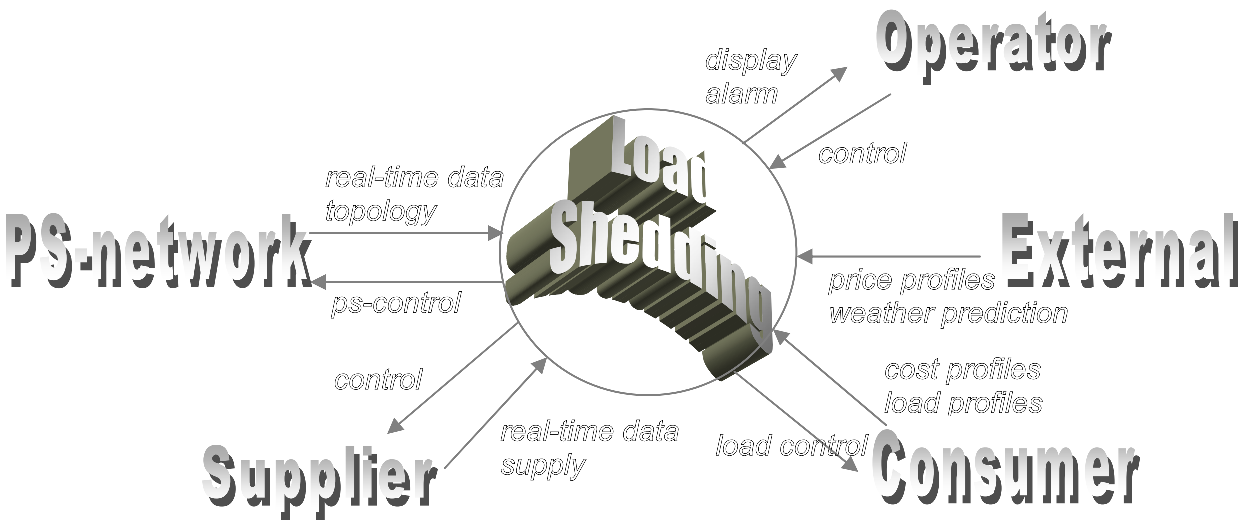

Figure 9 Intelligent Load Shedding Context Diagram

load profiles:	individual load priority tables
load control:	dynamic load priority tables
real-time data:	network performance, generation, loading, configuration & position
ps-control:	Voltage and Reactive power Control; Active power Control; Transformer LTC Control; Shunt Compensation Control; Series Compensation Control; Switching Capacitor Control; Load Shed Control

3.2.2 Short description of experiments

3.2.2.1 WP 3C – The Isle of Öland

The Isle of Öland, located in the Baltic Sea in the south of Sweden, is a prime place to observe the patterns of supply and demand due to several factors. The island is a popular place to spend summer holidays on but is much less populated during the winter. On and around Öland the amount of installed DG lies in the order of 30 MW. The load varies from 15 to 85 MW approximately. The patterns of demand are such that there is a peak during

Easter (when people start heating their holiday houses) and lowest during the autumn. The power generation on Öland is unable to supply enough during the spring so import from the mainland is necessary. However, in the autumn there is a surplus of energy generated so export to the mainland is possible. A single power cable connects Öland to the mainland.

The Isle of Öland provides a unique opportunity to introduce new technologies and accurately measure their efficiency. An experiment is scheduled in which field measurements are performed with the aim of capturing the load responses due to changes in the supply voltage and capturing the voltage responses due to load changes. These recordings will give knowledge for the theoretical studies on intelligent load shedding and the development of algorithms. Subsequently simulations will be performed, based on market approaches as described in D1.5, in which the different seasonal scenarios are taken into account. PSS/E (Power System Simulator for Engineering) [17] will be used as the simulation tool.

The measurements studies will enable us to see

- load reaction on voltage variation, supply from week/strong system etc,
- reaction of distributed wind generation on power system faults,
- power system reaction on distributed wind generation changes,
- reaction of power system for switching some big loads,
- power system & load reaction after disturbances,

and they will

- enable Sydkraft to make future decision about new wind farm installations in Öland,
- help to determine intelligent strategies for load shedding in case of power system instability,
- offer an excellent way to study, understand and visualise power system dynamic behaviour.

As mentioned in paragraph 3.1.3.2 the measurement results will also be used in the supply and demand matching scenario studies.

3.2.3 Requirements and scenarios for intelligent load shedding

The main requirement on "intelligent load shedding" is that it should be regarded as a means to improve power system stability, by providing smooth load relief, in situations where the power system otherwise would go unstable. The work with intelligent load shedding can be divided in a number of stages:

- To improve present load shedding schemes (where a circuit breaker on the 10/20 kV level is opened), to a scheme where individual load objects in the area are addressed and switched off, or ordered to reduce power, for a certain time.
- To keep track on the load available to be shed in every instant.
- To find an "optimal" amount of load to shed, with respect to a certain disturbance.
- To find the "optimal" location of the load to be shed, with respect to a certain disturbance.
- To specify/find relevant disturbances to prepare load shedding for, and to "interpolate" between these to find suitable actions for real disturbances.
- To initiate "intelligent load shedding" - when approaching voltage instability, angular instability, frequency instability or cascaded outages.

3.3 Fault detection and diagnostics

The protection system required for a distribution system is a complex combination of sequential and distributed actions, including moreover diverse response time for the relays and the equipment. A possible gain in time is expected for the DNO for a specific sequence: detection and fault location. The experiment is based on a new fast fault location system highly dependant on ICT, the target being a help tool for the operator decision (recommendation for the response to a detected permanent and cleared fault in the distribution EPS, gives the associated automatic sequences to reduce the faulty area)
The experiment is composed of a simulated part and a real part: the ICT is expected to be tested (real part), the remaining parts being simulated by appropriate real-time simulators.

3.3.1 Characterisation of fault detection and diagnostics

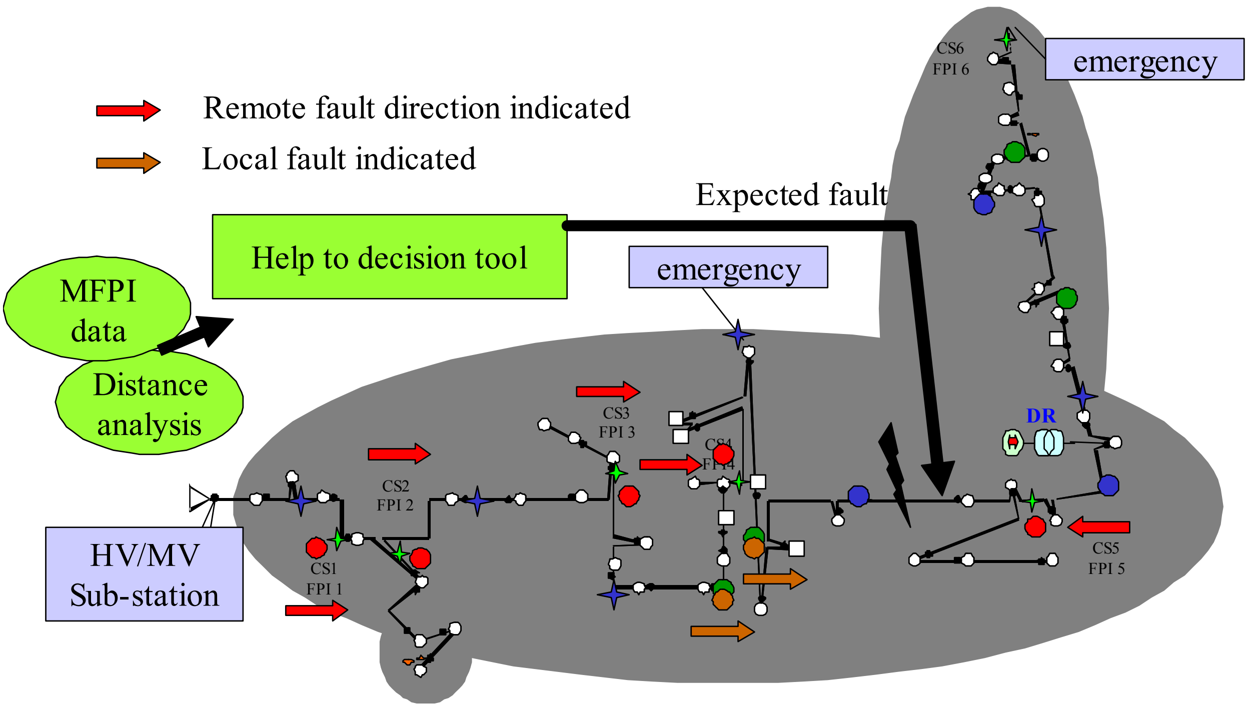

Figure 10 Fault Detection and Diagnosis Context

The fault location sequence reduces the faulty area to the smallest area thanks to the distributed EPS switches: installed emergency connections may be used after disconnection of switches around the fault.
The indicators distributed in the EPS (MFPI: monitored fault path indicator) send information to a central ‘help to decision tool’. A distance evaluation, based on industrial frequency variations of the measured voltages and currents, and combined with the information of the MFPI is carried out. A goal of the experiment is to find the minimal reachable time to complete the sequence.

real-time data: breaker and switches state, fault path indicators, measured currents in feeders sending-ends, measured voltage on the main substation MV busbar, electrical power system configuration,

ps-control: breaker and EPS switches Control

3.3.2 Short description of experiments

The proposed method is targeted to be tested for the ICT hardware and software available for the dedicated application. The remaining part of the EPS and needed control is simulated in adapted real time tools.
The part of intelligence covered by ICT is not yet decided, additional information is necessary on the detailed requirements for the equipment interconnected by the proposed method. Existing EPS components or computing system installed in the substation may be used, making this method very attractive for a DNO. On the other hand, if a more integrated ICT is more profitable, we keep the ability to test this extended solution. It is important to keep in mind that EPS equipment is heavily standardised, the DNO is in favour for reliable and experienced ones in general.

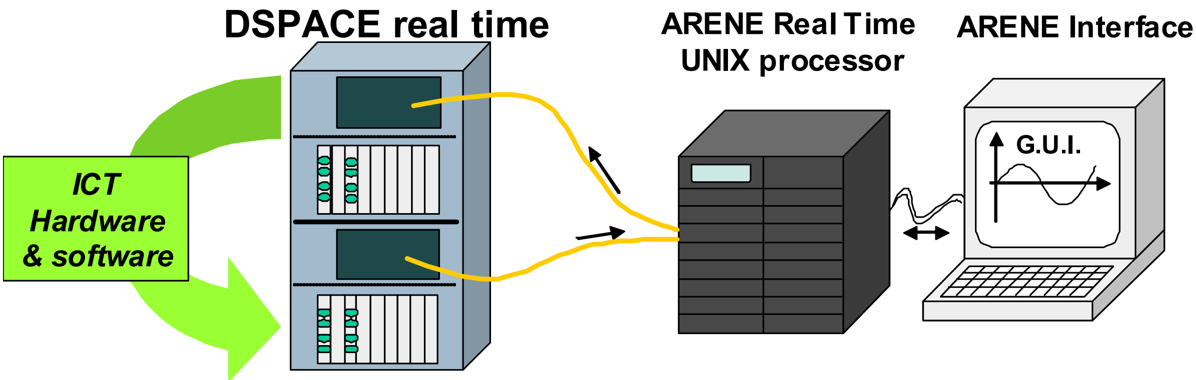

Figure 11 The INPG/Schneider experiment studied case for the tests- WP3B

The scenarios are composed of:

- Common fault without DR: permanent and not permanent
- Common fault with massive DR: permanent and not permanent

(DR disconnecting protection is taken into account)

The simulations will assume an ideal data transmission inside DSPACE interface in order to check the scenarios and the dedicated programs for fault location and help to decision. Then the real hardware and software will be added.

The fault detection and diagnostics experiments and simulations will be performed using the ARENE tool for digital real time power system simulations. The ARENE tool runs on different types of hardware, such as HP parallel computer and HP workstations; Sun workstations; and Windows environment under NT or XP. A complete overview of ARENE is given in [6] and [18].

3.3.3 Requirements and scenarios for fault detection and diagnostics

The fault detection and diagnostics experiments and simulations mainly concern the state of the EPS nodes, or the state observed in the EPS during the fault. It requires real-time measurements and capability not only to detect breakers and switches state changes, but also to be able to collect and memorise feeder current and voltage needed for the fault distance evaluation. We can define the requirements list as follows:

1. Polling and interrupt latencies should be in the range of milli-seconds.

2. Collecting, analysing and managing data at gateway nodes (MDFPI and numerical feeder protection); aggregating, analysing and managing data to a central location; sending information to operator and orders at gateway nodes (controlled switches).

Functionally the following requirements for fault location should be met:

1. Monitoring – Collection – distance estimation – analysis (fault path indicated and location expected between two switches)

From the FPI (Fault Path Indicator) devices, the following condition is assumed:

Two dry contacts to indicate the permanent fault and orientation relative to the FPI (up and down). These contacts are automatically reset by an appropriate control outside of the ICT chosen.

From the numerical SCADA system, the following condition is assumed:

Ethernet SNMP link delivers TSTP data files, with fault information memorised (with 12 samples per cycle for instance). Voltage and current are given for each phase. Specific filtering and selection in the file is needed to identify the fault signal and analyse it (cycles before, during and after the fault may be recorded).

The ICT may have a topology description tool (or collect data from a specific tool describing the EPS and its useful characteristics). The collected data are then used for the fault location by using a dedicated algorithm.

The ICT output is fault supervision by operator and recommended operation to follow to reach the goal of the fault location: reduce the power cut at the elementary fault area.

The goal in WP1.4 is to give a general understanding of the system protection in distribution EPS, focusing on the specific interest of fault location. An important gain on time is expected by a proposed method of fault location.
The goal in WP2.3 is to describe the proposed method as a tool composed of appropriate algorithms. Scenarios and simulations are carried out in order to present and characterise the principle.
The goal in WP3.2 is to have a real time experiment of the ICT and the proposed method associated. The ICT is expected to be real hardware and software, define by requirements previously given.

The ICT boundaries on monitoring EPS data are not easy to define, dedicated and complex equipment being normalised there. A low cost solution may be to use adapted existing devices to achieve the direct interface, these devices providing some ability to emit the desired information. This approach allows us to converge on a practical solution for our experiment, then to a feasible and easier experiment on a real distribution EPS and finally to an easy integration in the future distribution EPS (the two last aspects are not targeted in the CRISP project, but may be a logical perspective).

4. PS-Node network: Distributed Generation in the Power Grid

A characterisation of the traditional network and the distributed grid will be given, with a focus on the consequences for ICT applications. The utility point of view has been worked out in extent in WP 1.1 and we will repeat only a summary of its findings.

In this report we will identify those key elements of network operation which will facilitate the shift in operation from the traditional grid to a distributed grid. ICT does facilitate this shift in operation in which distributed generation, such as combined heat and power and embedding RES on a large scale, need new instruments of tuning the grid at the micro-level.

4.1 The low-, medium- and high-voltage network

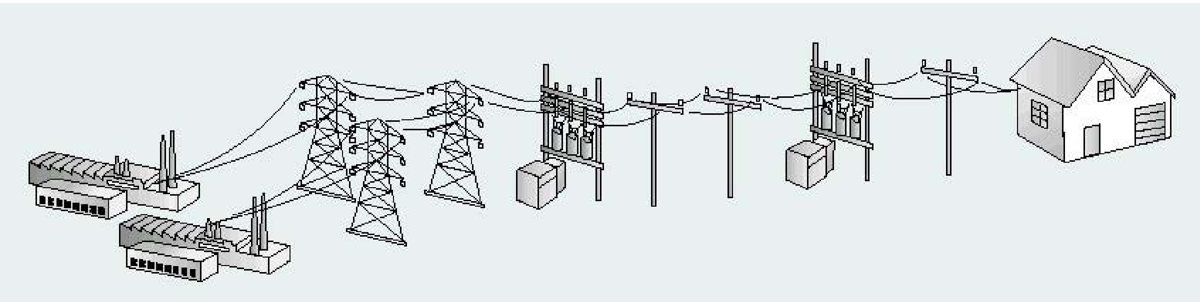

Figure 12 Today's power system – from Electricity Technology Roadmap. EPRI, July 1999

The electrical infrastructure is organised as a hierarchical network. Three main levels are distinguished: the transmission level, the sub-transmission level and the distribution level. These levels have the following characteristics:

- *Transmission level*: The national extra high voltage grid, with voltage level depending on country and ranging from 220 kV to 800 kV). Typically a meshed network connected to large generation units and to transformers to the sub-transmission level. The main international connections are also at this level.

  The transmission function is done at high voltage levels in order to reduce losses. Safety is a fundamental topic for the transmission network, since faults on the network will lead to supply failure for all customer units. Therefore the transmission network is continuously monitored and managed from a control centre.
- *Sub-transmission level*: Conducts the electricity to towns and cities and to large industrial sites. The voltage level ranges from 45/50 kV to 160 kV. This regional radial or coupled network can also be connected to large or medium sized generation units.

  Sub-transmission networks are organised in closed loop. Electricity can flow from both directions, so there is a redundancy in the supply of the energy. The sub-transmission protection system is organised similar to the transmission network. The control is regionally.
- *Distribution level*: Consists of the *'Medium-voltage'* network, ranging from 4 kV to 45/50 kV) and the *'Low voltage'* network, with voltage levels at 400 V and 230 V). The MV-network is typically a meshed network connected to small generators, medium sized

customers and LV (low voltage) stations. The LV grid is typically a tree network, throughout domestic areas for small customers and public lighting networks.

Operation of the MV-network is carried out either manually or by remote control from fixed or mobile control centres. Control within the LV-network often is done manually.

At the transmission level we find a transformer station to the sub-transmission level. The sub-transmission level has a transformer station to the distribution level. Details of these stations are not discussed, because they are not in the scope of this report.
At the distribution level an average distance of 500 m to 1 km lies between a substation or transformer station to the low-voltage customers. The size of the infrastructure at this level is the largest in the whole network. In the Netherlands there are about 60,000 10kV stations (100,000 km underground lines) and 40,000 400/230 V stations (estimation).

4.2 Distribution network layout

There are several types of network layout for the distribution network:

- Radial layout: composed of a single electricity supply input for the customers in the given network. This layout is mainly used for MV-distribution in rural areas (low load, wide geographical spread). No emergency loop connected to this layout.
- Open loop layout: any customer in the structure may have several electricity supply paths, in case of emergency. One unique and normal path is defined in general, the other path being used when a permanent fault occurs or when maintenance work is carried out. These open loops may be installed on the main feeder or also on the main derivations. Several EPS switches distributed among the network allow the operator to change the configuration, and so to isolate the faulty section.
- Double shunt layout: this type of layout is common in urban area, when a high level of reliability is needed. The principle is installing two circuits in parallel, enabling to switch from a cable to the other cable when a fault occurs or a maintenance work is needed in the normal cable. This solution is expensive compared with the open loop solution, but gives a back-up solution anywhere.

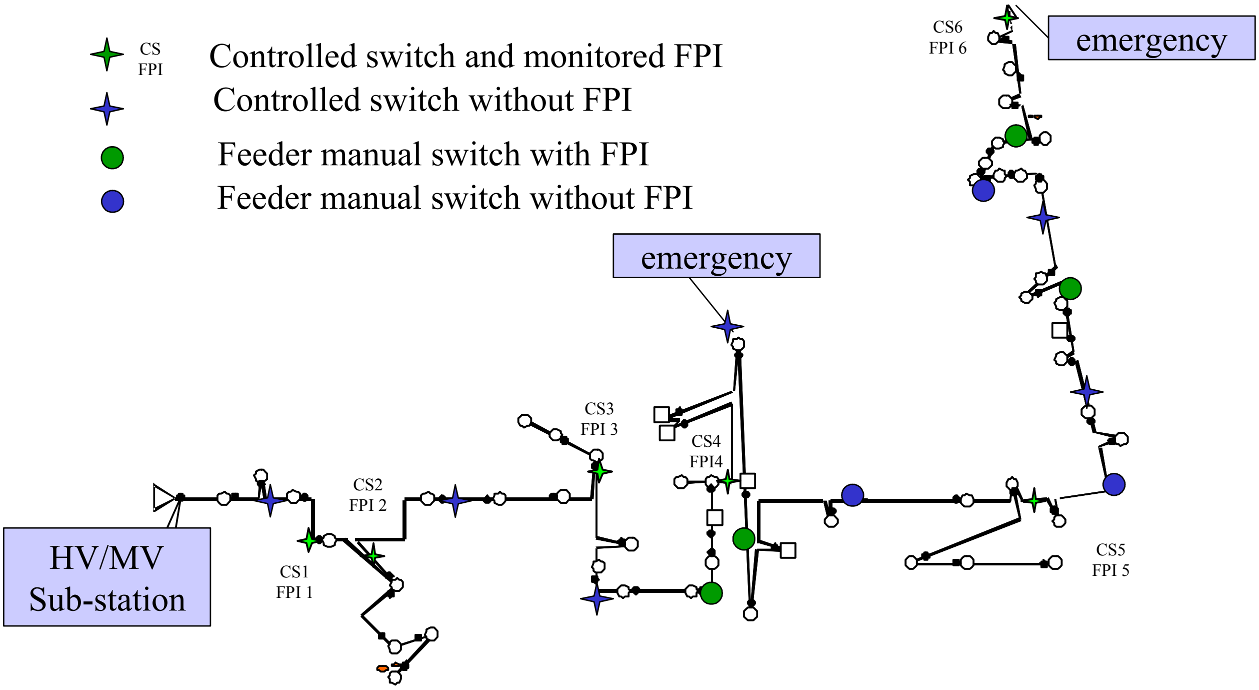

Figure 13 Open loop layout with two possible emergency connections

4.3 Current practice in network operation and control

Power system monitoring and control is aimed at detecting and resolving disturbances in the power system. Some of these disturbances can be resolved automatically by protective devices. In order to deal with other disturbances an Energy Management System (EMS) is used. An EMS operates in real-time. Its main task is to keep track of the current state of the system. Based on its findings it is able to instruct generating plants and control system components. In Figure 14 the hierarchic structure of an EMS is sketched.

At level 0 is the power system itself. Level 1 consists of the local controls. It operates on level 0 and contains communication channels to the levels above. At level 2 area control is taking place, using a man-machine interface and data concentrators.
Level 3 is the main level of control, operated by use of SCADA systems. It interfaces with the control operator and central systems, such as the Alarm Management subsystem.

The monitoring and control is heavily automated and handles with a.o. information gathering (topology identification; current and voltage measurements; ...), data validation processes (contingency control; economic scheduling; automatic frequency control; ...), fault detection and restoration, load estimation, optimisation and configuration.

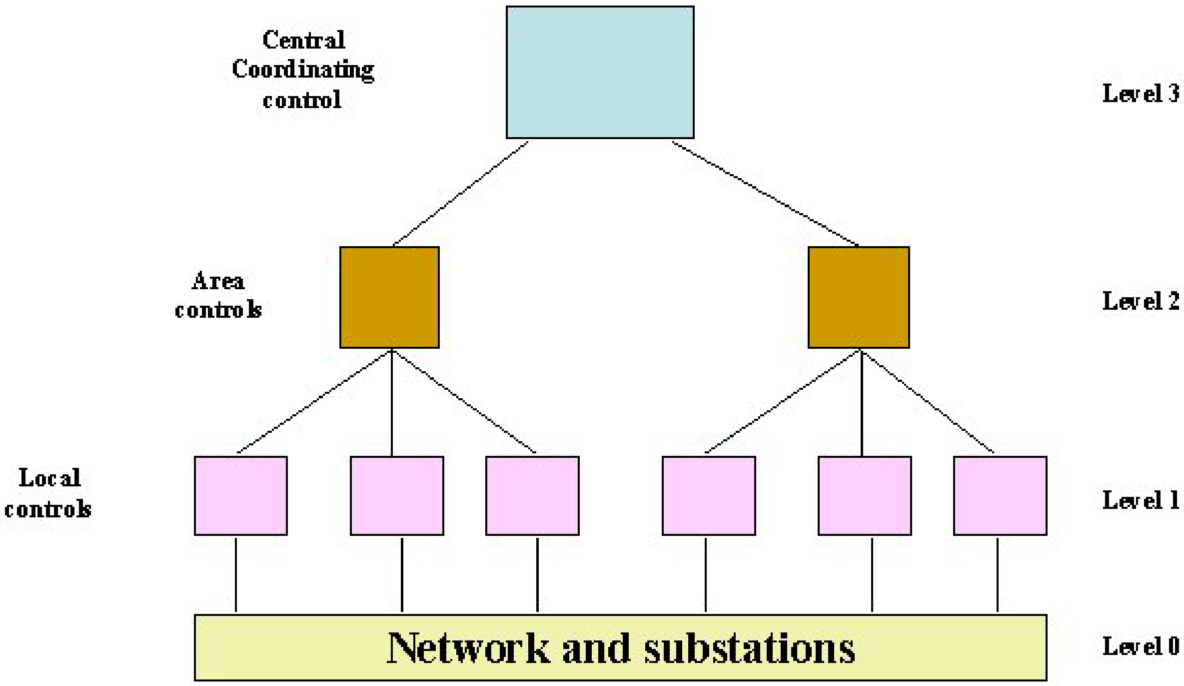

Figure 14 Hierarchy of controls required for an Energy Management System (EMS) (from D1.1 [1])

4.3.1 System security and Emergency control

The electric system ensures the transmission of the energy from the generators (distributed or centralised) to the customers. The operation and control of the system differs in case of normal operation or in case of emergency situation. These emergency situations can be caused by technical or natural events. The normal operation of the electric power system (EPS) in the transmission network allows the system to lose one or two major components (one VHV line or one nuclear unit for instance) without entailing a general blackout: this rule is named (n-1) or (n-2) rule. The prediction of power flow is computed at different scale (month, week, day before), helping the operator to plan the production and possible back-up solution to meet the (n-1) rule. In emergency situation, the operators try first to save the power balance in the system, with acceptable power flux in the circuits. When the situation is stable and less critical, new computation is launched to find a new way to come back to the (n-1) rule and minimise economical constraints.

Today the situation is less critical in the distribution EPS: the loss of a HV/MV substation will not endanger the transmission system because of the high difference in the power levels. The emergency situation inside the distribution is more dependent of the network design, including the number and location of the distributed EPS switches.

This kind of spirit will change in the long term, when intentional islanding will be a reality: the security and power balance inside the electrical island will have to be preserved as it was the case in the transmission system. At this scale, the emergency control becomes hard very quickly, with a loss of a major part of local load or production, or with a high variation of the normal load compared to the local generation. So a specific rule should be followed in the long term distribution network, but with a necessary adaptation to the intrinsic

characteristics. The loss of components should take into account the critical amount of power variation compared to the total amount of power locally generated.
If an emergency situation appears different actions could be taken into account: adjustments to the generator commitment and load are made i.e. by a contingency-constrained optimal power flow (OPF) and feedback rules.

4.3.2 Fault detection and diagnostics

When a permanent fault occurs inside the distribution public EPS (electrical power system), different sequences are followed in order to recover a normal situation.
Sequence 1: the fault is cleared by the main feeder circuit breaker located in the HV/MV substation, the appropriate relays being located inside this substation.
Sequence 2: the fault location (the purpose of the experiment) reduces the faulty area to the smallest area thanks to the distributed EPS switches (possible use of installed emergency connections).
Sequence 3: the reconfiguration of the distribution EPS may be done to improve the real time emergency situation in order to reach a right balance with the safety (mechanical or electrical work under supply), the security (current limitation, power flow) and the economy (conductor losses).
Sequence 4: the detailed location of the fault is achieved by appropriate mobile equipment in general (based on acoustic physics, wave propagation, or apparent impedance)

The present application is focused on the sequence 2, with an original combination of traditional fault location method and a new kind of fault distance analyser (adapted to distribution EPS electrical parameters).

Without DR, and in the present context of distribution, the sequence 2 generally combines a remote control operation first, and then a manual and locally operation. This sequence may last several tens of minute (sometimes a few hours), depending on the complexity of the network (number of the derivations and number of distributed EPS switches, on the lengths of the lines). A trial and error process is stressing for equipment (switch on with a present short-circuit) and needs time (the main breaker of the feeder in the substation is used iteratively).

Because the power flow and the current fault are clearly oriented, from the substation to the fault location, the non directional indicators are sufficient: the last activated FPI is above the fault, and the following and non activated FPI is under the fault.

In the present system, they are more EPS switches installed than FPI, so a necessary iteration of trial and error is carried out.

4.3.3 Load shedding

Load shedding is defined[*1] as: “the process of deliberately removing pre-selected loads from a power system, usually done automatically by relays, in order to maintain the integrity of the system under unusual conditions. “

Current practice depends on hardware control, using lines and generators. Load shedding basically means nothing more than disconnecting a radial feeder on 10 - 50 kV level. Sometimes you try to avoid area with elevators. Hospitals and other very sensitive

[1] Definition given at http://www.bpa.gov/Corporate/KCC/defn/defnsmal/l.htm

institutions are supposed to have their own backup. The most common criterion to activate load shedding is low frequency, with or without time delay, also undervoltage criteria and rate of change of frequency exists, but are much less common.

4.3.4 Load management

A main focus in current practice is on planning of the supply of electricity based on the expected demand. From the time-of-year, meteorological prospects and feedback of historical consumption data the demand of electricity is predicted 24 hours ahead as a base load, which has to be supplied. The supply is accounted for by delivery contracts, trading on a central market, the power exchange, which also encloses import capacity. One hour before delivery fine-tuning of the demand is made and differences are accounted for on the trading market or by ancillary services.

This fine-tuning market and ancillary services are one way of dealing with system peaks in demand. Another, and supplementary, way of reducing the system demand is to control customers load by load management. Load management can be defined[1] as: “methods or programs to reduce, reshape, or redistribute electrical loads to match available resources and comply with long-term objectives and constraints; generally, attempts to shift load from peak use periods to low use periods.” It differs from load shedding in the fact that load shedding tends to be performed as an emergency strategy. Load management is closely related to demand-side management (DSM). DSM can be defined[*2] as: “the strategies that focus on influencing when and how customers use electricity, with an emphasis on reducing or levelling load peaks, such as conservation measures and rate incentives for shifting peak loads, and energy storage schemes for reducing, redistributing, shifting, or shaping electrical loads.”

On demand side management experience in Sweden we focus on the Sydkraft experience. In the late ‘80s and early ‘90s Sydkraft made a substantial effort to develop demand side management and related knowledge. The interest stemmed from a need for generating capacity to cover the peak load demand of no more than a few hours a year. From this the question raised whether it would be not only possible to solve the peak load problem on demand side instead, but if this was an economical alternative too.

Both residential – i.e. small-scale – loads and industrial loads where involved in these schemes. The efforts of Sydkraft’s to utilise consumption side dynamics in such a way did not survive the transition to a liberalised power market.

Today e.g. industrial consumers in Sweden with alternative fuel possibilities that are buying (part of) their energy at dynamic prices may act price reactive. There is typically no or weak knowledge on distribution side of what action is taken by these actors. Furthermore Svenska Kraftnät, the TSO of Sweden, has engaged a number of large industrial actors in a scheme for reduction of extreme peak load (see the Annex of D 1.5 Intelligent Load Shedding [4]). From the experience of both Svenska Kraftnät and Sydkraft we could deduce that there is a potential in the industrial sector that could be involved more in the future.

An overview of both Sydkraft experiences regarding demand side management and the concepts of price reactive actors and full electronic markets is given in the Annex to

[1] Definition given at http://www.bpa.gov/Corporate/KCC/defn/defnsmal/l.htm

[2] Definition given at http://www.bpa.gov/Corporate/KCC/defn/defnsmal/d.htm

deliverable D 1.5 Intelligent Load Shedding [4]. The overview concerns both supply – demand matching and intelligent load shedding.

Most supply – demand matching techniques (involving demand side action) that has been developed in practice or in theory rely on estimations of the effect of a demand side action. Good estimations of the effect relies either on (i) a good personal knowledge and experience among involved personnel, or (ii) other knowledge based on consumption patterns of the involved consumer categories, etc. Sydkraft was involved in a large study on load patterns and load calculations published by Svenska Elverksföreningen in 1991 [15], this (and similar) material is interesting as a base for calculations on effects of different load side actions.

4.4 Large scale distributed generation

A distributed grid is characterised by an electricity network infrastructure in which a high degree of small scale Distributed Generation (DG) is absorbed. Critical parameters used in DG are [1]:

- The location of the producer and the production system that is positioned in the customers' installations or just outside. This is the case of the definition given by Energy Department of the United States and by California Alliance for Distributed Energy - CADE.
- The connection point to the network: only the energy sources connected to the distribution network and not to the transmission network constitute DG. This is the criterions employed by Cigre Work Group WG 37-23 and by Trade and Industry Department of Great Britain – DTI.

As in [1] we enhance these views by considering every generator connected to the electric network in the sub-transmission system or in the distribution system as part of DG, without any limit to the power generated.

The traditional operation is modified by the penetration of Distributed Generation (DG) and in some cases, the power flow can change its direction i.e. the distribution grid could be a power receptor.

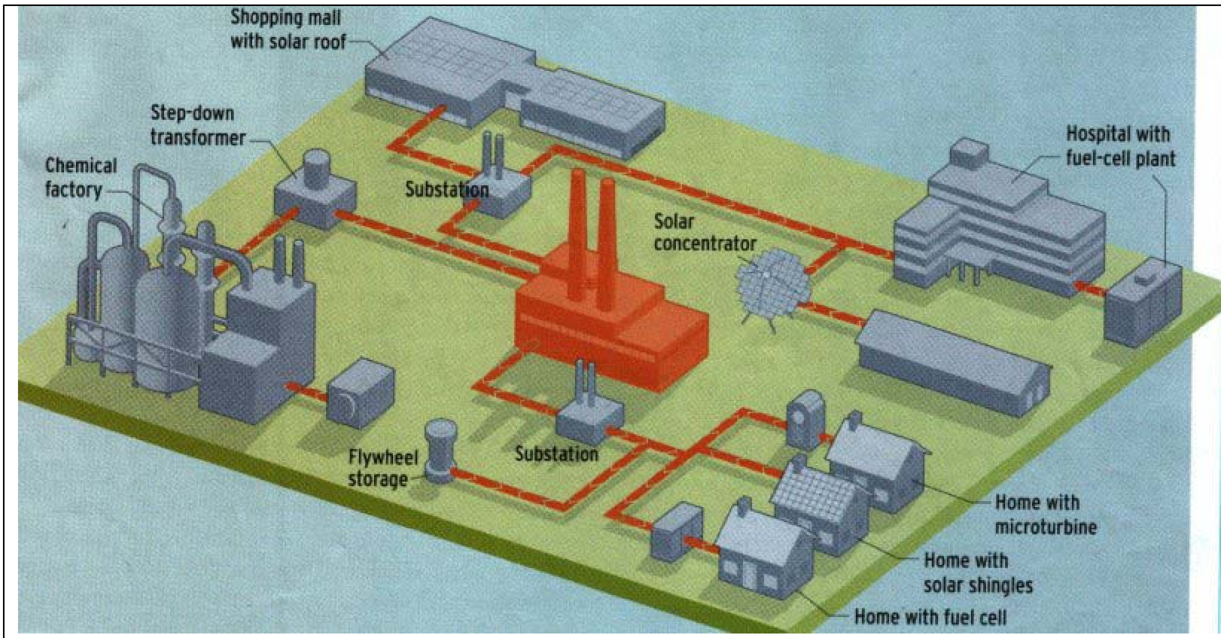

Figure 15 DG power system – from IEEE Spectrum, January 2001

New technologies, which can be seen as (part of) the next means of energy generation, lead inevitably to a growing share of distributed generation:

- Gas turbines have been implemented on a large scale. One reason for introduction of gas turbines has been the demand for peaking capacity, which can be delivered
  Power range (10 – 200 MW) depending on type of use.
  Heat driven, power exhaust, either to be used locally or to be redelivered into the grid.
  Power driven, heat waste utilisation.
  Control: PLC provisions.
- Micro-turbines can be seen as small gas turbines with power from 25 kW to 500 kW. One of the main areas of implementation is the residential houses where micro-turbines may replace central heating installations. One of the operational challenges of micro-turbine application is the control of large numbers of them as a 'virtual power plant', where surplus power can be sold in the distribution network.
- Diesel generators and Stirling motors basically serve the same functionality as gas turbines and micro-turbines.
- Fuel cells are devices that convert chemical energy directly to electrical energy. The preferred fuel for most fuel cells is hydrogen. In order to produce the hydrogen fuel secondary fuels may be utilised, such as methanol.
  Power range from kW (micro-fuel cells) up to MW order.
- Wind turbines constitute a large percentage of the renewable energy supply in Europe. They are applied from single turbine up to large on-shore and off-shore installations, thus providing power plants up to 50 – 100 MW.
- Solar Photo-Voltaic (PV) convert sunlight directly into electricity. A main application of PV is as stand alone systems in remote areas where it replaces a complex power infrastructure. It is also utilised within the distribution network, mainly integrated within

buildings, e.g. on the roofs of houses. The yearly production is in most cases substantially less then the yearly household consumption. If applied in regional PV power plants the power can be traded within the distribution network.
Power range few kW up to MW (PV power plants).

- Small-scale biomass plants can provide renewable energy within a distribution network by utilising biomass waste as fuel in combustion or gasification processes.
- Energy storage technologies can be used to bridge the time gap between production of electric energy and its use. Several types of energy storage exist but they tend to be expensive. Storage times vary from seconds to days or even seasonal storage.

We will not go into detail on these technologies. One is referred to literature such as [1] and [6].

4.5 Shift in grid operation

Table 1 gives an overview of the main characteristics changing when shifting from a traditional grid to a cell-based power grid. In the list both power characteristics, and characteristics from the point of view of operation and maintenance, and ICT characteristics are considered. Note that in the table two extremes are sketched. In reality the traditional grid is already moving. The resulting situation will be a hybrid one. However, in the CRISP project we are interested in the implications of decentralisation on network operation.

	Hierarchic / Traditional	**Distributed**
Energy flow	Plant to customer; HV → LV → MV	Customer to customer; within LV / MV network
Units	Large + HV	Small + MV
ICT	SCADA / DA and DSM	Autonomous + Local DA/DS&M
Modelling metaphor	Process – data – behaviour	Agents
Topology	Top-down	Bottom-up
Behaviour of nodes	“Dumb”	“Smart”
Overcapacity	Spinning reserve	Dynamic balancing / other MV cells
Protection	Macro events	Micro-events
D&S (T)	Predictable	Less predictable, esp. RES
Time ahead planning	Market controlled; day / hour ahead	Several time scales up to seconds
Market model	Trade + retail, liberalised, distribution regulated by law	Micro-transactions

Table 1 Shift in grid operation

4.5.1 Fault detection and diagnostics

The Distributed Generation causes several impacts in the operation of the whole system:

- Energy flow direction could change, also in case of fault of course. Since most components used for detection in the network are non directional, this requires modifications in the protection strategies. Solutions with directional FPI are already available, but monitoring a lot of FPI may be expensive.
- The short-circuit power due to a generating unit or a group of generating unit is no more a problem with the directional FPI: if the indicator is activated, the position of the fault relative to the indicator is given, and if the indicator is not activated (too low DR fault current contribution) the fault is located above the FPI. We assume that the threshold is set with the interconnected EPS.
- The distribution network is no longer a passive circuit supplying loads but an active system with power flows and voltages determined by generation as well as loads. As the amount of the distributed resources and the loads are not easy to collect at any time, assumptions and simplifications are necessary to evaluate the fault distance. The error induced by fault resistance will be reinforced by the DG feeding the fault. An advantage of this kind of evaluation is to use existing installed hardware and measurements in order to help to locate the fault.

The need to reduce the break time during protection sequences including fault location sequence leads to a fast combination of information analysis and exchange between a central control system (fault distance analysis is expected to be achieved inside the HV/MV substation) and distributed MFPI (the monitored fault path indicators are installed at specific points of the network in order to limit their number).
The proposed solution with this kind of fast fault location may allow the operator to minimise the amount of disconnection of DR in the future, the long term target being to introduce the fault location sequence inside the first protection sequence (in order to avoid a full feeder disconnection as currently done in Europe when the fault occurs in the public distribution EPS).
The solution proposed for the experiment is oriented on this kind of solution for the future with a massive installation of DR. See also Figure 10.

A main advantage of the proposed solution is to use existing and experienced devices and methods in the current EPS, to combine and adapt them to the future distribution characteristics and to speed dramatically the analysis and exchange of information thanks to ICT. The existing sequence may be highly reduced in time and adapted to any amount of DR installed in the distribution associated. The first approach will not allow us to introduce this sequence into the protection sequence, but the minimum time reached will give us the remaining gap and the identification of the weak points.

4.5.2 Intelligent load shedding

The traditional load shedding scheme, which has hardly been developed over the last 100 years, is less and less acceptable in today's society. The developments in computer and communications technology allow us to abandon the stage of hardware control and rely more on intelligent control in order to maintain power system stability.

In D1.5 [4] intelligent load shedding is defined as:

- a means to improve power system stability,
- by providing smooth load relief,
- in situations where the power system otherwise would go unstable.

The objective of load shedding remains unchanged. The means to improve power stability using intelligent load shedding changes to addressing individual loads in an area, based on knowledge about the power system and these loads, in order to switch off or reduce power for a certain time.

Intelligent load shedding deals with (i) the problem of detecting situations that will go unstable if no remedial actions are taken, and (ii) to take proper action in such a way that stability is restored by minimum cost load shedding. Intelligence and communication are essential means in order to achieve this. Communication is needed in order to obtain information on where and when load shedding is needed, to obtain information on individual loads and their constraints with respect to readiness to shed, and to address individual loads in order to reduce load or switch them off. Intelligence is needed in order to find optimal scenarios for the amount of load to shed and the location of these loads.

A main consideration in intelligent load shedding will be the cost criterion. Strategies may be based on dynamic prices and an electronic market.

4.5.3 Supply and demand matching

The need for load management is not reduced when distributed generation enters the grid. However, it is not only the load requests that influence planning of supply. Since also (part of) the supply is dispersed over the network, this has to be taken into consideration in the planning.

Depending on the type of distributed generation different properties may characterise the power supply:

- Most renewable energy resources, such as wind energy and solar power, are dependent on local weather circumstances and are subject to relatively large uncertainties. When they are applied on a large scale, this may have a substantial influence on the balance, locally as well as on higher levels.
- Management of combined heat and power (CHP) units is often based on the heat demand of the premise or area supplied with heat. Depending on the heat demand they either deliver electricity at different capacity levels, or they are not delivering any power at all.
- The usage of CHP-units can also be based on power demand, e.g. by adapting to peak demand e.g. at the premise. In a liberalised market we can enhance this concept by adaptation to peak demand within the distribution network.

In a distributed environment, traditional load management or demand side management does not cover the full planning scope. A need for developed supply and demand management becomes apparent. In the CRISP experiments and simulations we will introduce the concept of supply and demand matching as a way to control the power balance within the distribution network. In this, both distributed generation and consumption side could contribute and benefit.

Consumption side

The potential of consumption side action is large in many countries, but the character of the potential differs from country to country due to variations in consumption patterns. Here we take Sweden as an example.

In Sweden approximately 40% of the total consumption of electric power falls into the residential category (including some services). Furthermore, 40% of the small residential houses are electrically heated. Heating of apartment blocks is mainly based on district heating [1]. Hence from a Swedish viewpoint, action in the residential sector is an alternative that could have a major influence on the dynamics of the power system.

A major drawback of involvement of residential loads in any scheme is that each unit is so small that investment costs need to be either low or give other surplus to participants that motivates the investment. Anyhow, the Sydkraft experience [16] is that it is possible to involve residential loads in an economically justifiable way, since there is a high penetration of electrical heating of both buildings and tap water in Sweden.

The second largest sector (when it comes to energy usage) is the industrial sector. It is much harder to estimate the potentials of this sector, since each customer has to be studied and treated separately, in particular when it comes to the larger actors. On the other hand, the potential of each unit that is found attractive to incorporate in a supply – demand matching scheme typically is orders of magnitude larger.

The experience within the current situation in Sweden is that when it comes to cutting the most extreme load peaks, the need for controllable load is in the order of a small percentage of the total load. On the other hand, the potentials of advanced load side action schemes are much larger and hence they open up for enhanced utilisation of the dynamics within power markets. Furthermore, as increased power consumption gives a higher utilisation of production and grid, and hence smaller peak load margins – the need for controllable load is growing.

Supply Side
The large actors on supply side – the large power suppliers – are already part of today's supply – demand matching schemes, i.e. they take part in the trade on day-ahead markets, and some are engaged in balancing services, etc. The new actors on the market, small scale distributed generation, in general are not. When incorporating them, one has to pay attention to the properties of different energy sources. Properties that could be a challenging problem and that sometimes could be utilised to enhance the market in new ways.

Taking two market perspectives as a starting point, we could look at the specific problems of some of the new suppliers. There are short time uncertainties that make it hard for e.g. distributed renewable energy sources such as small-scale wind power plants to act with their full potential on planning markets such as day-ahead markets (in that case, since the uncertainty of weather forecasts is large when the market is cleared). Another example is micro hydropower plants with limited water supplies that have long time uncertainties on upcoming demand, rain, etc that make it hard to decide when it is optimal to utilise the resource. Other actors, mainly CHP-producers, have an optimisation problem to deal with; how to act optimally with respect to both heating and production of electricity for the market.

New Matching Techniques
An issue when it comes to development of supply – demand matching techniques is the control perspective. Traditionally we think of control as in the hands of the energy utility. An alternative approach is to rely more on distributed control, not only in the sense of physical distribution of control in the grid, but distribution to other actors than the utility / distribution system operator / power supplier, i.e. the end users.

Peak load shaving techniques of the kind that Sydkraft among others has experience of could be a base for development of schemes for supply – demand matching. Both consumption and some distributed energy resources do logically fit into such schemes. In this case control is still in the hands of one of e.g. the supplier.

Another approach is to introduce price reactive action on a larger scale, i.e. to give incitements for optimisation of energy usage and (small-scale) production in terms of dynamic prices. A logical price to operate with would be based on the prices of the day-ahead markets. In this case control would be transferred to end-users. A major drawback is that with large price reactive volumes in combination with a market such as a day-ahead power market, the price establishment process might be severely affected in an unpredictable way.

A third approach is to move one step further and introduce electronic markets for electricity. In this way, end user dynamics are utilised as in the price reactive scenario, but without the major drawback of that scenario – the unpredictable global effect of local optimisation. Since the end users act as participants on the market (in terms of software agents representing their interests) their behaviour affects the price establishment, i.e. the global optimisation. In this way, local optimisation may be utilised for demand – supply matching. More on the three concepts can be found in the Annex of deliverable D 1.5 [4].

In this presentation we have modelled the opportunities with respect to day-ahead markets. With small changes they apply to e.g. balancing service markets too.

4.6 Requirements for the PS-Node network

- The overall failure rate of the energy supply should not be higher and preferably lower than that of a traditional network. In the Netherlands typical availability of the LV and MV electricity grid is 99,995%. Typical availability of different types of communication networks are in the range of 99.9% - 19.99%. Therefore energy supply on the PS-node network should not be dependent on the availability of the ICT- and SO-layers.

5. The SO-Node Network

The main role of the SO-Node network (c.f., Figure 1 and Figure 2) is to collect data from the PS-Node network, via the ICT-Node network, process the information and act accordingly by sending messages back to the PS-Node network. The main functionality is the network control. However, the SO-Node network also plays a vital role in the dependability assurance of the total system. Of course, real time constraints might demand local reactive behaviour (damage control) in parallel with pre-processing and proactive measures determined by the SO-Node network.

The terms ‘application’ and ‘service’ are often used intermingled. In the context of the SO-Node network we will differentiate between the two in the following way, thus conforming us to the OSGi:

> *A service is a self contained component, accessible via a defined service interface. An application is built around a set of co-operating services.*

In other words: the services are building stones which can be used in order to develop applications. Different service implementations, each with the same interface, can be used to perform the same functionality. For example, different communication services can exist to deliver information from one source to another. Depending on the context and the available infrastructure an application can choose one or more communication services as part of its operational scheme.

The SO-Node network is designed as a service oriented architecture. An important subset of services is connected to components of the PS- or ICT-Node networks. Other services support, e.g., business processes or security measures, or high level reasoning capabilities. For instance, the SO-Node network may act as a mediator/conflict manager in the cases where the ICT networks and the PS network have conflicting strategies for obtaining optimal performance, according to some quality measure. The clear separation of concerns between the different networks (PS-Node, ICT-Node and SO-Node) benefits the design, implementation and maintenance of the system as a whole. Furthermore, it enables us to, in a systemic way, separate validation/verification of the sub-systems and models within the project, and provide a dependable interface for integrating new intelligent services into the system.

Services can have different views. In the context of e.g. supply and demand matching a service is an encapsulation of, and means by which, intelligent agents can communicate and co-operate with a set of other services (agents) in a manner that is not, necessarily, predetermined at the time of installation. In demand-and-supply-matching-related services we will focus primarily on the PS-related services within the >10s time scale, e.g., supply and demand matching.

5.1 Characterisation of services and applications

Fault detection and diagnostics, supply and demand matching and load shedding are three application areas that can be seen as supplementary to each other. One of the differentiations that can be made is the time scale:

- < 0.1 s fault protection, diagnostics
- 0.1 - 10 s emergency prevention, intelligent load shedding, system robustness
- > 10 s normal operation, supply and demand matching

Each of these types of application will have their own specific requirements. The service orientated network should support an environment in which applications can function either as separate items or as co-operating and mutually supporting structures.

One of the applications that can be performed on the SO-network is supply and demand matching. The overall goal of the supply and demand matching is that it should increase the cost-effectiveness of DG networks in a deregulated market, by examining and exploiting various sources of information, such as:

- price/cost information
- demand/supply profiles
- different quality of service levels for different customers

By incorporating these functions into a service oriented framework we will have greater freedom of validating, changing, and supplementing the supply and demand matching service(s) and the information sources themselves. For D2.1 the potential models should be described, how they relate to the systems and services. The tools constructed should simulate these sources and serve as a means to validate the interfaces and enable future connection to live data feeds. Furthermore, the tools produced shall support dynamic reconfiguration and measurements of these properties as a means to validate the ICT system functions.

The services for supply and demand matching, fault detection and diagnostics and load shedding scenarios will be described in chapter 8 (8.2.2, 8.3.1 and 8.4.1). The focus in this chapter lies in construction a framework for service-oriented networks, and will be provided for by BTH.

5.2 Actors in energy supply

In order to determine the environment of the field of energy delivery, we need to define the actors performing in this field. In the scenario development and the requirements specification we need to clarify whether they have activities in a specific scenario and how they influence the outcome of the scenario.

- **Regulator**
  In the Netherlands the DTe ("Dienst uitvoering en Toezicht Energie") functions as an independent arbiter for the gas and electricity market. Its main task is to supervise a correct implementation of the "Elektriciteitswet 1998" and the "Gaswet" (1998 law on electricity and gas) DTe is under the jurisdiction of the Dutch Ministry of Economic Affairs. DTe also fixes the tariffs for transmission and distribution of electricity.
  Other countries in Europe have similar bodies guaranteeing a correct implementation of the electricity deregulation process according to the EU guidelines in [8].

- **Transmission System Operator**

The Transmission System Operator (TSO) is responsible for operation and maintenance of the transmission system within an area, and its interconnection with other systems, including import/export.
The main task of the TSO is the reliability security of electricity supply. It manages the continuity of electricity supply on medium an long term, and the (im)balance of supply and demand on a second to second base. It also is in control of ancillary services.
In the Netherlands TenneT serves as the TSO.

- **Distribution Network Operator**
  A Distribution Network Operator (DNO) manages the distribution network and is obliged to supply all customers within the distribution area. It is responsible for operating a secure, reliable and efficient electricity distribution system. The DNO must ensure network access for all users, and will charge distribution tariffs for so called Third Parties Access. These tariffs will be regulated by the regulator.
  In the Netherlands a score of regional licenses for distribution system operation are given, which are owned by utility companies. The DTe fixes a maximum tariff for distribution cost.

- **Market Operator**
  The Market Operator manages the wholesale energy market on a short term and long term base. The long term base is a day ahead market, where on every hour suppliers and eligible customers may place a bid for selling and buying of electricity respectively. The Market Operator determines the equilibrium prices and fixes the contracts. On short-term, normally one hour ahead, adjustments can be made by both suppliers and customers, based on deviations in supply and demand patterns. These adjustments influence the price of electricity.
  In the Netherlands the APX (Amsterdam Power eXchange) acts as the Market Operator. The Market Clearance Price and the Market Clearance Volume are decided on based on a two-sided auction model for supply and demand. The APX works in close co-operation with the Transmission System Operator TenneT.

- **Producer**
  Traditionally a producer operates and maintains the big central power plants. Producers can sell their produces energy on the wholesale market, to energy suppliers and directly to eligible customers.
  DG also introduces small scale producers. From the customers point of view a difference can be made between the roles of **Close Producer** (on the same low-voltage network as the consumer) and **Remote Producer** (beyond higher level voltage distribution and transmission network).
  In the Netherlands large scale generation capacity is still mainly carried out by the ‘traditional’ energy suppliers, such as Essent, Nuon, Delta. Foreign energy companies have taken over part of the large scale generation capacity.

  Note that we can not restrict our view to electricity production since, esp. in supply and demand matching, we have to consider the case of co-generation.

- **Supplier**
  A supplier sells electricity to customers. Usually a contract with a customer determines the terms of delivery. The supplier pays the transmission and distribution fees to the Transmission and Distribution System Operators.

A supplier is not required to produce its electricity, but electricity can be contracted from producers and bought on the wholesale market.
In the Netherlands NUON, Essent, Eneco are the main suppliers (93%). New entrants are coming up due to the market liberalisation.

- **Customer**
  The customer purchases electricity. We differentiate two roles of the customer: The **Wholesale Consumer**, who purchases electricity for the purpose of resale, and then acts as a Supplier; and the **Final Customer**, or **Consumer**, who effectively consumes the electricity.

  In DG we can also differentiate between the roles of **Close Customer** (on the same low-voltage network as the producer) and **Remote Customer** (beyond higher level voltage distribution and transmission network).

  Another new element in a distributed generation environment is the fact that the customer, who traditionally only purchases energy, the **Purchasing Customer**, can change its role to **Selling Customer**. In many cases the purchasing and selling customer is the same person or institution.

  A further role division can be made between the **Eligible Customer**, who can buy electricity from market parties, and the **Non-eligible Customer**, who is forced to pay electricity at tariff prices. Due to deregulation of the energy market the latter will become extinct in the EU countries in due time.

- **Energy Service COmpany**
  Energy Service COmpanies (ESCO's) are dealing not with electricity as a commodity, but with electricity services towards the final customer. Besides delivery of electricity these services can exist of: energy saving; installation and operation of on-site equipment, financing and assuming risks for energy efficiency measurements

Other trends in energy supply
The emergence of renewable energy resources as a niche energy market places different actors on the market with special profile. **Green Suppliers** profile their electricity as coming from guaranteed renewable sources. Also customers can profile themselves as **Green Customers**. Renewable energy itself can further be divided in wind or solar energy, hydropower, biomass, etc.

ICT actors
Support of energy supply services will be delivered using ICT. Therefore also actors from the ICT field need to be determined.

- **Network operator**
  The ICT network operator is responsible for all operational aspects of the ICT communication infrastructure: configuration; fault management; security, performance.

- **Service company**
  The service company uses the ICT network for delivery of services on the network. It is responsible for proper execution of the content of these services.

5.3 Role of agents

5.3.1 Introductory notes

In the CRISP project the tools described here are to be used for simulation of market-based approaches to *(i)* intelligent load shedding (ILS) and *(ii)* possibly supply – demand matching (SDM). The main concern of the simulations is to investigate the potentials of a market based approach to ILS.
The system should be developed as an agent system i.e. software agents represent all major entities in the system.

The plan is to compare the market based approaches to ILS with a corresponding simulation of actions based on more traditional techniques, such as peak load shaving techniques.

5.3.2 Description based on the agents of the system

One way to describe the system and its entities is to start with the physical entities that should be represented and derive the corresponding logical entities. The physical entities are the end users and the critical nodes in the power grid, mainly substations. From them we derive their respective logical entities, as agents acting in the electronic market system. One could argue that only the end users need to be modelled together with a central marketplace, but in this setting the idea is to structure the market hierarchically, such that the hierarchical structure of the power grid is reflected in the market structure. In this way it is possible to achieve e.g. a market for ILS that could act locally on any level of the structure.

An agent of the system could be acting on more than one electronic power market. In this context a specific market is related to a time horizon. ILS markets are to operate instantaneously. SDM markets are thought of as day-ahead[1] markets and adjustment markets down to close to real time markets that are used as a balancing service (trading down to minutes ahead of real-time).

The market system could be viewed as a hierarchical tree with participant agents as leafs and intermediate market agents as inner nodes in the tree [19].
The leaf nodes are denoted “end user agents”, and are not specified as consumers or producers, as they might be either (buying) consumers or (selling) producers, or even have the capacity to act as both on the market.
The inner nodes are denoted “system cell agents” or “cell agents” as they – particularly in the ILS case – are thought to match a “cell” in the power grid, i.e. an HV cell, an MV cell, or an LV cell, as described elsewhere in the CRISP documentation.

In the ILS case there is no central market node (agent) that is different from other cell nodes (agents), load-shedding action can be initiated at any level in the system. On the other hand, day-ahead markets are cleared on a regional (e.g. national) level, as day-ahead markets of today are.

[1] We use the notion of day-ahead markets as this is the practice of today, even though the perspective of such a planning market does not have to be a full day, and market clearance e.g. could come closer to real-time than today. For example, with an eight-hour-a-time planning market where bids are to be given twelve hours in advance, the last hour traded is twenty hours ahead instead of 36 hours ahead as it is on the NordPool Spot Market of today.

All agents

All agents of the system should

- have an interface to and knowledge of other agents that it is relevant to communicate with in the hierarchical market structure, Figure 16, and
- be able to handle constraints, e.g. flow constraints, and incorporate them into their market behaviour. The constraints could be both static (a max flow over a substation, flow direction constraints, minimum and maximum capacity of an end user), and dynamic constraints, due to changes in the power grid (loss of lines etc.).

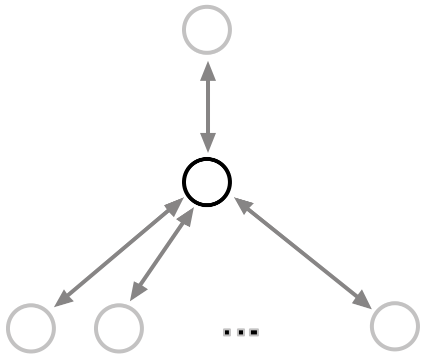

Figure 16: Agents at all nodes should have communication interfaces to relevant nodes in the system, i.e. closest higher level agent in the system and agents representing subsystems.

End user agent

An end user agent should

- have the capacity to calculate and put a bid on any market where it is active. The bid should be given according to a predefined bid format (to be specified),
- a bid should be delivered on demand and/or when the status (demand or capacity) of the end user is changed, according to the rules of the market,
- react correctly on price information, and
- have an interface to the underlying system of loads or internal load agents. In practice the end user behaviour within the simulations could be defined in text files.

Since end user agents representing different end users might have properties that differ substantially, a basic end user agent (with basic market behaviour and communication features) could be a kind of template or super class that other more specialised agents could be derived from.

System cell agent

A system cell agent acts on behalf of an inner node of the hierarchical structure of the markets.
A cell agent shall be able to

- ask for bids from substructure agents,

- receive bids from the same category,
- communicate changed bids upwards in the hierarchy,
- set prices, and
- communicate prices, whether set by itself or received from super level,

and all this should hold for all different markets.
Furthermore, it should have an interface towards the technical ILS-system, such that it is possible to initiate an ILS action within the cell.

Central market agent

A central market agent is a cell agent with capacity and responsibility to calculate equilibrium prices on SDM markets.

System cell agent with "aggregated subsystem"

For a number of basic simulations of system potentials there is no need for to simulate all actors as individuals. A leaf node of the simulation system could represent a set of actors, e.g. an LV-cell in the power grid, with an aggregated behaviour.
The corresponding agent type could be derived from the basic end user agent.

5.3.3 Description based on market perspective

Another way to describe the system (and the properties of its entities) is to start with the market perspective (or time frame).

Intelligent load shedding markets
On any aggregate level of the system, i.e. in any kind of a cell, the following should hold for the agent:

- at any instant it should have an updated knowledge on volumes available for load shedding and at what costs,
- updates higher level agent whenever it updates its own knowledge,
- it should take immediate action on volume signal from the technical supervision system of the cell or on price signal from the higher level agent, and
- when it is not able to meet the demand for load shedding the technical system takes over and uses traditional "red button" principles.

Close to real-time markets
Not specified yet.

Basically an agent (representing a cell or an end user) should give a bid when demanded (or even on his own initiative, when the state of the system he represents has changed). A number of different approaches to how to define the good in this setting are possible. The good could be *(i)* energy to be delivered during a short, predefined time period[1], *(ii)* energy to be delivered during a short time period that is defined when the bidding start, and *(iii)* it could be defined as a power level.

[1] The time period is in the order of minutes.

Day-ahead markets
On demand an end-user agent should enter a bid for a specified number of consecutive time slots (e.g. hours) according to a specified bid format (to be defined).
Cell agents aggregate the bids of their cell, and give the resulting bid to higher level agent.
Central market place agent computes a set of equilibrium prices based on the given bids.

5.3.4 Bids

Bid formats for the different market types are yet to be defined. On ILS markets they should reflect the load volumes available for load shedding action, and the associated cost. On close to real-time markets adjustments in consumption and production are traded. On day-ahead or planning markets there might be possibilities to express some dependencies between time slots [20]

5.3.5 Input data

In the planned CRISP simulations input data from the Öland grid will be used. Some details on customer behaviour, e.g. the flexibility of their consumption patterns, are not available. In these cases realistic assumptions are to be used and clearly stated in the simulation reports. End user behaviour could be described in text files used as input to the simulations. Details on file format etc. have still to be decided.

5.4 Requirements for the SO-Node network

The requirements for the SO network are separated in the following subsections.

Infrastructure
It shall be possible to interface the SO nodes with the PS and ICT nodes in order to facilitate intelligent behaviour utilising the information exchange capabilities of the ICT network and the physical coupling of the PS network.
A service oriented layer will be built in which the ICT and PS nodes can be addressed and interfaced with as services.
Tools to observe and interact with the services in this network will be built. They should provide the support of both static configuration of the system and dynamic reconfiguration of this system.

Models
In order to mediate (see Section 5) between the ICT and PS networks, services that encapsulate intelligent agents are to be constructed. Specifically, services for supply and demand matching should be constructed. Furthermore, enabling technologies and services supporting the major requirements shall be defined.

Domain
For the purpose of this work package, the SO-network shall primarily enable experimentation of the system with respect to different operating properties and strategies. This enables observation and articulation of a more refined set of requirements for the qualities that relate to intelligent supply and demand matching, with respect to ICT, SO, and PS –network capabilities. Furthermore, new business opportunities in the deregulated market may be identified.

Requirements

1. The nodes should be hot-configurable. This means, that software components should be able to be inserted in the network without shutting down existing applications. Configuration of the nodes should be possible without interference to current operational tasks. Configuration data for instance may include changing underlying databases.
2. The network topology should be hot-reconfigurable. This means, that network connectivity schemes should be dynamically changeable over time. According to changes in contracts it should be possible to invoke changes in the cluster configuration and size of producers or consumers.
3. The availability of additional services (not related to safety or reliability of energy supply) should be high enough to ensure profitability of these services. This means that financial losses and customer dissatisfaction due to failures in the ICT-node network and the SO-node network should be limited. This can either be done by increasing reliability of the ICT- and SO-infrastructure (which is more than just the network) or by increasing robustness of applications.

6. The ICT-Node Network

ICT is not a miracle cure for every problem. ICT should be seen as an enabler of functionality. In Figure 2 ICT is modelled as the 'glue' between the PS-node network and the SO-network. It enables services across the network and hence the enrolling of applications such as supply and demand matching. Network operation in traditional grid operation is already based upon a dedicated ICT network, enhanced with a SCADA network which enables monitoring and control of the PS-node network on the time scale of milliseconds. This dedicated ICT network operation should under no circumstances be disturbed by the introduction of new services. Under this restriction new services may take over (part of) the SCADA monitoring and control.
Thus we should differentiate in the ICT network two 'layers': the dedicated, layer laying close to the PS-node network; and a supplementary network functionality enabling services on the PS-node network.

Mainly because of the developments in the Internet society the ICT-node network has changed dramatically in the last years and will change even further in the near future. Emphasis has shifted from data handling towards information exchange due to emergence of new communication infrastructures, such as cable, dsl, wireless, plc, etc., facilitating always on Internet and broadband connectivity. Low-cost local intelligence allows new decision infrastructures in which (partial) autonomy plays an important role. This autonomy is supported by new paradigms such as agent technology.

The economical impacts are large. Business processes are being streamlined within companies and between companies using the Internet paradigm. Also at a consumer level micro-transactions are becoming common: on-line stores and marketplaces such as www.amazon.com and www.ebay.com are replacements or supplemental to traditional shopping; the iTunes Music Store initiative from Apple (www.apple.com/music) is a promising answer to the music piracy. E-Services are emerging for e.g. health care, security, energy related services.

6.1 Network topology characterisation

One of the main consequences of the distributed grid will be a shift in the decision process from centralised management to new levels of control. In chapter 4 we have seen that the PS-node network is changing from a traditional hierarchical top-down network into a network in which on different levels a more autonomous control will emerge. The functionality on such a network can be summarised as follows:

- monitoring and control of the state of the power network;
- ensure safety, stability and quality of the power network;
- protection of the network and emergency control;
- enable the control of large scale small energy supply;
- ensure partly (or not obstruct) local independence of power networks;
- enable supporting strategies such as load shedding and supply and demand matching.

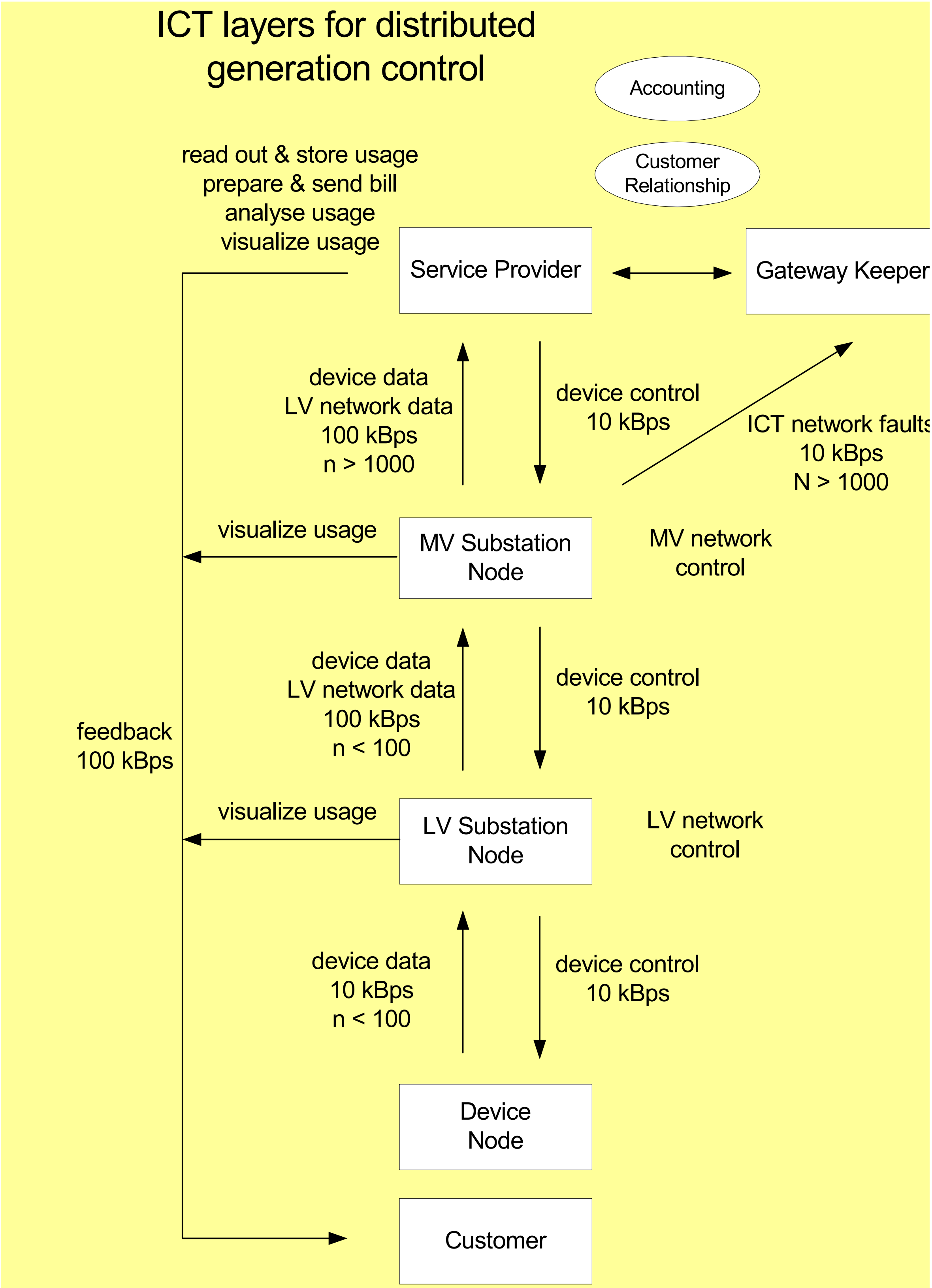

Figure 17 ICT layers for distributed generation control

In order to facilitate these tasks by ICT we will have to identify both a physical ICT network topology, and a logical structure. The physical topology can be used as a base communication network for monitoring and control of the power network. It will closely relate to the information nodes in the power network infrastructure.

The logical structure is reflected in the software applications operating on the power network. The main task is to identify the decision nodes in the ICT infrastructure. A logical structure, based on a bottom-up approach, can be defined as follows:

Embedded device control – at this level each device, in its connection to the grid, can act as a stand-alone unit, independent of its surroundings. A number of topics in the area of safety and quality can be solved at this level as well as optimal performance of the device.

Aggregation level – at this level local intelligence can combine devices into subsystems, in which a number of devices are co-operating. A subsystem can be e.g. a virtual power plant, a bundled load request, a self-supplied power grid, etc. Internally each device can be seen as an independent entity, while to the outside world only the subsystem itself is visible.

Local access & control – devices within a subsystem may need to interact which each other in order to take proper measures. The local access node may gather information from a wide area network, make evaluations and decisions, and communicate decisions to each device. Also at this level a number of topics in the area of safety and quality can be solved.

Central unit – general overview functionality as performed traditionally by the central grid operator.

The heart of the ICT network is formed by the communication infrastructure. If an always-on connection is required, this will not pose any problems. With respect to the physical data transfer medium a large number of combinations can exist between powerline, RF, cable or fibre optic to interconnect individual nodes. We will have to consider two main topics in the communication infrastructure: connection failure and security. The latter shall be addressed in other CRISP reports.

6.2 Hardware and software developments

Application area

As we have already brought forward earlier distributed generation networks can benefit largely from distributed control and intelligence. ICT-based control techniques have indeed evolved more and more from central control and intelligence to distributed control and intelligence. Devices have become smaller, smarter, and more networked. A number of open network standard already exist, based on industrial PCs and microprocessor-based intelligent devices. As a consequence one of the main requirements will be the operation in a multi-vendor environment. This is helped by the fact that network standards more and more integrate with TCP/IP and Internet technology, this providing easy access from anywhere.

Advantages of distributed control are a.o. time saving and problem simplification. By working on nodes parallel network traffic is reduced and we don't need sequential central processing. And by breaking the problem up into smaller parts, handled on each node separately, the complexity can be diminished.

Easy operation of distributed control applications requires a number of issues to be solved: plug and play both for hardware and software components; remote deployment through the network; change control; operational self-diagnostics.

In such a distributed control environment the design process also changes and has to take care of an optimal distribution of application logic and responsibilities in the network layout (see also Figure 17). This means that application logic and intelligence should not be brought to he lowest level in the network, but to the lowest level as required from the application point of view. In a hybrid environment, where older technologies are integrated into distributed applications, routers and gateways can be used to take over (part of) the control.

Hardware
Several pieces of hardware can be used in creating networks. A hub is a device that connects two or more points, thus creating a network. A router can be used to link different local networks together. A router can also be used to link local area networks with a wide area network, i.c. the Internet. In this case we rather use the term gateway. Probably best known is the residential gateway, which is often seen as an ‘intelligent’ modem, which allows different computers in a network to share an Internet connection, and at the same time functions as a firewall and provides dynamic host configuration.
We will use the term ‘service gateway’ in a much broader context as a central access device to a local area, through which value-added service applications from external service providers can be connected to all types of local devices. Besides security and addressing the gateway takes also care of the different protocols through which external servers and local devices each offer their functionality.

Standards for device interfacing and inter-device communication
A main topic is the emergence of low-cost connectivity of appliances for control purposes. In the Annex 2 an overview of a number of industrial standards is given.

Implementation models
Innovative ICT solutions provide access to information and the tools to act on that information whenever and wherever there is a need to. Web services are small, reusable applications In today’s world they are able to reach every location and allow applications everywhere to share information. More and more we see web services to be based on XML, the universal language of data exchange on the Internet. By making use of XML, web services can be called across platforms and operating systems, regardless of programming language. One of the key issues in using web services is a comprehensive security model, ensuring the protection of the integrity, confidentiality, and security of the application.
In the Annex 2 an overview of a number of existing standards is given.

The services gateway
Once a communication structure is established and available software exists that can function on a network, a main task remains to deliver and maintain services using the network and this software.
The Open Services Gateway initiative (OSGi, www.osgi.org), founded in March, 1999, has the objective of providing a forum for the development of open specifications for the delivery of multiple services over wide-area networks to local networks and devices, and accelerating the demand for

products and services based on those specifications world-wide through the sponsorship of market and user education programs. More than forty companies have committed to support the full incorporation and charter of the organisation.
With the OSGi Service Platform, high-value services may be dynamically loaded over a wide-area network, and accessed through a Services Gateway in a home, office, vehicle, or mobile device.
Once present in an Open Services Gateway, services may be accessed by all connected devices and networks in the home, small office and remote/mobile locations. The Gateway consolidates and manages voice, data, control, Internet and multimedia communications, and provides a framework for interoperability between Service Providers, Network Operators, Service Gateway Manufacturers and Home Appliance Manufacturers.

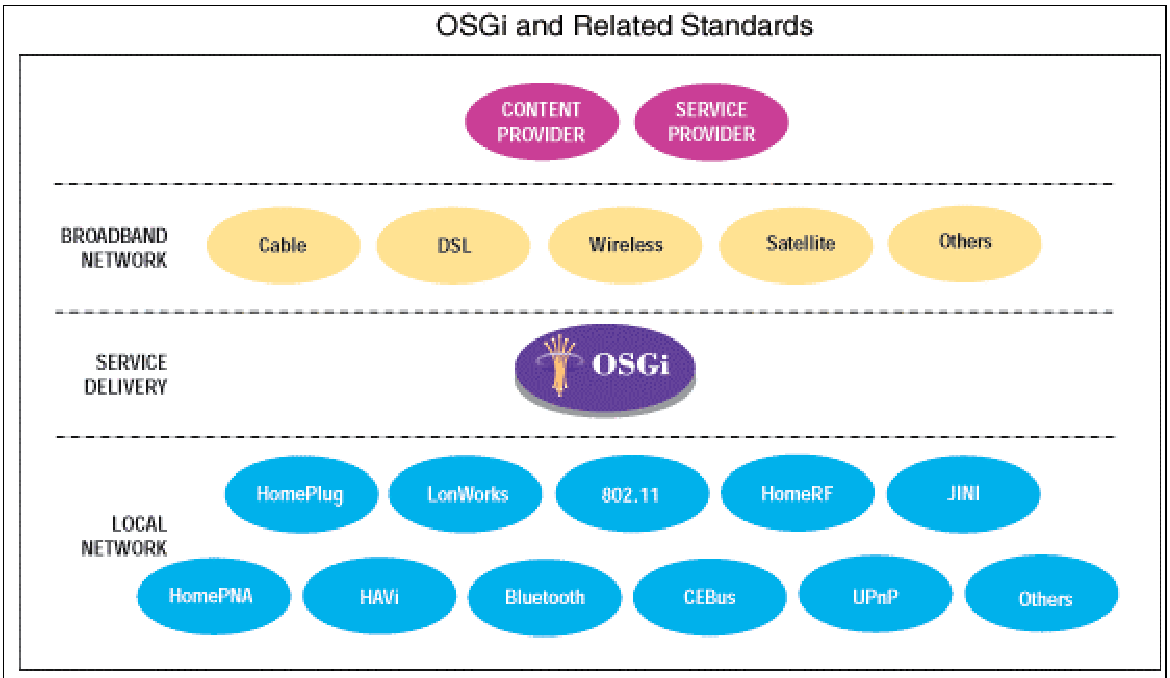

Figure 18 OSGi and related standards (© OSGi)

6.3 Requirements for the ICT-Node network

In the CRISP experiments and simulations, one of the main purposes is to demonstrate the added value of ICT for information exchange and for processing of data in operating an electricity distribution network. The data needed may be roughly classified as operational and diagnostics information, expected loads and generation capacities, market prices, meteorological information, period-ahead prices, all as a function of time. These data may be expected values, real-time data or historical values. Another primary aspect of the CRISP-project is to show the advances with respect to network operation and control of a bottom-up architecture of the distribution network as opposed to the current top-down control architecture of the distribution grid. This leads to the following requirements for the software and hardware of the information and communication infrastructure.

4. An always-on communication connection has to be present, that enables simultaneous data collection from every node to every other node in the network (peer-to-peer). Polling and interrupt latencies depend on the type of application and range from milliseconds to a timeframe of seconds or even minutes.
5. A standard operating platform containing primitives for distributed inter-process communication should be present on each node.
6. Distributed processing: Depending on the type of application, each individual node should have enough processing capacity, e.g. to execute (part of) a distributed control algorithm.
7. The software on each node should be implemented using common inter-process communication standards and portable programming languages.
8. The network must be hot-pluggable. This means, that hardware components should be able to be inserted in the network without shutting down the remaining parts.
9. Flexible, layered fall-back sequences should be defined in case of hardware failure of components in the network. Remaining parts of the network should not be functionally impaired. Nodes should re-enter the network without interference to other nodes.
10. The safety of the PS Node network should not be endangered by any failure in the ICT-node network or the SO-node network. This means that safety functions may be enhanced by interactions with the ICT-node network and the SO-node network, but only under the following conditions: all safety functions are able to operate locally in case of failure in the ICT-node network or SO-node network; and no safety function may be influenced negatively (postponed, halted) by failures in the ICT-node network (the ‘local robustness’ principle and the ‘safety enhancement’ principle).

7. Requirements for tools – an overview

In previous chapters we have derived a list of requirements for the tools for simulations prototype software. We have seen a split between the functional requirements from the view of the application areas and the more generic requirements with respect to distributed intelligence environment in general. The last is essential in a good ICT model to set up a generic framework underlying all application areas.

General requirements underlying a stability and safety of the grid: in distributed generation applications are:

- Reliability and security
- Self-diagnostics and analysis
- Alarm and follow-up repair
- Automatic (re)action to internal and external faults and events
- Automatic resynchronisation
- Preventive monitoring and maintenance

These topics are addressed in detail in D1.1 [1]. They form the underlying structure upon which other measures can be taken for cost-controlled and prioritised load shedding and for cost-effective operation of the network using supply and demand matching algorithms and online cost-information.

7.1 Simulations and prototype software

In Chapter 3 the requirements for the simulation tools and prototype software are identified. Since existing simulation tools are used for fault detection and diagnostics (the ARENE tool) and intelligent load shedding (PSS/E Power System Simulator for Engineering) we mainly focus on the simulation studies for supply and demand matching. Note that there are some similarities between intelligent load shedding and supply and demand matching, esp. where rules is concerned on which loads can be shifted / shed, based on economic value.

- Networks under study
  We have seen different network layouts. The tools should support definition of radial and open loop layout structures in which generators including their characteristics can be defined both at the transmission level and the distribution level, up to the local LV-network.
- Articulation of supply and demand
  Through the articulation of supply and demand profiles we should be able to express the possibilities for shifting the supply and demand in time. In [2] these articulation profiles are worked out in terms of maximum/minimum load for each period, or the spread of the load over a timeframe, the uncertainty of delivery, the cost depending on the load, etc.
- Underlying logic of energy usage on site
  the articulation of demand must express the functional usage of the load, e.g. a cooling process must ensure that the temperature at a location remains within a certain temperature range; demand shifting is only allowed within this constraint.

- Algorithms
  In follow-up work in the CRISP project a number of algorithms will be developed for optimisation within supply and demand matching. These algorithms will partly be based upon agent technology and micro-economic market theory. The tool should support the applicability of these algorithms. This poses a number of requirements for the usage of an agent based market-based approach as has been worked out in 5.3.
- Software architecture issues
  In order to enhance flexible use of the software a loose coupling is proposed between the price-responsible market model (day ahead / hour ahead prices; real-time price-forming), the functional model of supply and demand loads, and the type of power network (esp. grid layout).

7.2 ICT Network and Service Oriented Network

We also have identified requirements for the ICT network requirements and the service oriented network , which are more oriented towards experimentation and implementation of applications.

- Security and reliability
  We have argued that ICT is not a goal in itself, but it is only an enabler of functionality. As such we have to ensure that ICT itself supports the functionality in an optimal way. This requires a dependable environment in which security and reliability of networks and components are of vital importance.
- Robustness
  From the previous point it follows also that robustness of the power grid (overload protection, etc.) must be enhanced to robustness of all grid operation. If this operation is supported by ICT systems and intelligent services, then these systems and services should perform at the same level of robustness as the core grid operation. The grid operation must not be hampered by failures in these systems and services.
- Performance
  Depending on the type of application there are different requirements for performance. the process of fault detection, diagnosis and elimination of the fault should be executed within the range of 50 to 250 of milliseconds. The time available to take proper load shedding actions lies in the order of 0.1 to 10 sec. Supply and demand matching processes range from a few days ahead to a quarter of an hour ahead or minutes when applied as distributed balancing services.
- Configuration control
  Applications supporting the power network are supposed to perform 24/7, i.e. 24 hours a day, 7 days a week, without interrupt. Hence every change within the network, whether hardware or software, should not interfere with the execution of existing applications. Moreover, applications should automatically incorporate network changes if necessary. Configuration control includes: hot-configurability of nodes and of the network topology; hot-pluggability of hardware and software components; version control.
- Operation and maintenance
  Network operation and maintenance contains all actions to keep the ICT-network in good order. It includes items such as performance monitoring, failure detection and diagnostics, etc.

7.3 Next steps

In the CRISP Workpackage 1 strategies and scenarios will be defined for the application areas of fault detection and diagnostics, intelligent load shedding and supply and demand matching. These strategies and scenarios serve as input for the simulation studies, for which the tools are developed in the Tasks 2.2 to 2.4 in the CRISP Workpackage 2.

In this report the requirements for the mentioned applications have been identified. These requirements describe what the tools are supposed to do. In order to develop the supply and demand matching simulation tool the next step is to define how the software will work in detail. This step is called the 'specifications' phase. In task 2.2 these specifications will be specified and based on it the tool software will be written. As a specification tool we will make use of the Unified Modeling Language (UML, see Annex C).

In task 2.3 we will make use of an already existing simulation tool, the ARENE system. The main emphasis in task 2.3 is not how the software will work, but how we will utilise the existing software for studying new techniques for fault detection and diagnostics in high-DG power networks. This will e.g. lead to detailed input descriptions.

The decision support tool for network security models in Task 2.4 will consist mainly of an existing environment at BTH (see [5]). The main task for employing this tool will be to closely connect to the existing application scenarios in order to be able to perform experiments on what would happen to the high-DG power network in given scenarios.

8. Architectural Implementation Issues

ICT elements which play an important role in the architecture discussions are partitioning of functionality, required management and configuration facilities, object persistence, replication mechanisms, serialisation and versioning, multi-agent architectures and control timing implementation and synchronisation. The level of aggregation within the distributed grid for operation and control will be determined by operational and maintenance issues. The service oriented network should enable the rolling out of different applications.

8.1 Partitioning of functionality

In the CRISP project we are looking at three different types of application: fault detection, intelligent load shedding and supply and demand matching. Although each application has its own characteristics, it would be preferable to set up an ICT-architecture in which the applications share as much functionality as possible. Sharing functionality can take place on different levels:

- Infrastructure: embedded processors; sensors and actuators; control stations.
  The different applications may require information from the same sensors or may be able to influence control of the same appliances. Applications may be using processing capacity on the same control stations. This not only leads to the possibility of sharing functionality, but also poses dependencies between different applications. If one application decides to switch off an appliance, it should be clear whether another application is allowed to overrule this decision or not. Sharing knowledge of decision models then is necessary.
- Communication channels.
  Distributed applications rely heavily on communication, which takes place at different layers. Information needs to be transferred to different layers of the applications and depends on two-side communication. Complex communication mechanisms have to be designed and delegation of control and distribution tasks to suitable concentrator subsystems in the chain are necessary.
- Data processing.
  Current developments in software and hardware technology lead to an increasing processing power and bandwidth for small scale, powerful dedicated systems. In this respect there is less a need for **big** bandwidth, but for **smart** bandwidth. Efficient and reliable usage of limited bandwidth between powerful processors is more important than a high bandwidth between “dumb” processors. Important in this respect is the point at which data is converted into information and control directives.

8.2 Required management and configuration facilities

8.2.1 Object persistence

In current software design methods nowadays, data (attributes) and procedures and behavioural aspects are contained in objects. Depending on the functionality of applications and for security reasons, the attributes of objects and the state information have to be saved at the proper level. In case of outage of the application or system, procedures have to be designed to restore the object’s state to the one before the crash.

Depending on the type of information the requirements for object persistency can be different. For thin-client applications, such as existing in embedded processors, to be able to operate in a local environment we require objects to be persistent at the local level in order to have reliable status information. In more complex control applications, more complex software is implemented on larger processor capacities. Memory requirements will be larger. Information contained in objects can be downloaded at regular intervals from a larger computer system in the network. Again the emphasis in reliability and computing power is on the processing level. Loosely coupled feedback (analysis of measured data and adaptation of parameters) on the performance of the algorithms from larger computer resources higher in the network hierarchy will be a major benefit but not essential prerequisite. Sustained operation in the absence of larger computing systems is essential.
For other application types the emphasis for secured object persistence may be on the server side.

8.2.2 Replication mechanisms, serialisation and versioning

If object information is needed at other levels in the application hierarchy, data and state information have to be transferred and replicated across the network. For successful execution of remote procedure calls between objects residing at different nodes of the network, a serialisation mechanism transfers all necessary information to the correct nodes. A number of standards facilitate this mechanism. Currently COM and CORBA are the mainstream standards for remote procedure calls, but the needed resources are heavy and are geared to larger processor-capacities than present in current small scale apparatus. In the SOAP and DOM, a WWW based document object model, a connection to these standards is made also incorporating XML. In Java, a mechanism for serialisation using the RMI standard is also contained. This technology however, especially concerning real-time Java, is in the development phase and has a lack of support of the leader in the field of real-time software development. Furthermore, firewalls pose large difficulties for RMI.
From a software maintenance point of view, many appliances will have a long usage cycle. Maintenance of hardware and software versioning therefore is important for proper operation of applications. Current software standards, such as the OSGi initiative (www.osgi.org, paragraph 6.2), have a versioning mechanism to check if objects interact with each other are generated with the same compiler products and support libraries. This mechanism will be mandatory for distributed power applications.

8.2.3 Multi-agent architectures

Applications, in which a large number of information-sources have to be monitored or inspected, benefit from multi-agent architectures and technology. Agents have the advantage of an auto-replication mechanism. Furthermore, they are autonomous in negotiation with other agents for a resource using market algorithms. In this way optimisation problems are easier to solve in a computer network environment. Especially for large distributed systems the agent abstraction has its benefits. The control behaviour of these systems is hardly codeable in conventional ways because the large number of possible states of the system as a whole. Also the optimisation of the system operating with distributed processors in a concerted way is not always easily solvable by central, analytical algorithms and procedures. Successful implementation may depend on market and auction algorithms implemented in a large number of autonomous processes in a distributed processor network.

8.2.4 Control timing implementation and synchronisation

A large layered control-network has delicate timing. Frequent time synchronisation and propagation mechanisms are necessary to guarantee secure parallel operation.

Annex 1 – The Isle of Öland

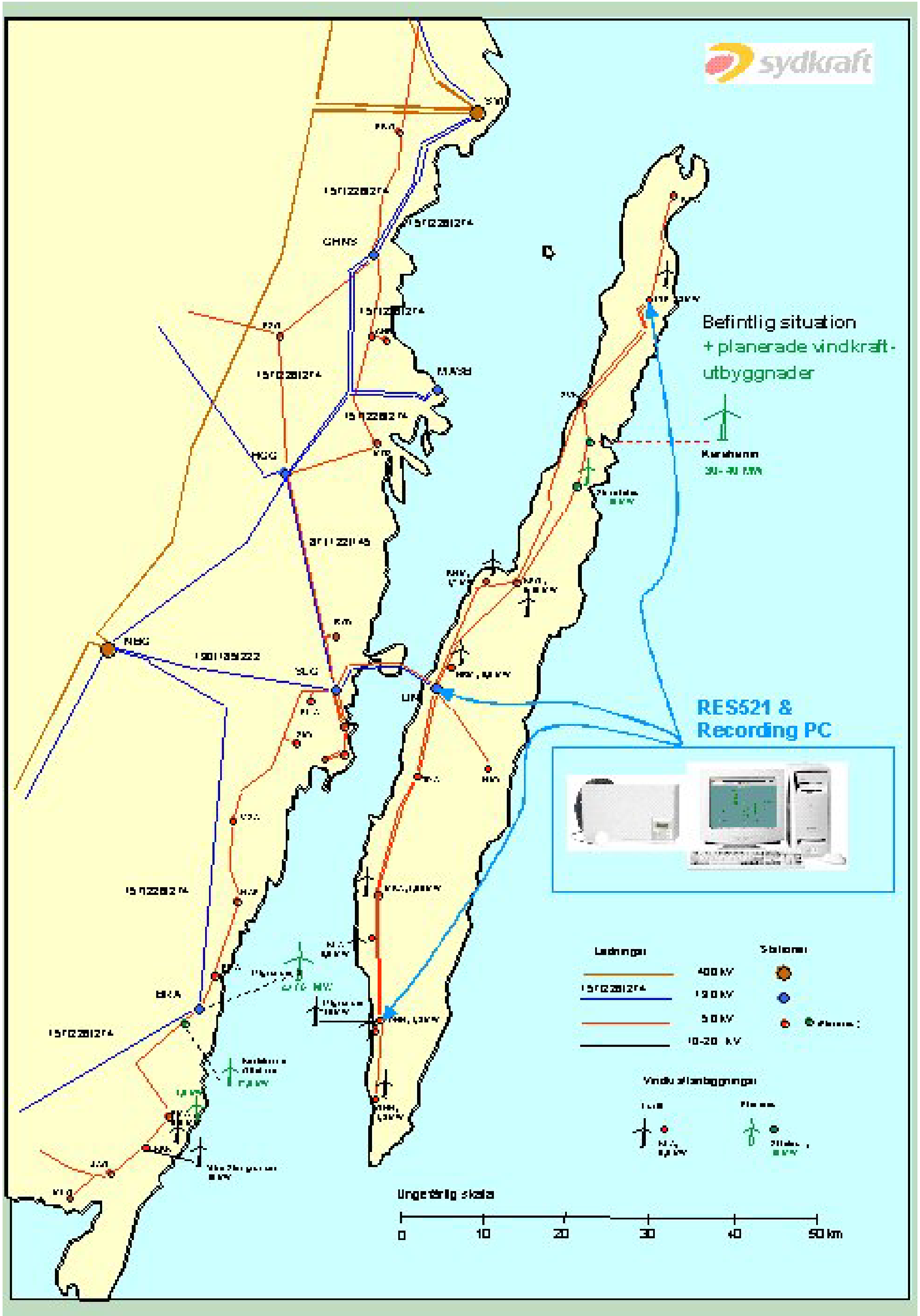

Figure 19 The test area of Öland, with wind power farms and recording nodes marked

Annex 2 – Standards for device interfacing and inter-device communication

Recently, with the specification of the IEEE standard 802.15.4 [IEEE, 2002] the first step has been set to achieve low-cost connectivity of appliances for control purposes. Compared to previous standards (e.g. Bluetooth) additional attention is paid to reduce the cost of communication nodes in the network and of maintenance cost (batteries) and to enhance the life cycle (prevention of battery replacement). In a number of EU-research projects [Eyes, 2002] self associating and configuring sensor networks are being developed.

Developments in hardware and communication technology, together with continuing efforts in the Internet technology, have led to the introduction of the IP-stack in small and embedded devices. Thus inexpensive and thin-client applications can be built using the standard Internet communication protocol, with main operation responsibility delegated to a connected web-server.
In an alternative architecture individual devices can be connected to a gateway, containing a web-server for communication to the outside world, and a non-IP based communication with its local devices, such as LonWorks, WebChip, ProSyst.

LonWorks[1] is a network technology for connecting device control networks. It is used in a variety of environments, such as building automation, home networks, traffic management, aircrafts, etc. LonWorks is moving away from centralised control solutions based on point-to point wiring and hierarchical master-slave control. In stead it offers interoperability between different vendor systems, robustness and flexibility in development. LonWorks is a de facto industry standard, set by Echelon can be implemented over basically any medium, including power lines, twisted pair, radio frequency (RF), infrared (IR), coaxial cable and fibre optics. *i*.LON provides Internet access within the LonWorks control network.

WebChip[2] is an Internet enabling technology, consisting of a silicon chip (the) and a gateway, that connects any type of microcontroller with the gateway networking capability, thus allowing complete Internet monitoring and control of multiple devices using a single point of contact. The gateway also takes care of security management, which extends the basic Internet functionality. The WebChip™ architecture is aiming at a cost-effective solution for embedded developing. Communication media include CAN, Bluetooth, USB, Powerline, 900MHz, X-10, RS-232 and RS-485.

ProSyst[3] also aims at technology for the Internet-based networking of stationary and mobile electronic devices. It offers open and scalable software solutions for deployment and management of network-based applications. ProSyst is based on the OSGi standard. It is closely working together with MetaVector, who provides an "Integrated Service Gateway", PyliX™, between the home or office's internal network and the external network, e.g. the Internet. Supported access technologies are Ethernet, cable and xDSL.

[1] LON is extensively described at www.echelon.com

[2] Information on WebChip™ can be found on http://www.webchiponline.com/products_webchip.asp

[3] Information on ProSyst can be found on http://www.prosyst.com

Implementation models

Innovative ICT solutions provide access to information and the tools to act on that information whenever and wherever there is a need to. Web services are small, reusable applications In today's world they are able to reach every location and allow applications everywhere to share information. More and more we see web services to be based on XML, the universal language of data exchange on the Internet. By making use of XML, web services can be called across platforms and operating systems, regardless of programming language. One of the key issues in using web services is a comprehensive security model, ensuring the protection of the integrity, confidentiality, and security of the application.

The Java 2 Platform, Enterprise Edition (J2EE)[1] is a component based model, which manages and supports web services to enable development of secure, robust and interoperable business applications. The J2EE platform is the foundation technology of the Sun ONE platform and Sun's Web services strategy. J2EE simplifies enterprise applications by basing them on standardised, modular components, by providing a complete set of services to those components, and by handling many details of application behaviour automatically, without complex programming.
Different pendants of J2EE exists, such as the Java 2 Platform Micro Edition (J2ME), the Java platform for consumer and embedded devices such as mobile phones, PDAs, TV set-top boxes, and a broad range of embedded devices. With J2ME, applications are written once for a wide range of devices, are downloaded dynamically, and leverage each device's native capabilities.

Microsoft® has developed a similar architecture, called .NET[2] (DOT NET), which is a set of software technologies for connecting information, people, systems, and devices. This new generation of technology is based on web services – small building-block applications that can connect to each other as well as to other, larger applications over the Internet. .NET is heavily depending on the Microsoft® environment.

Integration through XML/DOM and SOAP

Several software vendors are strongly advocating XML at the moment to tackle problems with distributed data management. In the Microsoft®.NET-architecture the standard plays an important role for application development. All various components are integrated to the XML meta-language. XML features data management aspects for very large-scale applications, XML has self-describing mechanisms for device access. Inter-application mapping using XML is facilitated through the Document Object Model standard. In this standard, distributed objects are made understandable in a transparent way across a network.
SOAP (Simple Object Access Protocol)[3] is a lightweight communication protocol designed to let COM or CORBA objects communicate. SOAP is a lightweight protocol for exchange of information in a decentralised, distributed environment. It is an XML based protocol that consists of three parts: an envelope that defines a framework for describing what is in a message and how to process it, a set of encoding rules for expressing instances of application-defined data-types, and a convention for representing remote procedure calls

[1] See for a complete overview http://java.sun.com/j2ee and http://java.sun.com/j2me

[2] See for a complete overview http://www.microsoft.com/net

[3] See for a complete overview http://www.w3.org/TR/SOAP

and responses. SOAP can potentially be used in combination with a variety of other protocols (COM, CORBA). With the SOAP protocol methods can be invoked through the Internet. SOAP codifies the existing practice of using XML and HTTP as a method invocation mechanism. The SOAP specification mandates a small number of HTTP headers that facilitate firewall/proxy filtering. The SOAP specification also mandates an XML vocabulary that is used for representing method parameters and signature, return values, and exceptions. SOAP has been submitted to the W3C for the formation of a working group.

Annex 3 – Model specification methodology

In order to specify the ICT- and SO-model entities in D2.2 – D2.4 the UML-standard (Unified Modeling Language) will be used. ([5], [10], [11]) Notably, the object describing tools, the event description methodologies and the process model design framework will be used.
For the purists: UML is not a method or methodology. It is a language which describes terminology and visualises it in standard diagrams. UML can be used within different software development methods, such as OMT (Object Modeling Technique) and RAD (Rapid Application Development).

UML starts with the definition of use cases and scenarios, which describe the tasks of a (sub)-system. First the system can be described externally, thus giving the context in which the system operates, and identifying the actors in the system. The internal scenarios describe what happens in the system itself in order to perform a task. From the latter object classes are derived with their characteristics, both static (the class attributes) and dynamic (state and operation), and their associations. A UML model leads to the following diagrams:

- Context Diagram
  The system is considered as a black box. The context diagram provides a framework for all process modelling activities and describes what is to be included and what is to be excluded from a process model. A context diagram describes what areas of the business are to be affected by the system.

- Use Cases and Scenarios
  An (external) use case gives a description of a number of interactions between one or more actors and the system. The system is still considered as a black box. A use case describes one way of interaction with the system and may contain exception handling. A use case diagram can be seen as a requirements diagram.
  An (internal) scenario describes a series of events during one specific session with the system. Normally it is a specification of a use case in which the interactions between the objects in a system are elaborated. The system is turned into a white box.

- Class and Object Diagrams
  A class diagram contains the classes in the system with their attributes, operations and associations. It describes the static structure for the objects belonging to the different classes. The classes and their characteristics are derived from the use cases and scenarios.
  An object diagram is a representation at a given point in time of a consistent number of objects created according to the structure in the class diagram. It is mainly meant to clarify certain elements of a class diagram.

- Sequence and Collaboration Diagrams
  A sequence diagram describes interactions among classes in terms of an exchange of messages over time. It is derived from one or more scenarios.
  A collaboration diagram represents interactions between objects as a series of sequenced messages. It describes both the static structure and the dynamic behaviour in a system.

- State and Activity Diagrams
  A state diagram describes the dynamic behaviour in a system in response to external stimuli. It is especially useful in modelling reactive objects whose states are triggered by specific events.
  An activity diagram illustrates the dynamic nature in a system by modelling the flow of control from activity to activity. An activity represents an operation on some class in the system that results in a change in the state of the system. Typically, activity diagrams are used to model workflow or business processes and internal operation.

The diagrams are supplemented with descriptive documents and OCL (Object Constraint Language) expressions in order to define modelling constraints.
The UML model is meant to be implementation-independent up to the last stage. At the end an implementation model is derived, after which the application is divided into components (*executable software modules with identity and a well-defined interface)*. The components can be deployed over the nodes of an information network.

- Component diagrams describe the organisation of physical software components, including source code, run-time (binary) code, and executables.
- Deployment diagrams depict the physical resources in a system, including nodes, components, and connections.

Class identification in the power grid domain

From D1.1, chapters 1-1 to 1.4, we introduce the following basic classes:

HV-Network	The high voltage transmission network carries the electricity from the large production power plants to the main consumer zones
MV-Network	The medium voltage network carries electricity form sub-transmission network to points of medium consumption. These consumer points are: either the public sector with access to MV/LV public distribution substations or the private sector, with access to delivery substations for medium consumption users.
LV-Network	The low voltage network carries electricity from the MV network to points of low consumption. It represents the final level in an electrical structure.
Substation	A substation is a physical entity defined by its position and its function within electrical networks. The role of a substation is essentially to perform the transition between two voltage levels and/ or to supply the end user. (D1.1) One can differentiate between HV-LV substations, MV-MV substations, MV-LV substations and delivery substations for HV and MV customers.
Transformer	The actual transition between two voltage levels is done by the transformer. It is part of the substations.
Producer	A producer delivers electricity on the grid. It can be placed on the HV-, the MV- and the LV-network, based on the size of the generator. Typically, generators connected on the transmission network (HV) constitute centralised generation, and generators connected on the distribution level constitute distributed generation.

Consumer	A consumer is any party / device that demands energy from the grid. Large consumers can be connected on the HV and LV network. The end user normally will be connected on the LV network.

From above definitions we can derive the following classes and associations between these classes, in order to describe the physical structure of a power grid.

We start with step 1: the basic functionality of the power grid:

- The Power Grid consists of a HV Network, a MV Network and a LV Network
- An MV Network is coupled to a HV/MV Substation
- A HV/MV Substation is connected to a HV Network
- A HV/MV Substation contains a Transformer
- An LV Network is coupled to a MV/LV Substation
- A MV/LV Substation is connected to a MV Networks
- A MV/LV Substation contains a Transformer
- A Producer delivers electricity on the Power Grid
- A Consumer demands energy from the Power Grid

Different application types require further specification of the above class/association model.

- In DG it becomes important to know the level of connection of producers and consumers. This connection can be on the HV Network level (traditional power plant as large producers, large customers), on the MV Network level (medium size producers and medium size consumers), or at the LV Network level (distributed generators, small customers).
- In grid operation the behaviour of the power grid and the dynamics of the infrastructure become essential to describe. Therefore the exact connections need to be described, such as radial, open loop, double shunted layouts. Also additional components in the power network come into play: breakers, feeders, and any location on the grid where measurements are being made.
- In market-oriented applications, such as supply & demand matching, it is insufficient to know the physical behaviour of the power network. Market parties have to be made responsible for electricity supply: suppliers, brokers, ESCO's. Also the role of the TSO and DNO might be disclosed. Also the amount of electricity produced and/or consumed at each place in the network need to be known for accounting.

In the following figure we visualise the basic classes and associations between them in an UML class diagram for the infrastructure model. Applications can build upon this basic class diagram.

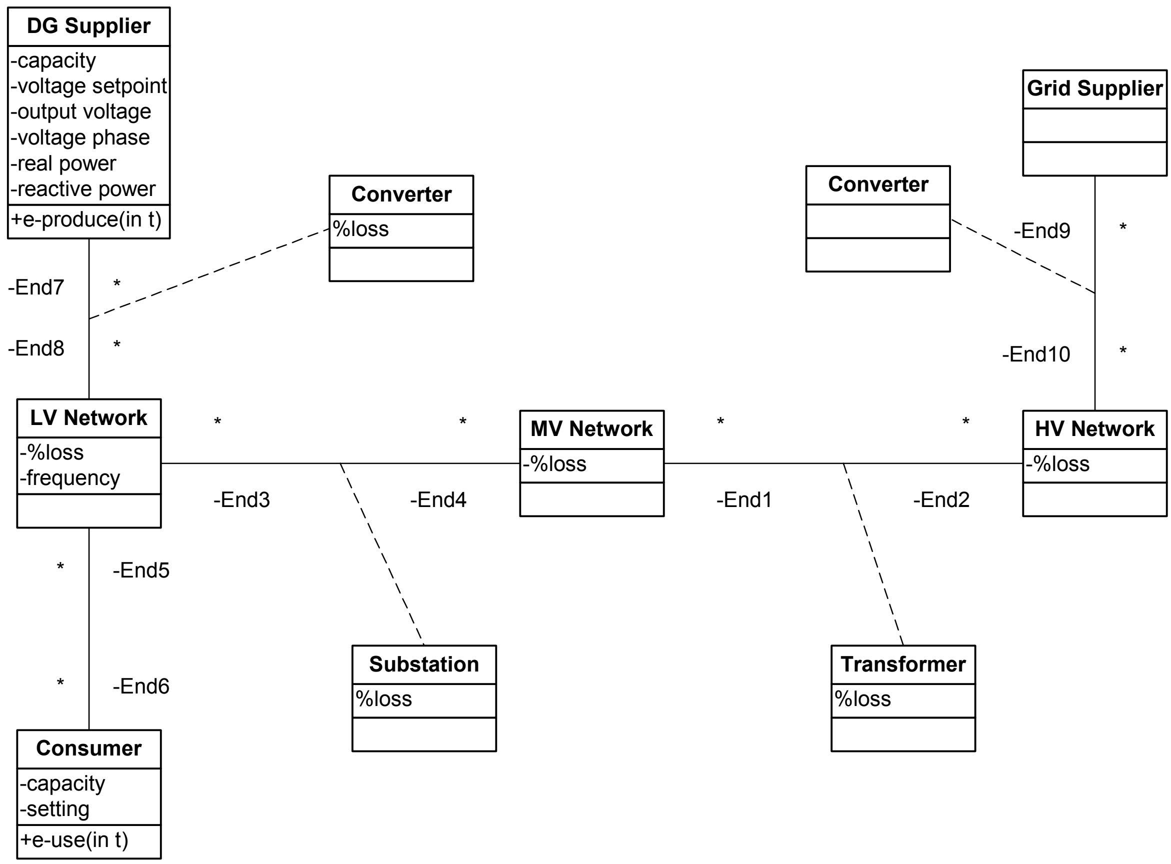

Figure 20 UML class diagram for the distributed generation infrastructure model