Distributed Intelligence in Critical Infrastructures for Sustainable Power

ENK5-CT-2002-00673

D3.1 Specification of experiments and test set up

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Blekinge University of Technology	Principal Contractor	Sweden
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Document Description

This document describes the experimental set-up of the three field experiments in the CRISP project.

It is put together from the documents D3.1A, D3.1B and D3.1C, written by the respective experimental groups.

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Executive summary

In the CRISP project three field experiments are implemented for using novel ICTs for better integration of Distributed Generation in the electricity grid. These experiments deal with:

A. supply demand matching
B. fault detection and diagnostics
C. intelligent load shedding.

For each of the experiments the problem statement, the project definition, the project description and the planning and organisation are described, respectively in section A, B and C of this document.

Section A : Experiment A:

Real-time monitoring and control of electricity supply and demand in a commercial setting to avoid short term market imbalance due to intermittent renewables

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Document Description

In this document a detailed experiment description and implementation plan of an SDM-IRS (Supply-Demand Matching - Imbalance Reduction System) is given. SDM-IRS fulfils the requirements to be met in the CRISP EU-project as Experiment A in working package 3 of the project plan.

This document is based on previous versions of a field test description by R. Chin and H. Kroon from ENECO. Additional interviews were made and information was obtained from:

Dirk Cederhout	Eneco/Energy Projects
Charel Hakkert	Eneco/BtB-Trade
Otto Verbaan	Imtech Projects/Leidschendam; System integrator
Gerard van der Hoeven	Priva Building Intelligence B.V. Delft
Tobias Wobben	General Electric Wind Energy, Germany

Summary

This document describes the setup of the Imbalance Reduction System IRS field test within the framework of experiment WP3 part A of the CRISP project. The field test implements the commercial scenario described in WP1.2 and WP2.2. In this scenario power flow fluctuations from the embedding of intermittent power production from renewable energy resources like wind turbine parks and PV-systems in the grid are compensated for in near real-time by other suppliers and consumers of electricity, using the market-based supply and demand concepts developed in WP2.2. It demonstrates the possibilities of distributed intelligence, using the network communication facilities and processing capabilities of modern ICT.

Table of Contents Section A

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References Section A

Label	Reference
ADL, 1999	Distributed Generation: Understanding the Economics— White paper prepared by Arthur D. Little, Cambridge, MA, 1999. See http://www.eren.doe.gov/der/pubs.html
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Acronyms and Abbreviations Section A

Acronym	Means
AMR	Automated Meter Reading
APX	Amsterdam Power eXchange
BUSMOD	Business Modelling in a world of distributed generation
CHP	Combined Heat Power
COP	Coefficient Of Performance
CRISP	Distributed Intelligence in CRitical Infrastructures for Sustainable Power
DG	Distributed Generation
DG-RES	Distributed Generation- Renewable Energy Sources
DER	Distributed Energy Resources
DRR	Demand Response Resources
DSM	Demand Side Management
FDD	Fault Detection and Diagnostics
HVAC	Heating Ventilation and Air Conditioning
ICT	Information and Communication Technology
IEC	International engineering consortium
IEEE	Institute of Electrotechnical and Electronics Engineers
IP	Internet Protocol
IRS	Imbalance Reduction System
IST	Information Society Technologies
OPC	Ole for Process Control; OPen Connectivity
OSGi	Open Software Gateway initiative
PLC	Power Line Carrier
PQ	Power Quality
PV	Photo Voltaic
RES	Renewable Energy Systems
RUE	Rational Use of Energy
SDM	Supply and Demand Matching
SQL	Structured Query Language

TSO	Transmission System Operator
UML	Unified Modelling Language
VINEX	VIerde Nota ruimtelijke ordening EXtra (Dutch policy document on spatial planning)
VPN	Virtual Private Network
W3C	World Wide Web Consortium

1. Introduction

In novel electricity grid architectures, that accommodate an increased proportion of small scale DG-RES, modern computer and network technology plays an important role [EU, 2003].

The CRISP-project (ENK5-CT-2002-00673) consists of five work packages focusing on a number of possible ICT-applications, that increase the low-level intelligence in the power grid. Within the project, advanced techniques for fault detection and localisation, load shedding and management of supply and demand of electricity are developed. In work package 2, using a bottom-up control strategy; the results of these innovative techniques are simulated. The applications are validated with concomitant experiments in working package 3. In WP-III 3 field tests are defined. This document describes experiment 3A.
The field test 3A implements the commercial scenario described in WP1.2 and WP2.2. In this scenario power flow fluctuations from the embedding of intermittent power production from renewable energy resources like wind turbine parks and PV-systems in the grid are compensated for in near real-time by other suppliers and consumers of electricity, using the market-based supply and demand concepts developed in WP2.2. It demonstrates the possibilities of distributed intelligence, using the network communication facilities and processing capabilities of modern ICT. Application and governance of information and communication technology, in use in other sectors of industry for decades now, is still in its infancy in the power sector right now.

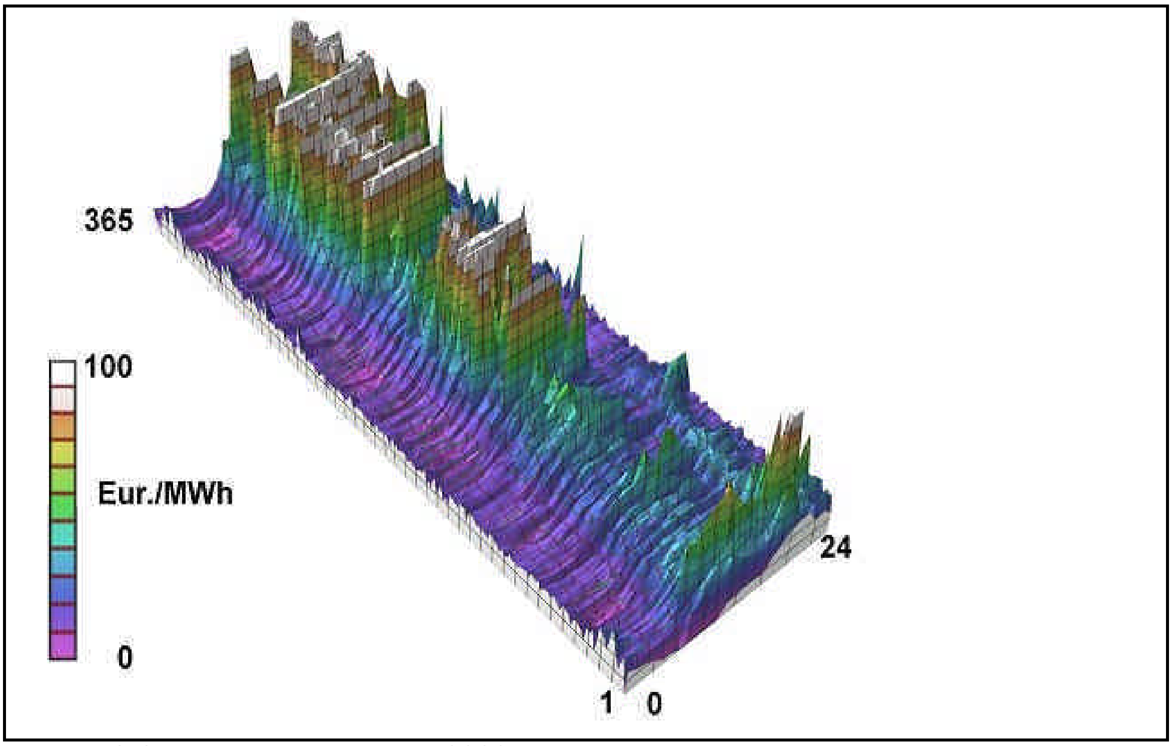


Figure 1-1 APX-price volatility in 2003 showing summer and winter peaks

The market mechanism, designed for matching supply and demand of electricity in countries with a liberalized electricity market, consists of a number of steps. In a portfolio of an energy trading company, long-term term bilateral contracts account for a substantial part of supply and demand of electricity. A trader uses shorter-term exchange markets to steer to a net zero balance on the basis of the aggregated prediction of production and consumption in the total portfolio. An example of prices traded in a day-ahead market is shown in Figure 1-1. ; Some price peaks extend to 1800 €/MWh.

Furthermore, shorter-term markets exist, too, for near to last minute control of power flow, spinning reserve and ancillary services. In the latter, the TSO acts as the single buyer in an auction setting. Price profiles in these markets are even more volatile as day-ahead markets.

An example of this volatility can be found in Figure 1-2. Deviations, even a few percent, from the programme can be seen to lead to financial consequences for supply and demand imbalance.

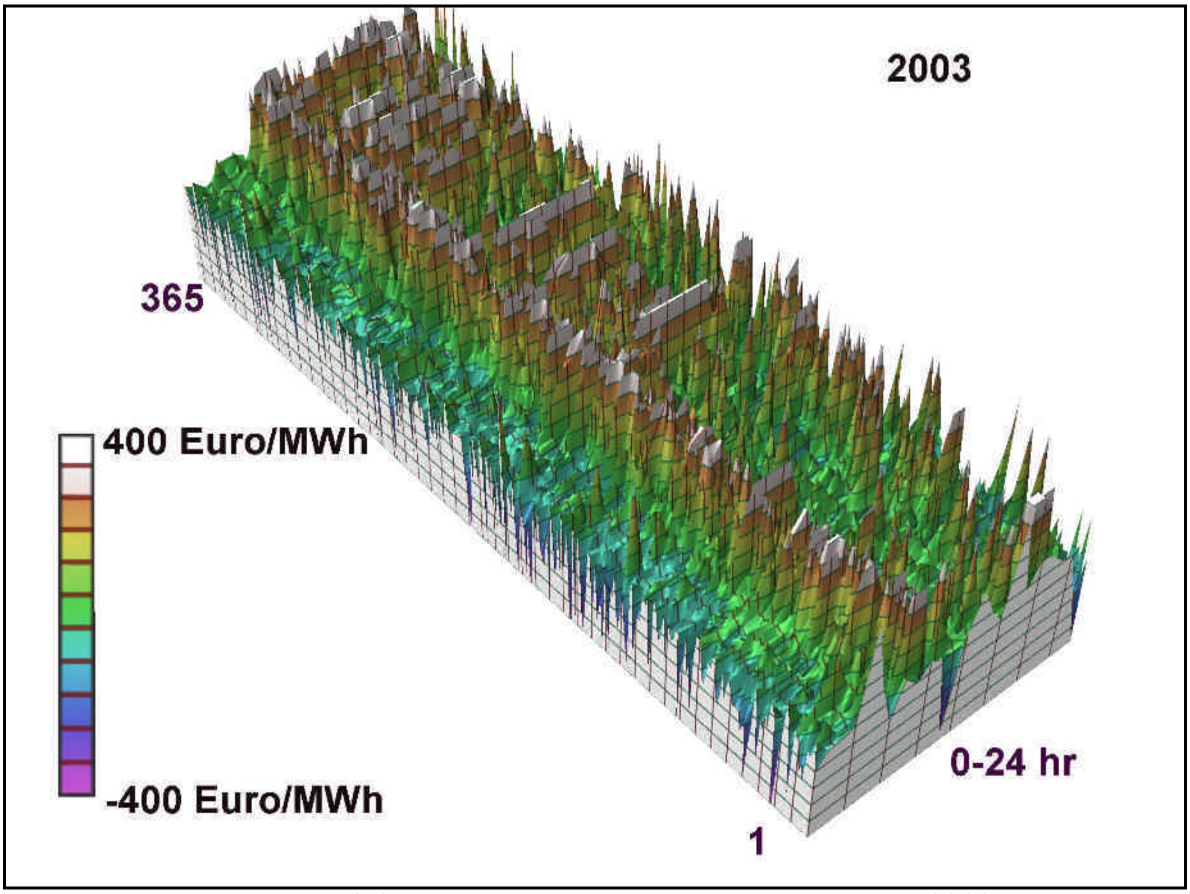


Figure 1-2 Imbalance price in the Netherlands in 2003

At the moment, the value of production and consumption facilities, then, is the same for every type of device. Lenient supply and demand however has additional value.

Electricity trading firms have prediction models that enable them to identify determinants for the amount of electricity consumed and produced for the next day. Typical accuracies between prediction models and realisations, achieved, are in the order of a few percent. The production of electricity by intermittent, renewable energy resources like wind and PV leads to additional imbalance on the day-ahead market for a trading party: the day-ahead (12-36 hours) predicted amounts may deviate more from the actual realisations than other electricity suppliers and demanders. In the energy market design in most liberalized electricity market countries, producing more or less than the amount specified in the programme leads to a fine from the transmission system operator. Production and consumption figures are settled a number of days after actual delivery using metering data as collected by a certified metering company. Thus a time gap exists. Mostly, there are no real-time production or consumption data available to adapt to changes in the programme as submitted the day before nor is the effect of improved accuracy of shorter time-ahead predictions taken into account. A plot showing a typical example of imbalance is shown in Figure 1-3.

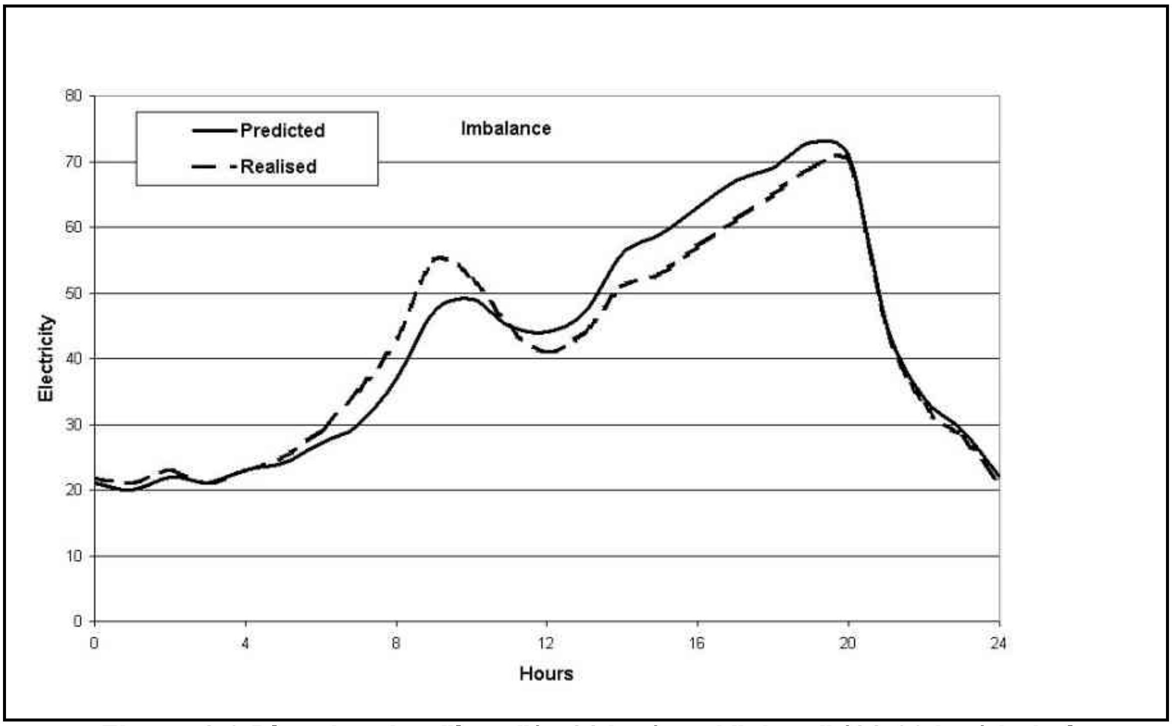


Figure 1-3 Plot showing "long"(5-11 hrs) and "short" (11-20 hrs) imbalance

At the moment, no real-time electricity production or consumption figures are measured nor utilized for real-time steering of producers or consumers in order to reduce cost of imbalance. Programme responsible parties in the electricity market could minimize fines by real-time compensating for the deficit or surplus of power by controlling shiftable loads or generators according to more near-delivery predictions or real-time realisations. Price volatility on the day-ahead market, which is currently amplified by the increased degree of usage of the generation infrastructure, leads to smaller deviations in the programme for the next day having larger effects on fines.

In the commercial portfolio of ENECO-owned facilities a total of 200 MW generation capacity is present. The peak load in ENECO's portfolio is 3700 MW. In this portfolio, the "Slufter" wind turbine park produces 12 MW. The power prediction of the wind turbine park is made using meteorological prediction data of the wind direction and wind speed. The error margin in the 12-36 hours ahead prediction of wind power production is about 20 %. A potential solution to this imbalance is compensating by demand elasticity or by operating flexibly available supply.

For some of these installations, similar problems of imbalance might exist; now not necessarily due to electricity, but to heat delivery. Examples of this type of installations, then, are cogeneration facilities (CHPs), which Eneco operates at large heat distribution networks near new urban areas (so called VINEX-locations). These networks have a heat demand, which fluctuates with ambient temperature and cloud coverage, which vary with local climate. The heat demand, which is much less articulated than electricity demand, may be satisfied in an energetically efficient way by using co-generation using natural gas engines, by heat pumps, connected to soil heat storage, or by central heating installations.

2. Problem statement

Large scale introduction of Renewable Energy Sources and Distributed Generation requires a good matching of supply and demand of electricity. Current metering and settlement schemes do not support this. The aim of work package 2.2 is to see whether it is possible to achieve a better matching of electricity supply and demand using agent algorithms and Internet-like communication technology

The field experiment A supports this aim implementing an ICT infrastructure for supply and demand matching, focussing on portfolio management as sketched in the previous paragraph. This problem may be stated as follows:

Real-time electricity demand and supply realisation figures of installations in the trading portfolio of parties on the electricity market are not available for fine-tuning of control and pre-emptive scheduling of these installations. In the current setting, only historic metering data are available for settling imbalance cost afterwards. Especially intermittent DG-RES producers, not being able to trade on the long term bilateral market and having peak production at peak prices, are subject to the risk of over- and underproduction and, and as a result, to a poor market position.

3. Project definition

3.1. Goals of the experiments

Goals of the experiment are:

- To demonstrate the ease of computerisation of a power network aggregation in a commercial setting spread over a large geographical region with common, off-the-shelf ICT-components.
- To demonstrate the ability to characterise and model the behaviour of the majority of installations in the experimental setting from an energetic perspective from a set of initially collected monitoring data. The operational effects on the Eneco installations will be assessed by simulation. In this way the way will be paved to a staged testing methodology of new control strategies in critical infrastructures without impairing or harming vital utility assets.
- To demonstrate the added value of novel bottom-up control strategies, that use information, derived from monitoring real-time data, for diminishing the imbalance cost caused by the intermittence of DG-RES resources in a liberalised market situation.
- Providing a practical sample scenario to validate simulations in WP-2 of the CRISP-project. Within the CRISP Project ECN and Enersearch have developed novel mechanisms for matching demand and supply of electricity. These supply and demand matching (SDM) mechanisms are based on electronic markets, which are a form of distributed optimisation; in this case especially targeted at imbalance reduction.

3.2. Applied technologies

Off-the-shelf computing and communication hardware will be used to interconnect and interface a cluster of power generation and comsumption installations in a network using secure Internet-technology in an isolated branch of the public Internet, a virtual private network. On these computers, tools will be installed for data-collection, database storage and safe execution of novel control algorithms.

3.3. Expected results

The result will be deliverable WP3.3A. containing:

1. Local process monitoring data analysis and process characterisation of equipment part of the field test.
2. Local CRISP-node and central CRISP-node architecture and design descriptions
3. A functional design of IRS that bridges the application domain and the construction of the software.
4. Technical design of the field-test network especially focussing on the role of the local CRISP-node computer.
5. Analysis of the data from the monitoring phase and derivation of the control model for each installation.
6. Analysis of the "live"-test data and estimation of the potential in terms of:
    a. Avoided over- and underproduction within the commercial cluster portfolio comparing the real-time settling and the day-ahead / days-afterwards settlement scenario's.
    b. Comparison with the simulation cases for the demand/supply curve market variants.
7. Implementation and assessment of novel control strategies for diminishing short term imbalance.

The deliverable will focus on the analysis of the measured data with respect to the total of DG-RES imbalance avoided by pre-emptive or delayed control of the aggregated cluster.

3.4. Integration with other CRISP-activities

WP3.A closely follows the commercial scenario defined in CRISP-deliverables D1.2 and D2.2. Furthermore the detailed functional specifications and implementation of the technical design lead to innovative concepts to include in D1.7 (novel grid architectures) and D1.8 (analysis of simulation in light of field test data).

3.5. Boundaries and dependencies

The following boundaries and dependencies have to be kept in mind during the set-up of the experiments:

- The availability of the installations for exerting control via the new algorithms is limited to a residential heat pump installation at the ECN-premises; the effect of control actions on other installations in the cluster is simulated from models built up early in the project

- Only off-the-shelf software support and hardware components are to be used.
- The optimisation algorithms from WP2.2 have to be completely implemented, tested and verified prior to the start of the test.

4. Project description

4.1. ICT-network

Process computer configurations at customer sites

The local process computers will be loosely coupled to the Imbalance Reduction System (IRS) network according a topology as sketched in Figure 4-1. Apart from the ECN-test dwelling, only measured data will be transmitted from field process computers. The impact on operational characteristics of the other installations will be derived from installation models that are constructed and validated from the data measuring campaign in the initial phase of the project. The IRS-network of Crisp test-systems will be linked in a VPN. A sketch of the IRS-network is represented in Figure 4-1.

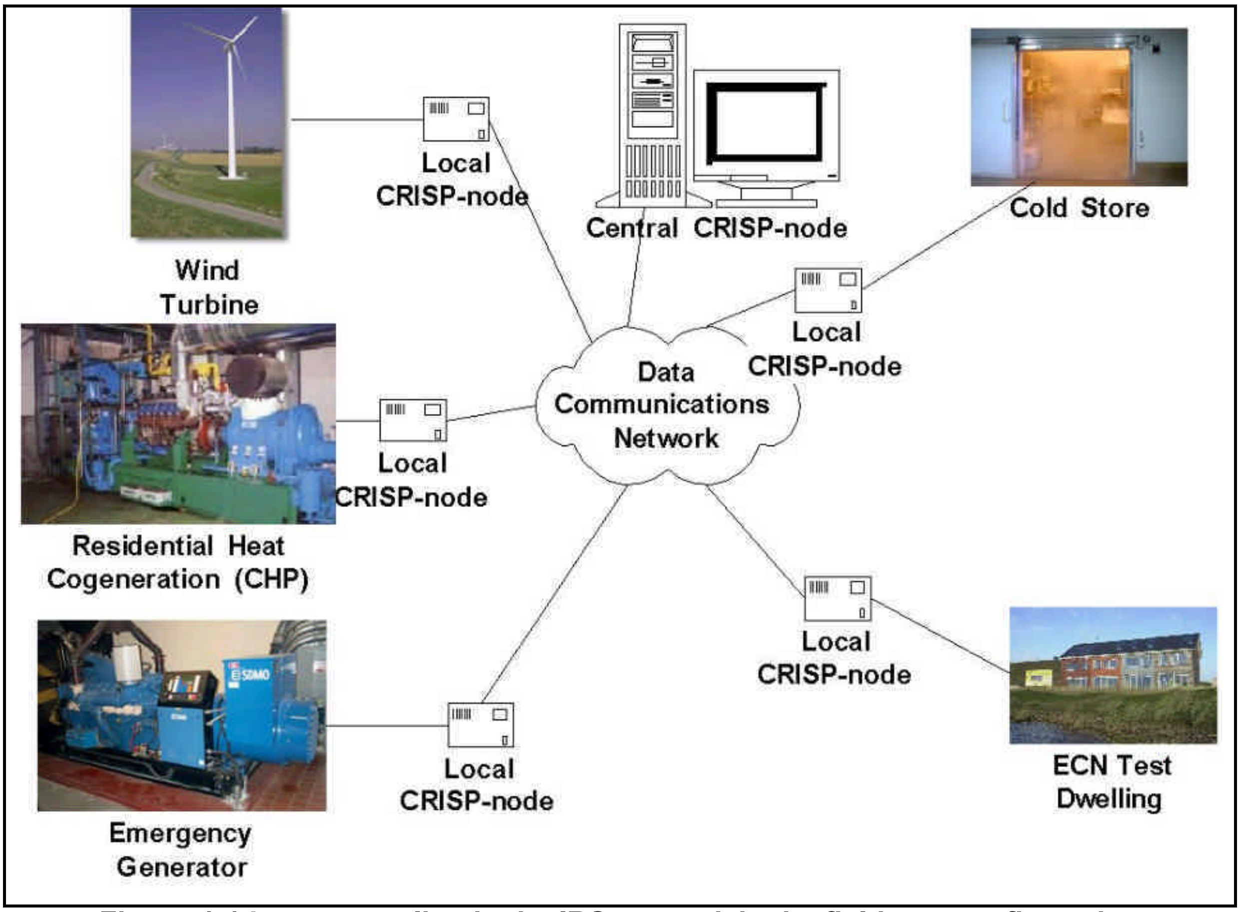


Figure 4-1 Loose coupling in the IRS-network in the field test configuration

The emergency generator and the CHP of the process computers of ENECO are equipped with proprietary PRIVA local controllers. These controllers are configured for a certain functionality using the PRIVA TopControl package. Digital and analogous I/O to the installations is performed using a rail-mounted system with I/O cards connected to the installations. These PRIVA-controllers also have local and remote user interfaces using dedicated programs or WEB-technology using browsers to monitor and control from a distance. However, in order not to impact normal operation of the installations, separate local computers (local CRISP nodes) will be installed at the premises interfaced locally. These PC-based systems are able to log all necessary measurements autonomously.

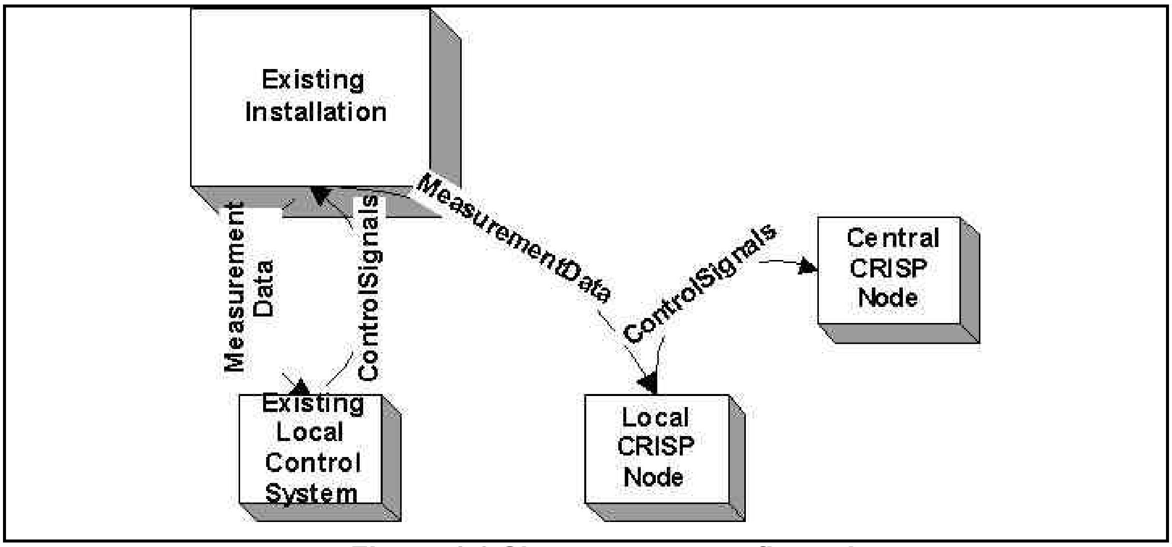


Figure 4-2 Site computer configuration

The CRISP-node computers are not the same as the process computers; their choice and way of interfacing is the result of decisions in the technical design.

Networking hardware

The CRISP-nodes are connected to the public Internet network through an ADSL-modem. The ADSL-modem has a **fixed** IP-address and is furthermore equipped with a firewall. In order to assure security constraints, the configuration is protected by a VPN (Virtual Private Network).

Coupling of local process computers to the CRISP-nodes will vary according to the type of installation and will be specified in the detailed technical design. During the monitoring stage, the PRIVA-substations from version HX8E onwards, having the possibility to communicate via Ethernet, could be used directly. To establish the network, the HX8E-systems form the end-nodes. The central station uses the PRIVA TC-LAN software in an OPC-Server configuration. In this way third party software has access to every installation's data and is able to set certain signal values in order to exert an influence on the strategy of the local process computers.

In case of the Wind-turbine park, the PLC will be connected to the local station using the MODBUS-protocol. It is possible to upgrade the GE-VisuPro software, that controls the Wind Park, to a new version supporting communication via TCP/IP. VisuPro uses the Paradox database package with an SQL database.

The local CRISP-node is interfaced via standard Priva process computer building blocks and also has a external connectivity via IP. Demand response related I/O fields are implemented as extra analogous and/or logical signals. For the emergency generator, a digital I/O-module has to be used. Via the digital port logical signals are to be transmitted and received. In Figure 4-3 the components connected in the physical network are shown. The Internet protocol allows seamless, transparent communication.
A subscription for the ADSL lines has to be obtained from a provider.

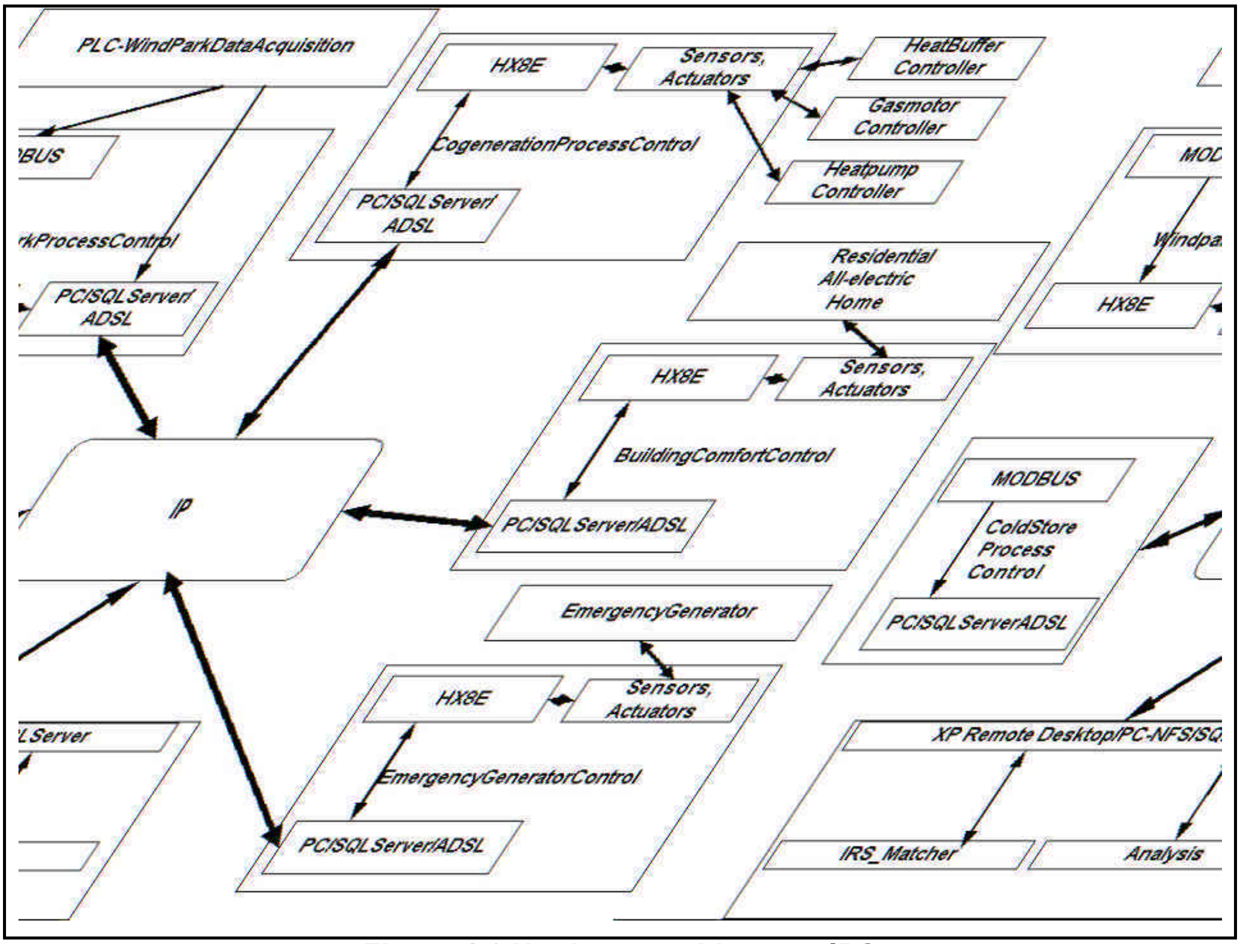


Figure 4-3 Hardware architecture IRS

Networking software.

On the CRISP-local nodes in the network connected to Priva-systems an OPC-server (OLE for Process Control) is configured. All PRIVA-project-information is available on the IRS-machine. Through this mechanism, the individual signals on each process computer are available for read-out. Only a selected set of control signals is defined per installation type. Signals are identified by `InstallationName` and a unique `SignalId`, all other networking information is configured in the OPCServer-tables. The TC-History module of the TopControl software package will be configured to collect historical data during the tests.

Software implementation

Apart from building the IRS-main module, extra functionality has to be programmed in each process computer of the participating installations. Some aspects require attention from the

beginning. Synchronisation and time keeping is not a part of IRS; every local installation has it's own timing and synchronisation mechanism. The absolute time-difference between components of the installation will be in the second range.
The approach followed in the ECN B-Box-project to operate filling and emptying of heat storage from a cogeneration plant within a fixed price vector environment will be adapted to fully exploit the financial opportunities give operation of the resources over a whole day.

IRS-software environment

The SDM-software environment is a standard Windows-2000/XP environment. The tool is written in C#, an object oriented, Java-like object oriented multi-purpose programming language, fully utilizing the Microsoft's .NET-framework. Connecting other systems to this environment is most simply done by using an OPC-server, using well-established protocols.

Performance evaluation, data collection and remote control

In order for ECN to be able to connect to the IRS-system, the remote desktop of Windows XP is very suited. Using an ISDN-modem or ADSL connection, files and Windows sessions may be shared easily from different locations. It has to be verified if a PRIVA-based infrastructure would be suitable for this. Firstly, most easy to use are Excel tab-separated column based ASCII text-files with one header record, a time stamp (dd-mm-yyy hh:mm) and data. ECN has tools to process, combine and analyse the data. Some preliminary data-files, if present, would enable ECN to check the formats.

4.2. Power network

Table 4-1 List of installations to participate in the field test

gives the data of the specific installations for the power production and consumption to use in the field test. Note that this information is the most likely configuration at the time of writing.

Installation Type	Specific Installation	Nominal Power
Wind Turbine Park	De Slufter, Rotterdam	12 MW (8*1.5)
Residential Heat Distribution Network	VINEX Houten (CHP with heat buffering)	2 MW
Cold Store	The Hague	800 kW
Emergency Generator	Parking Garage, The Hague	1.2 MW
ECN test dwelling	ECN, Petten	15 kW, includes heat pump, ventilation system and domestic appliances

Table 4-1 List of installations to participate in the field test

4.3. Information streams

The first step in identifying information streams is defining the context of a system as closely as possible. After the context is defined, the individual objects can be modelled using UML. UML forms the connection to the technical design. Two variants of involving the demand side will be modelled. In one centrally issued step-up/step-down commands are transmitted; in the second supply and demand bids are sent and prices and allocations are returned.

Context

The imbalance reduction system's context is shown in Figure 4-4. The terminators, which confine the scope of the system, are:

- IntermittentElectricalPower. This entity is a power producer, for which a prediction is made a certain time ahead, which might differ from realisation.
- Programme Responsible. The power programme states the amount of power a trading party delivers for a certain time period a day-ahead. The programme is submitted to the TSO. For wind power, predictions based on meteorological models are typically made 36 hours, 24 hours and also 8 hours ahead.
- ControllableElectricalPower. This class of devices in the grid consumes or produces power to take care of a primary process at a customer site. Examples of primary processes are heating, cooling or air conditioning processes in buildings or the

horticultural sector. The input to ControllablePower is a PowerRequest and the output is a RequestResponse, stating the extent to which the suggested Request has been succeeded. ElectricalPower can be influenced within primary process defined limits.

- Power market. This terminator provides the time dependent day-ahead prices, with which the imbalance has to be settled after delivery of power. The programmes and prices are fixed typically at 11:30 the day before actual delivery.
- CP_Owner. This entity represents the owner of the Controllable Power device. The owner has a contract with the trading firm for delivery of power or for curtailment of electricity demands.

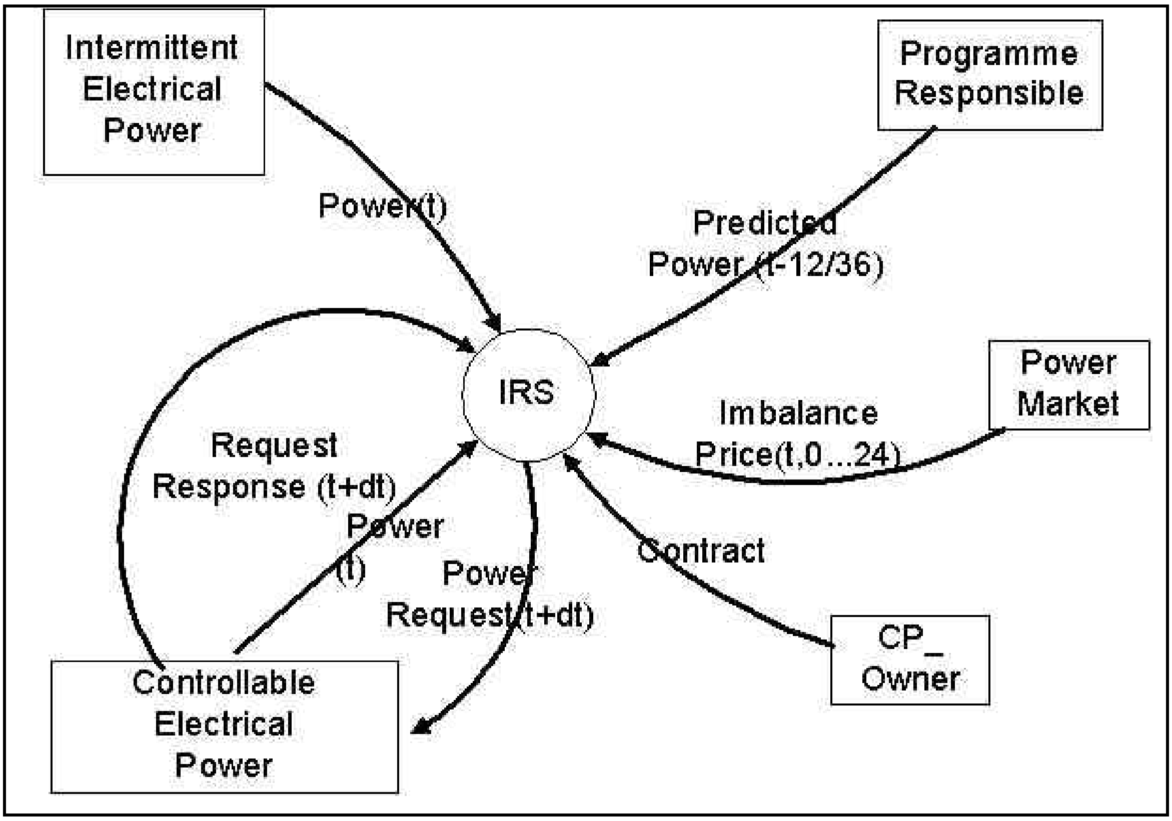


Figure 4-4 Context diagram IRS

The data flows contained in the diagram are:

- Power(t). This is the real-time power as a function of time generated by the producer or consumed by the installation. The unit is MW.
- Predicted Power. This is the power predicted for the current time on which the programme responsibility is based. Typically the prediction has been done 12-36 hours ahead. The unit will be MW.

- ImbalancePrice. The price is formed on the day-ahead market plus fines for over- or underproduction. The price-vector typically will have a one-hour resolution. The unit will be Euro/MWh.
- PowerRequest. This data flow represents the request issued to ControllableElectricalPower installations to increase production or consumption in order to minimize the difference between contracted and delivered amount. The format of the StepCommand is determined specifically for each device. Elements are the requested power and an indication of the current imbalance, that could be translated locally to a contractual fixed price reduction associated with the request. One might think of including a price-coding scheme in defining this structure. Note, that IRS is not aware of the status of the primary processes of ControllablePower-sites; it is up the local primary processes to determine in how far the request will be succeeded.
- RequestResponse. The RequestResponse is the actual increase/decrease in power from the device emitted within a fixed timeperiod after the PowerRequest was sent.

In the second, more bottom-up variant of control, supply and demand curves (statement of amounts and prices) are sent to IRS and allocations and prices are returned.

- Contract. Between the IRS and the owner of the CP-devices contractually the value of the demand response has been settled. For different types of PowerRequests the financial gain is stated. The financial gain is not time dependent, the type of PowerRequest issued by IRS will be time dependent. The StepCommand can be compared to a two-tariff meter signal changing tariff class, but

To give an impression of the inner workings of IRS for the step-up/step-down variant, the pseudo-code of the basic IRS-functionality is as specified as outlined in Table 4-2. Apart from real-time calculation of the needed imbalance, there is optimisation as to which resource is used most optimally over the total 24-hour period; this means, that pre-emptive scheduling of installations takes place in order to optimise the financial yield; in this implementation the contract is the reference point. The strategy is according the ECN B-Box-concept.

```
t = time()
ControllablePower[] cp
while(notStopped)
{
   expMWh = updatePrediction(t)
   realMWh = updateRealisation(t)
   toCompensate = expMWh-realMWh
   apx = getPrice(t)
   foreach step in stepCommandSequence
   {
      step = newStep(realMWh,cp,apx,toCompensate)
      step.emit();
      toCompensate = toCompensate-step.getResponse()
      if (toCompensate<0.||step==0) // no more valid steps
         break;
   }
   t = t +deltaT;
   wait(t);
}
```

Table 4-2 Pseudo-code for IRS

Class diagram

After the context diagram, a class diagram can be used to connect entities in the problem domain in the form of connected classes. From a class diagram, classes can be derived with appropriate interfaces, that form the basis for the implementation in software. The class diagram can be found in Figure 4-5.

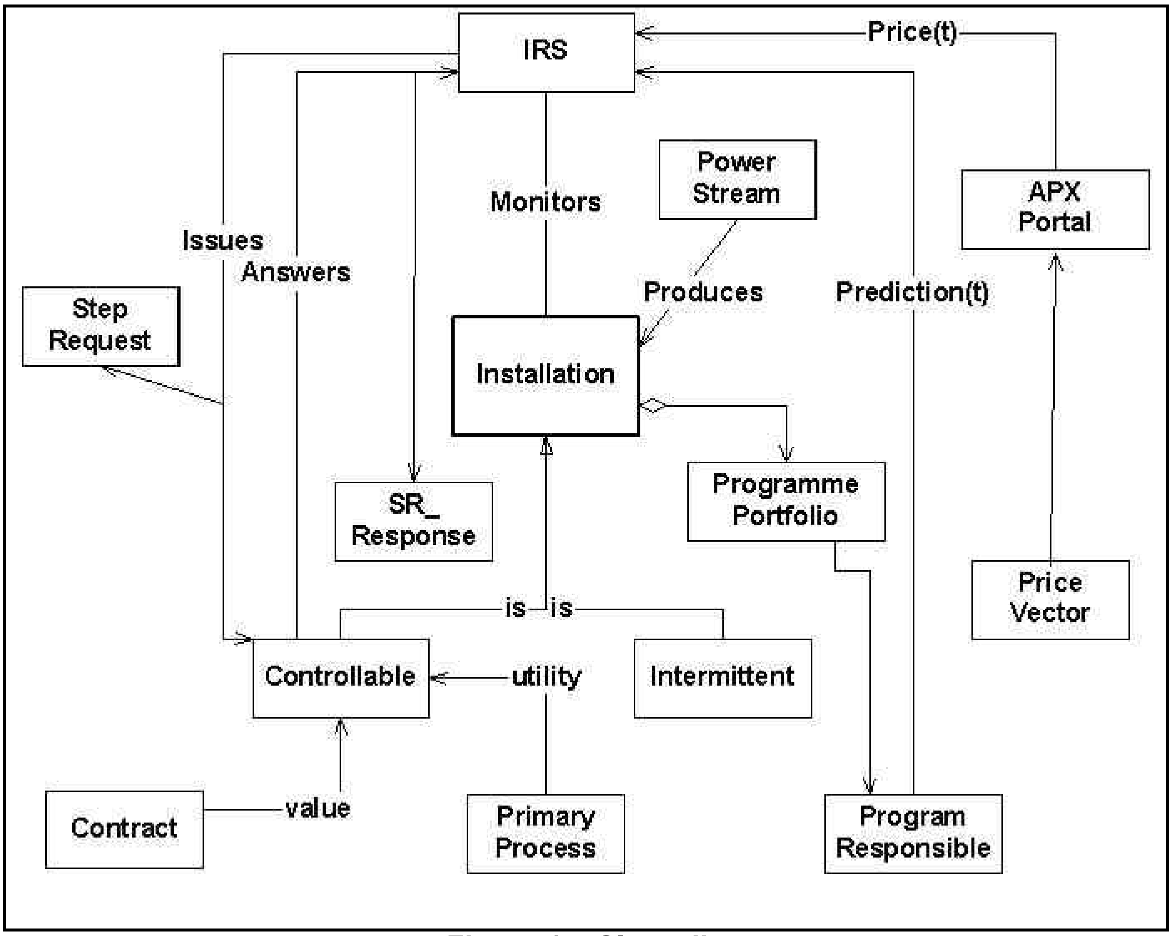


Figure 4-5 Class diagram

In the class diagram, the following entities can be discriminated:

1. Installation. Subclassed into Controllable and Intermittent Power Installation. An installation sends, with a certain frequency, power yield or consumption data to the imbalance reduction system.
2. A Programme Portfolio consists of an aggregation of installations. The aggregating factor is the common and individual power prediction as necessary on the market.
3. A Program Responsible. Given a certain installation portfolio, a prediction for the total load can be made given historic trend data and specialized tools for predicting intermittent resources.
4. StepRequest. The request denotes the maximum required power deviation from the programme and the compensation remunerated delivering/consuming less or more.
5. Contract. In a contract the value for the installation owner is specified in terms of cost reduction if a certain Step request is acknowledged. Note that contract data are not linked to the ProgramResponsible.
6. PrimaryProcess. The primary process is connected to the ControllableInstallation to

take in account the impact load/generation reduction/increase might have.

7. SR_Response. The response on the step request in terms in the percentage of the requested load reduction/generation increase.
8. APXPortal. The APX-portal object takes care of updating price information after the bidding processes have stopped. In the APX-mechanism this will be at 11:30 AM.
9. PriceVector. This class contains the time dependent pricing information.

Note, that status and maintenance information of installations is not part of the scope. These have to be accounted for in the SR_Response for ControllableInstallations and in the Prediction for Intermittent Producers.

Object instantiation descriptions

In view of the class diagram in the previous section, the instantiations of classes in terms of concrete objects, can now be discussed.

Intermittent Producer

The wind turbine park of the Slufter in the Maasvlakte near Rotterdam has the role of the intermittent producer. Currently, the power production is estimated using a meteorological weather prediction model and micro-modelling of the terrain roughness of the park. The total possible production of the park is 12 MW (8 turbines of 1.5 MW). The average uncertainty, the difference between predicted and realized power, in the 12-36 hour-ahead predictions of power production is some 20 percent.

Controllable co-generating heat producers in residential heat distribution networks

In a number of VINEX-locations in the Netherlands capacity for cogeneration of heat and electricity and generation of heat for heat distribution networks have been recently installed. These installations have electrical heat-pumps with soil storage of water. Furthermore they have electrical generators (gas motors) of up to 2 MW and water buffers to store excess heat. In case of heat demand during electrical peak periods they may operate the CHP-installation, given the fact, that gas price volatility with night-time peaks is opposite to electricity price volatility with peaks in the (end of the) afternoon over a period of a day. The process is sketched in Figure 4-6.

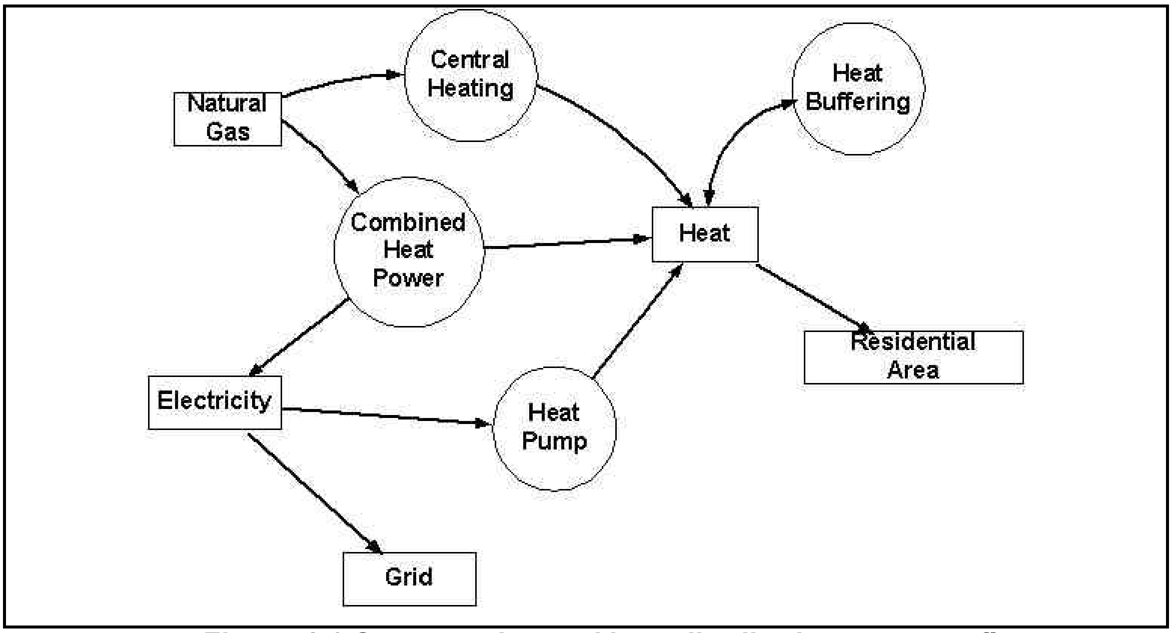


Figure 4-6 Cogeneration and heat distribution resource flow

Local process control is based on heat demand (for heating or warm tap water). Depending upon the current situation of the status of these processes, the SR_Response will be different. A possible response could be defined in the form of a decision table consisting of expected heat demand, the real-time gas price and the heat buffering capacity in the next period. A possible table with four tariff classes (increasing in retribution price class: A to D) is depicted in Table 4-3.

HeatDemand	GasPrice	BufferingCapacity	Response
Low	Low	High	B,C,D
Low	Low	Low	C,D
Low	High	High	D
Low	High	Low	-
High	Low	High	A,B,C,D
High	Low	Low	B,C,D
High	High	High	C,D
High	High	Low	D

Table 4-3 Decision table to determine response as a tariff group for co-generation

Emergency generator

Emergency generators are available and controllable by a relay. The response to a request by IRS of this type of generator is either ON or OFF. As an example, the emergency generator of the Parkgarage in the Hague is available to be remotely controlled. The response to a request may again be taken according to a decision table locally based on potential maintenance status and the time of day. Operation during certain periods may be not allowed because of disturbance of the neighbourhood.

Controlling comfort in an all-electric home.

Comfort control by air conditioning in homes consists of heating or cooling air and distributing the air using the ventilation system. The thermal buffering capacity of the building mass can be used to cool or warm buildings in advance in the morning in order to avoid having to control comfort in high-electricity price periods. Operating only the ventilation system, then, would give a cost advantage without impairing the realised comfort in the building. Factors, then, influencing the decision to an IRS-request are the outside temperature, an indication of the cooling set-point deviation, the building's use and the wall-clock time.
Air conditioning in buildings gives two possibilities for shifting electricity demand:

- Switching between ventilation and ventilation and cooling.
- Pre-cooling in anticipation of hot days.

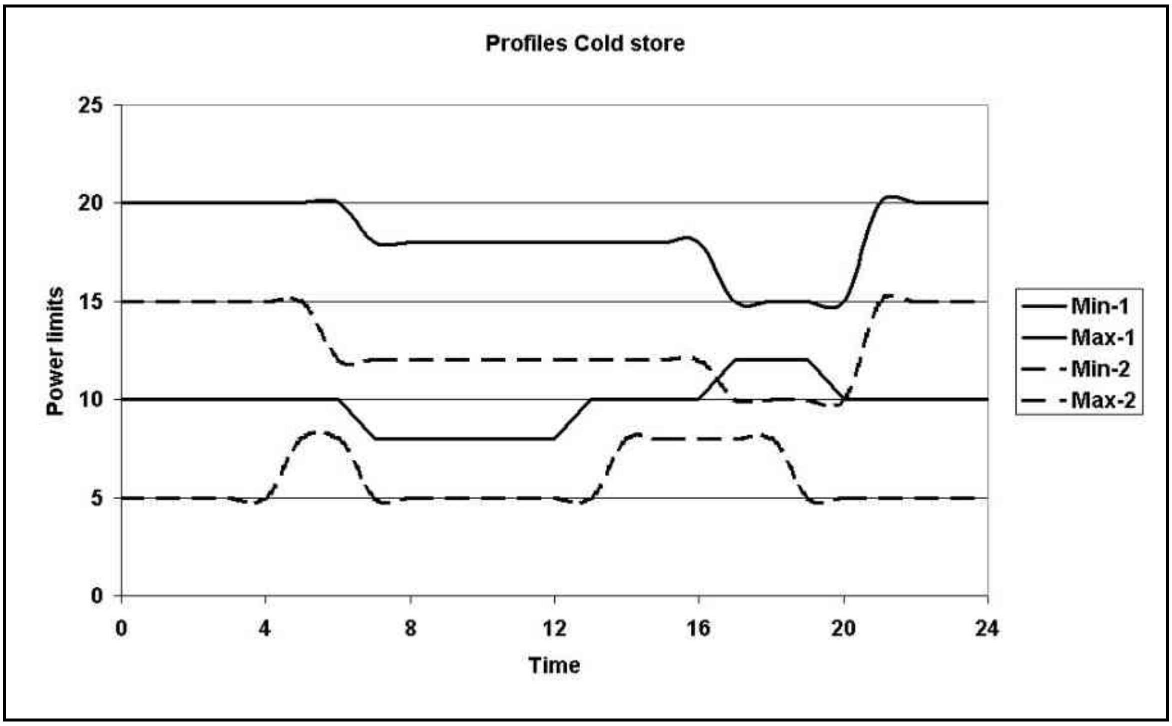
A decision table could be as follows:

DayType	SetpointDeviation	Wall-clock	Response
Cold	Minus[1]	12:00 PM<>02:00 AM	B,C,D
Cold	Minus	02:00 AM<>12:00 PM	C,D
Cold	Plus	12:00 PM<>02:00 AM	D
Cold	Plus	02:00 AM<>12:00 PM	-
Warm	Minus	12:00 PM<>02:00 AM	A,B,C,D
Warm	Minus	02:00 AM<>12:00 PM	B,C,D
Warm	Plus	12:00 PM<>02:00 AM	C,D
Warm	Plus	02:00 AM<>12:00 PM	D

Cold store

A cold store with a capacity of 800 kW in the Hague is part of the experimental configuration. Cold stores can be used as flexible electricity demanders. Being large electricity consumers, cold stores have time-of-the-day dependent profiles of minimum and maximum power to take from the grid. Extra charges are imposed if they exceed their maximum time-dependent electricity consumption as contractually agreed with the utility company. The StepRequest for Cold Stores will be contractually be fixed by a change in these profiles. An example of a ColdStore profile is shown below.

[1] A minus sign indicates, that the setpoint is lower than the actual temperature.



The distance from the realised energy consumption to the projected amount, then, provides a measure for responding. Additions to the contract have been made to account for this.

Programme portfolio responsible

From the electricity trade department, the historic prediction value from the day before has to be collected, that was used for the programme construction for the current day. The energy contract information will also be in the hands of the trading department.

24-hour ahead Power market and imbalance market

Connection to this market is realized using a connection to the latest market result; a time dependent price definitively determined before 12:00 AM at the day before the programme is made. Between 11h30 - 12h00 each day the APX Index will be imported as published on the APX-website for the next day. Imbalance prices are made available using a real-time market portal from TenneT, the Dutch TSO.

StepRequest and SR_Response

A step request contains the requested power (generated or to be consumed) for the coming

15 minutes and a reference to the current ImbalanceState, according to which the amount will be settled financially. The SR_Response is the power, that will be the new setting of the power delivered/consumed the next period.

Power and primary process data

Apart from the current power production and consumption (kWh and KW), information about the primary processes (e.g. heat storage capacity for a CHP) is necessary. Detailed specification of what data to collect will part of the local technical inventory specification. Typically, IRS will operate with a periodicity in the order of minutes. First step will be the collection of current consumption or production of power in MW to build up historical data.

The step-up/down signal (StepRequest)

This signal contains a composite measure:

1. The first value transmitted is the requested output power; i.e. an increase or decrease w.r.t the current level
2. The second is the price class. The price class refers to the contractual price the power reduction has.

A valid message would consist of a real followed by a real and an integer-code.

The DR_Response

This signal is a simple Boolean, indicating if the required amount will be delivered/consumed during the following time-block.

4.4. Scenarios and strategies involved

Given the configuration described above operation of IRS depends on the primary user processes state. For the processes having a link to heat generation, these are closely connected to seasonal ambient temperatures or wind speeds. For another part, they follow a pattern dependent on the time-of-day as well. This f.i. holds for the emergency unit generator and the residential area heating systems. Therefore, the measurement programme has to cover the winter, the spring/autumn and the summer period. Within each of these periods cases with different temperatures and wind regimes are discriminated. The days are shown on the table below:

4.5. Test program

The field test will be conducted in the reference situations of the table below.

	Summer	Winter	Autumn/Spring
T-high, V_{wind} low	v	v	v
T-high, V_{wind} median	v	x	v
T-high, V_{wind} high	x	v	v
T-median, V_{wind} low	x	v	v
T-median, V_{wind} median	v	v	v
T-median, V_{wind} high	v	v	v
T-low, V_{wind} low	x	v	v
T-low, V_{wind} median	v	x	v
T-low, V_{wind} high	v	v	v

Table 4-4 Summary of conditions to consider in the experiment

5. Planning of activities in the experiment

5.1. Phasing of activities

The design and implementation of the complete system plus the field experiment itself consist of the following phases:

1. **On-site operational inventory.**
    - Analyse on-site operational procedures,
    - Characterise energy producing and consuming hardware and process computer connection facilities.
    - Prepare data collection plan.
2. **Monitoring and characterisation.** This activity will start-up as soon as possible in order to be able get enough data for deriving the IRS-component models.
3. **ICT Infrastructure and Local Controllers.** Build-up and configuration of ICT-Infrastructure. Constructing local control system equipment based on the existing local control systems. Adapt them to accommodate for SDM algorithms. Testing of the client-systems, both locally and networked.
4. **CC VPN portfolio requirements and Specifications.** Verifying the system requirements and extend them regarding technical installation details. Make detailed specifications, test plans and test-scenarios for the communication components.
5. **Make a simulation model development of the test system.** A generic simulation model for SDM mechanisms has been developed in another part of the CRISP-project. The field test installations will be modelled and included in this simulation model. This model will be used to assess the operational effects on the Eneco installations of applying the SDM-algorithm.
6. **CC VPN design and rollout.** This pertains to the central coordinating Crisp node and the definition of the control model.
7. **Implementation and Testing of the IRS Server software.** Detailed software design control algorithm. Implementation and testing server software.
8. **Overall System Tests.** Integration test of complete system according to integration test plan. Pre-operational test. Evaluation of pre-operational monitoring data.
9. **Field Test with novel control algorithms.** The demand response is emulated, but not signalled to the installation hardware apart from the control to the ECN-dwelling.
10. **Analysis of field test data.**

11. **Writing EU Deliverables.** Documenting the field test set-up and the test results in order to comply with the contract obligations to the EU. After the end of the Field Test in December 2005, three months are available for analysis of the data in WP 1.7, provided that the project will be extended with 6 months.

5.2. Time plan

The planning in time of the field test is shown in the table below:

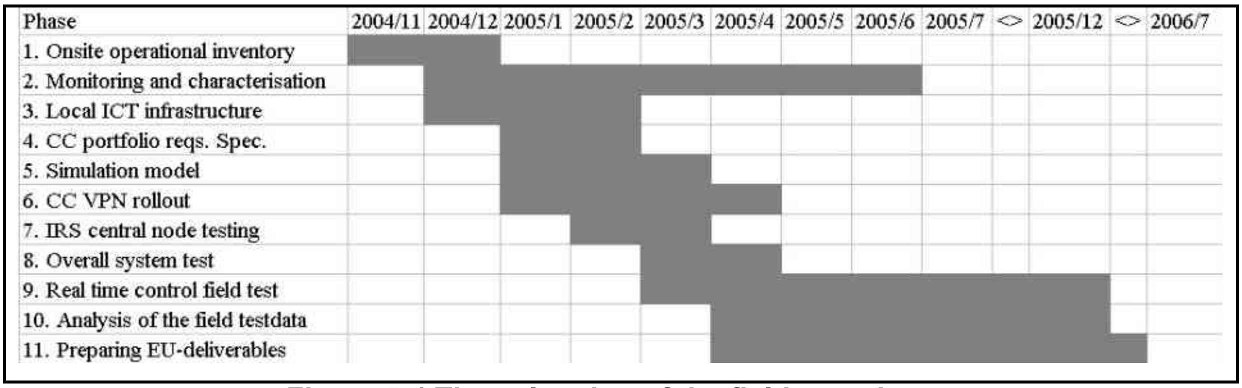


Figure 5-1 Time planning of the field experiment

5.3. Organization

The following parties are involved in the set-up and execution of the field test:

- **ECN Renewable Energy in the Built Environment**: Project management, overall system design, design and implementation of the supply/demand matching algorithms.
- **Eneco**: provides access to the needed installations, and the amount of manpower necessary to deploy the installations in the field test.
- **ECN Technology Services and Consultancy** (TSC) is the engineering department of ECN and takes care of the technical systems integration. Detailed technical design and implementation, hardware and software set-up.
- **Local Process Control Systems Integrator**: Adaptation of the local control systems. This role is most likely fulfilled by the company Imtech for the Eneco installations. Their efforts will be sub-contracted by ECN as 'services'.

5.4. Milestones and deadlines

Important milestones are at 2004/12, when the local inventory is ready and at month 2005/4 at the final rollout of the VPN.

Section B: Experiment B: fault detection and diagnostics

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IDEA

Control Versions:

Version	Date	Author	Description of Changes
01	28-04-2004	C.Andrieu	Version I _ draft1
02	23-09-2004	C.Andrieu	Version I _draft2
03	04-10-2004	C.Andrieu	Version I _draft3
04	06-10-2004	J.Kester	Editorial changes
05	22-02-2005	J. Kester	Suggestions for changes
06	11-03-2005	Ch Andrieu	Corrections additions on part B experiment
07	8-04-2005	J. Kester	Some editorial changes
08	8-08-2005	C.J. Warmer	Prepare for final state

Summary

The document describes the different tests and preparation done in order to carry out the experiments of the WP 3 part B. The main goal of the part B experiments is the test of different ICT components dedicated to the fault detection and localisation algorithm. The simulation tool described in the deliverable [crisp D2.3] gives the description of the proposed EPS topology used for the experiment and the main context of the experiment (scenarios and expected electrical results except for time frames due to ICT components). So this tool gives the results of the algorithm in case with ideal ICT components and is composed of the basic codes that will be used during the experiment. The experiment B shows the real performance of ICT components developed specifically for this EPS application.

Additional codes need to be developed to build information exchanges between the ICT components, and to deal with information security aspects (interoperability, reliability and non intrusion capacities). A main result expected from the experiment is the time characteristics of the dedicated ICT components and time of the total process for the fault diagnosis. Two scenarios of [crisp D2.3] have been selected as reference cases for the experiment and will be demonstrated.

Table of Contents Section B

References Section B

Label	Reference
[crisp D1.3]	M.Fontela & co, "Distributed generation as a means to increase system robustness", deliverable D1.3 of ENK5-CT-2002-00673 CRISP-project.
[crisp D1.4]	C. Andrieu & co, "Fault detection, analysis and diagnostics in high-DG distribution systems ", deliverable D1.4 of ENK5-CT-2002-00673 CRISP-project.
[crisp D2.3]	C. Andrieu & co, "Simulation tool for fault detection and diagnostics in high-DG power networks ", deliverable D2.3 of ENK5-CT-2002-00673 CRISP-project.
[crisp D2.4]	R. Gustavsson & co, "Dependable ICT support of Power Grid Operations", deliverable D2.4 of ENK5-CT-2002-00673 CRISP-project.

Acronyms and Abbreviations Section B

Acronym	Means
CB	Circuit Breaker
CPU	Central Processing Unit
CRISP	Distributed Intelligence in CRitical Infrastructures for Sustainable Power
DNO	Distribution Network Operator (same as DSO)
DNS	Domain Name Server
DoS	Denial of Service (security study)
DR	Distributed Resources
DSO	Distribution System Operator (same as DNO)
EPS	Electric Power System
FCI	Faulted Circuit Indicator
FDD	Fault Detection and Diagnostics
FPI	Fault Passage Indicator
FR	Fault recorder (information from the protection system)
HF	High Frequency
HTFD	Help Tool Fault Diagnosis, fault diagnosis support tool for the operator
HV	High Voltage
ICT	Information and Communication Technology
IP	Internet Protocol
IVP	Integrity Validation Procedures
LAN	Local Area Networks
LV	Low Voltage
MMI	Man Machine Interface
MV	Medium Voltage
PCC	Point of Common Coupling
PLC	Power Line Carrier
PPP	Point-to-Point Protocol
QoS	Quality of Service
SCADA	Supervisor Control and Data Acquisition
SCL	Substation Configuration Langage

Acronym	Means
SW	Switch
UML	Unified Model Langage
WAN	Wide Area Networks

1. Introduction

The distribution network automation is not yet achieved. A lot of applications may appear from a massive insertion of DER, and most of the existing functions in the EPS will have to be adapted. These applications may be needed by or useful for the DNO, and some of them may be included in various DG units. With the increase of actors (producers, network operators, active and passive consumers) a crucial need on a new and efficient information system is growing for the design, exploitation, operation and market management of the EPS.

The application HTFD (Help Tool Fault Diagnosis) experimented is dedicated for a DNO support system. The goal is based on the feasibility evaluation of an EPS dedicated tool including several ICT components, a main aspect being the time response measured for the transmission of information and the calculation time needed.

This document is composed of the experiment description, the goals, the applied technology, the expected results and the planning.

2. Problem definition

About the fault diagnostics in MV network, the problem of fault localization with DR or without DR has been described in work package 1.4 of the CRISP project (see in [crisp D1.4]). The application targeted is not yet solved conveniently in the existing network without DR: it takes time in general (minutes or hours) and entails numerous break of power for the feeder involved. While the main role of the distribution EPS is to supply loads, the break of power during short time period is not so expensive or problematic. But with the DG and the DG-RES distributed in these networks, and the constraints associated with brutal disconnection or slow and delayed reconnection ask for questions. Two axes are followed in the experiment proposed: study and make the fault diagnostic tool adapted to a high penetration of DG and DG-RES, and also boost the localization limiting the unsupplied area. This experiment is based on the possible application of a dedicated fault diagnostic tool including an important role to ICT and is defined in the work package 2.3 of the CRISP project (see in [crisp D2.3]).

3. Project definition experiment B

3.1. Goals of experiments

The equipment associated with ICT used for the HTFD application will have to achieve conversion, calculation, communication with remote equipments. The goal of the experiment is to check the ability of dedicated ICT to comply with the application in term of calculation amount and time and in term of information security aspects.

The EPS timing process is evaluated for an expected realistic future situation based on the technical knowledge of existing electrical devices. The amount of calculation will be taken in coherency with existing capability of fault diagnosis real time devices (see in [crisp D1.3]).

The questions that the experiment is intended to answer are:

What is the ICT equipment that may comply with the application? What is the expected possible cost involved by the solution? What is the associated software requirement?

What are the difficulties to face when developing the solution proposed? What are the recommendations for ICT, MMI, EPS intermediate equipment (crossed constraints between existing EPS automatic processes and programming a flexible tool adapted to the main existing MV networks and easy-to-use by a network operator)?

What are the timing constraints of the different subtasks defined in the application due to existing limitation of the equipment and of the protocols? What are the possible future improvements?

What is the possible real time response during such localization in order to integrate this sequence into the main protection sequences? (total time expected for localization, time remaining for decision making)

What are the different aspects of the information security in this application? How to characterize the interoperability, the reliability and non intrusion capacity of the information network? (problem caused by shared data between applications as topology data) (see in [crisp D2.4])

The future trend in ICT for real time application is to combine adequately local calculation and needed minimal communication: This kind of optimisation of the information system will enable the design of a large and fast communication system between numerous and various electrical equipments, involving also a certain level of local analysis or data conversion. The cost constraints are high in the MV system (compared with the transmission system), the ICT is expected to bring an adapted low cost solution in the long run.

3.2. Applied technologies

A first approach consists in simulating the EPS system and tests the expected calculations. Then knowing the constraints of existing devices, and the ability of them to boost the information, a timing process and data preparation is defined to test the ICT devices and associated software. Figure 1 refers to a work for developing the different programs expected and running in the different ICT components, including in the HTFD. At this step the communication are assumed instantaneous and ideal.

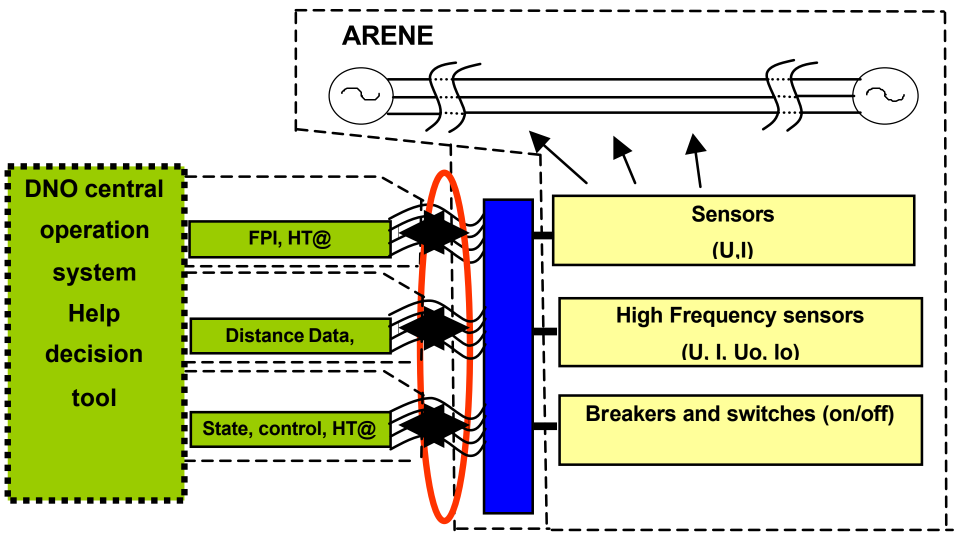

Figure 1: The architecture of the ARENE Real Time experiments

The experiment in open loop for the ICT is then followed to check their real time response and compare with the expected values (theory, simulation). The figure 2 refers to the phases 1, 2, 3, 4, 5 and 6 of the experimentation dealing mainly with the achievement of an information architecture. The evaluations of the programs modules are based on previous simulations results and assumptions for electrical variations (indications of the FPI, current and voltage measured in the substations).

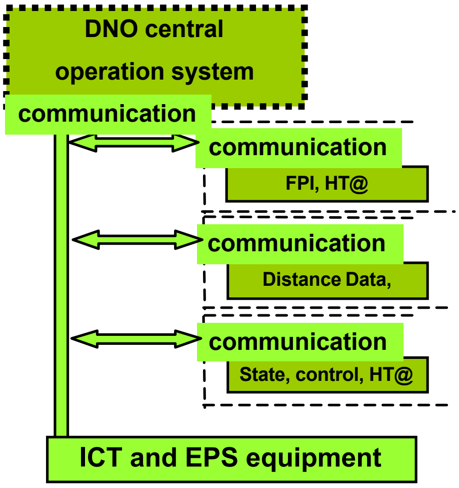

Figure 2: External ICT components and EPS to be tested

From the results reached, the closed loop will be initiated to study the possible interactions between the EPS real time signals, the ICT information resulting, and the feedback control to the EPS switches. Figure 3 refers to the phase 7 of the experimentation, including a complete closed loop with Arene real time and a real network of PCs taking into account the communication constraints.

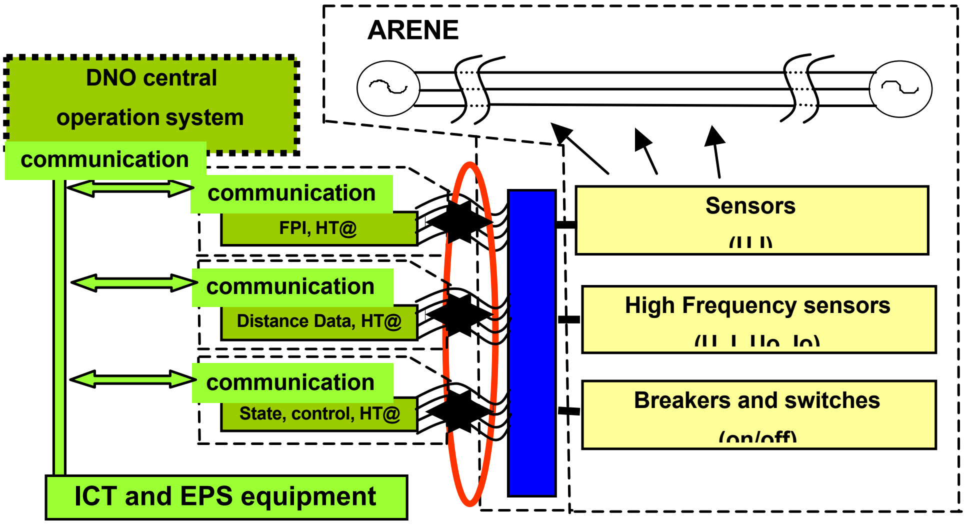

Figure 3: Expected closed loop experiments with ARENE Real Time

Experiments results will be based on three-phase and two-phase faults. The codes associated with the ICT components, physical link representation, TCP/IP description and setting of ports, management of the inputs/outputs of communication (in asynchronous mode) will be described in the experiments results.

Using Arene real time is not necessary for the main results of the experiment. The inputs for the experiment have been prepared with Arene (generation of comtrade files, results of simulation). Depending on the obtained results, the closed loop will be used in order to show the interest in a fast protection new application.

From exchanges with BTH and ECN in Amsterdam the 4th-5th of March 2004, the technical solution the most adapted to our application is using TCP/IP communication protocols. The ICT components are clearly identified in a level 1 cell to allow the operator a simple re-configuration process.

Input for ICT components:

FPI: We expect to use an existing technology (electronic device) and to use simple and logical information of the device state. We keep the possible adoption of a known internal timing process to give a realistic timing expectation for a dedicated use in a boosted solution. The existing clear and external interface existing today between the FPI manufacturer and ICT component manufacturer is through dry contacts. For dedicated communicating FPI, the

FPI manufacturer may propose some alternatives to take our proposed solution into account. In our case, direct change of state in the input of the FPI ICT component is scheduled in the main processor (main HTFD ICT component) which contains the reference timer.

Fault recorder: We expect to use an existing technology, with a timing adaptation to a possible development inside numerical existing protection (boosting if possible the external information monitoring ability). If transient data exchange is needed by full data file, the international standard leads to use COMTRADE format. This kind of file may be generated by Arene (version COMTRADE 98). We intend to use this ability of Arene to generate the file used by the ICT component associated to the fault recorder or the protection device used.
In our case, a comtrade file is sent to the input of the FR ICT component, the sending instant being scheduled in the main processor (main HTFD ICT component) which contains the reference timer.

EPS Interrupters: As for the FPI, a simple interface will be taken into account to lead to a general solution. The main input from interrupters (except its identification) is the information about its status (open or closed), which enable a clear and fast update of the real configuration in the distribution EPS. This is important information for the HTFD ICT component.

Help Tool for Fault Diagnostic: this major ICT component has to collect all the prepared information from the FPI, interrupters and fault recorder at the right time (depending from the occurring events), has to exchange information with HTFD ICT components of the same level 1 cell, has to manage an MMI (man machine interface) in order to have the needed topology and technical data, and also to inform conveniently the operator of the current state and of its solution proposal.

The hardware between the EPS equipment and the ICT components is expected to be numerically based.

The basic operation of the EPS is modelled by ARENE real time simulator. The equipment that includes control command or advanced evaluation is modelled with Dspace software, enabling an easy and clear interface for the used program (using matlab with simulink description for the control).

3.3. Expected results

The time frame of information streams between the ICT components will be given, detailing the delays and sequences involved by the TCP/IP protocol.
The scenarios 3 and 6 described in WP2.3 will be tested, and tables of results will show the expected time for information exchanges, calculations and decisions. A clear and complete re-closing sequence will be presented in the case of our solution for two-phase or three-phase faults.
Figures will show the results observed on Arene real time during the experimentation.
Aspects relative to security and dependability will be demonstrated during the development and refinement of the software / hardware solution.

3.4. Integration with other CRISP activities

The concept of MV level 1 cell is of a more general perspective than unique application to the localisation sequence as described in this experiment. The issue on ICT component used in our application may have resonance with other applications as load flow management and supply demand matching in a same distribution EPS approach. Since our application is oriented on an operational type, the attention paid for timing process is crucial, what is not so critical in a SDM tool as defined in the CRISP project.
The experiment proposed has multiple security aspects to deal with, as secure transmission, secure analysis, secure protection against intrusion and corruption of data. These aspects are being studied with our partner BTH.

3.5. Boundaries and dependencies

IDEA defines the requirements for ICT components mainly in collaboration with ECN and BTH. These ICT components are based on using existing or near existing network equipment. Specific exchanges with BTH are achieved for security and choice of components purposes.

IDEA is intended to use dedicated real ICT components to evaluate and check the timing process. A specific preparation for the real time simulation with Arene RT is in process. The ICT components may be developed in collaboration with BTH.

4. Project description experiment B

4.1. ICT components

The different ICT requirements for the use of the fault detection and localisation tool were defined in WP2.3. In the next paragraph, the different operations and functions of the required ICT are described in detail. These ICT components have been implemented into C language in order to integrate them in the experiment. The communication media used to link the different ICT components will be IP network. A specific processor will be used to model the link in order to represent radio link, optic link or PLC (power line carrier). The wireless solution is typical for FPI and SW ICT components because of the distance involved in the grid (10km up to 40km).

Expected configuration for the ICT components:
TCP/IP version 4 (version 6 not applied intentionally)
PC 500MHz, 1GB minimum
Exploitation system UNIX: FreeBSD 4.10 & OpenBSD 3.5
Networks cards: two per PC,

For CPUs distributed among the networks in the real application, a cheaper solution will be investigated in the field of existing EPS devices, but also with the goal of using updated software environment (FreeBSD for instance). The first step of the experiment is based on standard PC.

The purpose of the experiment is to convert the local information into a specified format, use the practical protocols for communication and test the topology analysis for fault diagnostics. The goal is to reach a fast communication system in order to verify the ability of ICT for operation mode application.

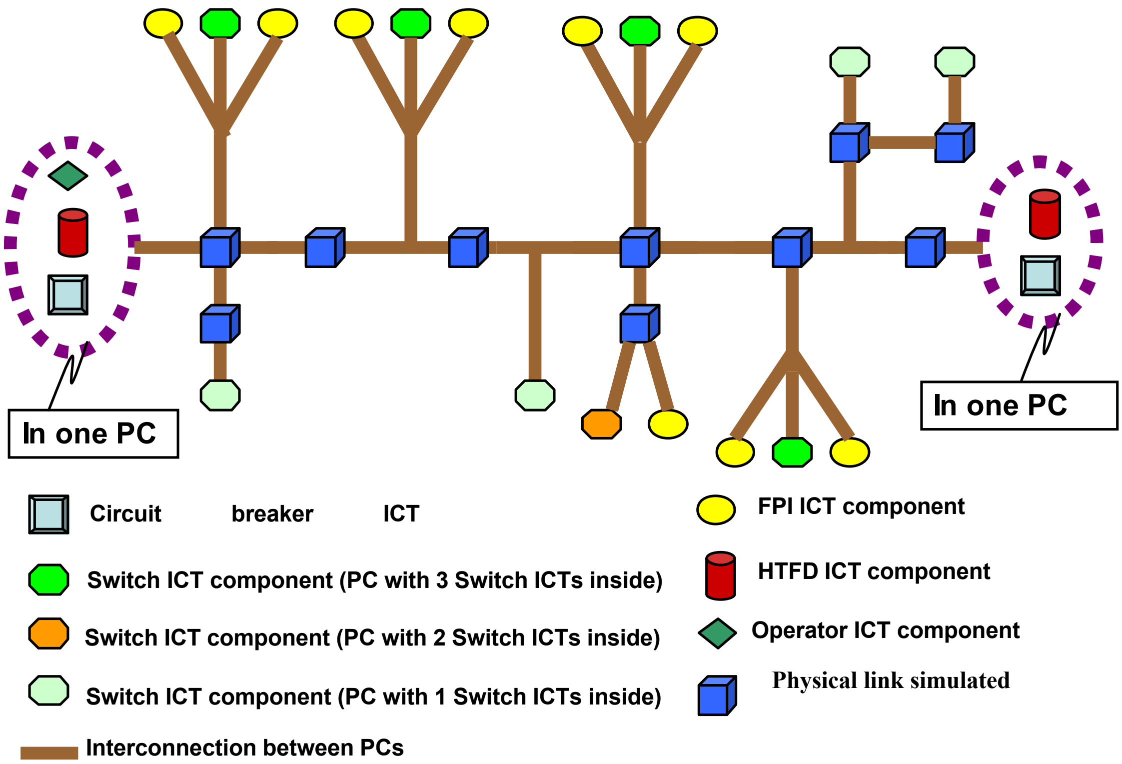

Figure 4: information architecture for the experiment

ICT component associated to the directional FPI

Object diagram:

FPI_ICT_component
FPI_topology FPI_communic_identifier FPI_communic_detection_status_output FPI_communic_direction_status_output
Read input data Send converted information to HTFD comp. Self-control diagnosis (internal failure detection)

The main input data for experiment is composed of the identifiers, an integer for the state of fault indication and an integer for indicating the direction of the fault. The change of state is scheduled in the main ICT component (HTFD) which has the timer reference in the experimental benchmark.

ICT component associated to the fault recorder or protection system

Object diagram:

FR_ICT_component
FR_topology FR_communic_identifier FR_communic_data_output FR_main_data_file_input
Read input data file Analyse signals Convert information into FR_HTFD format data Send converted information to HTFD comp. Self-control diagnosis (internal failure detection)

The main input data for experiment is composed of the identifiers and a comtrade file of 600ms (with 200ms before fault occurrence). The FR ICT component receives the file in a scheduled time inside the main ICT component (HTFD) (timer reference in the experimental benchmark). The file is used to generate formatted values (current magnitude) and identify the type of fault. The information is then sent to the HTFD.

ICT component associated to the EPS switch

Object diagram:

SW_ICT_component
SW_topology SW_communic_identifier SW_communic_status_output
Read input data Send converted information to HTFD comp. Self-control diagnosis (internal failure detection)

The main input data for experiment is composed of the identifiers, an integer for the state of the switch (this switch is controlled by the operator thanks to an external control system located in the substations). The change of state is scheduled in the main ICT component (HTFD) which has the timer reference in the experimental benchmark.

This change of state of the interrupters is important for the reconfiguration purpose, and associated consequences on expected following analysis.

ICT component associated to the HTFD

Object diagram:

HTFD_ICT_component
HTFD_topology HTFD_communic_identifier HTFD_communic_data_output HTFD_FPI_data_input HTFD_FR_data_input HTFD_fault_history
Read input data from FPI Read input data from FR Analyse_updated_information (fault_type, grounding system) Convert information into operator format data Send converted information to operator Self-control diagnosis (internal failure detection)

The input data for experiment is composed of the identifiers and the information from the FR, SW or FPI ICT components. The main ICT component (HTFD) includes the timer reference in the experimental benchmark. The outputs will be the information for the operator, indicating the fault location (or locations if doubt exists) and the proposed sequence to clear adequately this fault.

Operator

Object diagram:

operator
SW_status_input SW_status_output (control) CB_status_input CB_status_output (control) HTFD_communic_data_input
Read input data from SW Send output control to SW Read input data from CB Send output control to CB Analyse updated information from HTFD Take decision on SW and CB control

In the first step of the experiment, the operator is only a target for the information of the HTFD. In the case where the ICT experiment is fast enough to introduce the sequence into a protection system, the decision to make will be describe in an automation mode in order to have the right sequences in less than 30s. So it is useful in this way to keep the description of the operator as a specific agent, whose part of its mission could be automated.

4.2. Power network

The grid involved is intended to be simple enough but enough representative of a real case. The electrical simulated components have typical real values and the radial configuration of the network has section length similar to existing ones. In order to take into account the concept of the level one cell, a basic two feeder network has been defined. The multiple derivations of the grid allow us to experiment the efficient combination of FPI and fault distance analysis.

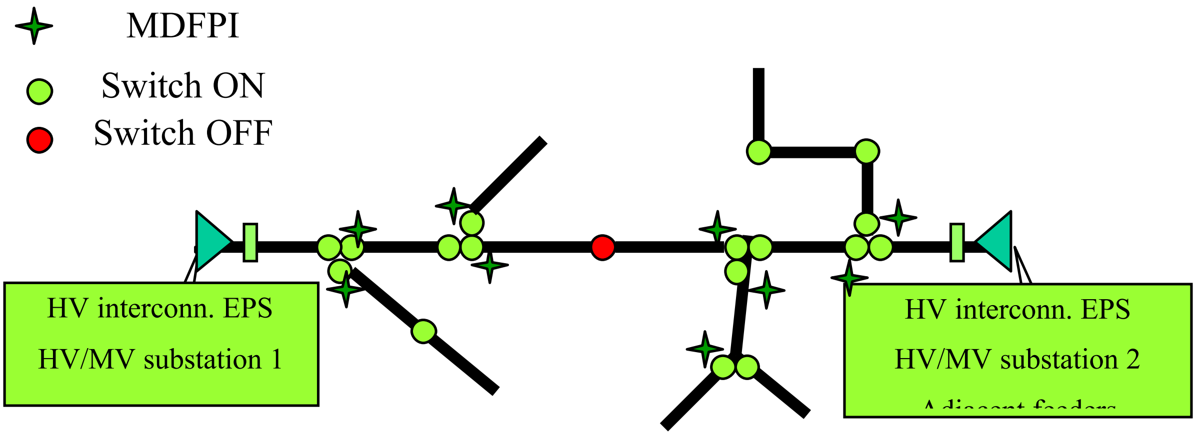

Figure 5: Topology of the simulated MV feeders

The description of the network is detailed in the CRISP D2.3, giving all the data assumption and distributional aspects. Each line in the figure is associated to a 5km section. The communication path between each dispersed point and the control information room is simulated with a dedicated CPU.

The two different scenarios of faults are described in detail in the document D2.3.

The EPS network used for the experiment has been described in the deliverable D2.3. The following figure gives the elementary level 1 cell used. Loads and DER units are distributed in the given EPS.

4.3. Characterisation of experiment

Two scenarios have been chosen as reference cases for the experiments:

Scenario 1 composed of one sequence (fault cleared by opening S7)

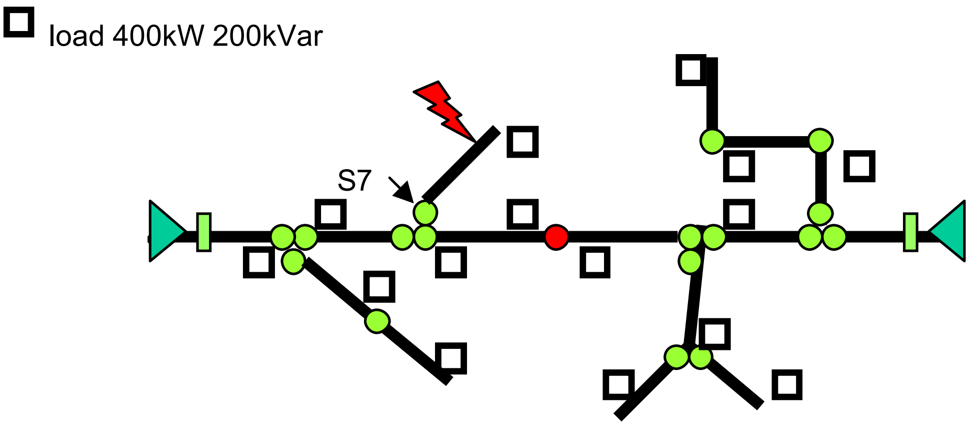

Figure 6: Fault location with scenario 1

Scenario 5 is composed of two sequences (first fault cleared by opening S1 and breaker, second fault cleared by opening S4). A specific interest in this second test is to check the reconfiguration sequence, followed by a new fault in the new configuration.

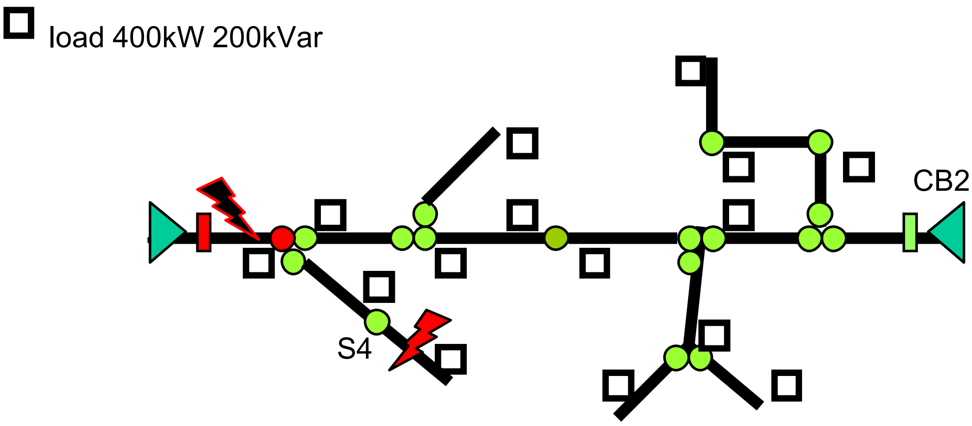

Figure 7: Faults locations with scenario 5

The EPS system and associated protection system are assumed to work properly. The EPS equipments distributed in the network are supposed to be connected to local dedicated ICT components which communicate with a central information room.

An extrapolation to real application is expected to be done from the experiment results. The various observations on the four types of ICT components (six possible ICT components in fact, but in the experiment the CB is associated to SW kind of ICT (monitoring the state open or closed) and the operator serves as an actor rather than as an ICT component) should give enough information to have trends of limitation about communication aspects (depending on volume, time transmission, security) and analysis aspects (depending also on volume, time transmission, security).

4.4. Information streams

Adequate measurements of time data must be implemented in the programs. As the time involved may be nearly 10ms (execution of some function in a program), the calibration between several PCs may lead to some difficulties. Then the results may have to be reconsidered for other kind of operating systems or hard ware (micro controllers for instance): the extrapolation of results will be needed. The control of the circuit-breaker and the EPS switch is already done by various systems and is crucial for the system. It could be an issue for the real application of the HTFD tool, trying to insert an exploitation tool into the sequences of protection. Some specific check will have to be developed in order to satisfy a right level of secure switching during fast re-closing sequences (no breaking power in the EPS switches).
The experiment B is based on TCP/IP. The datagram involved will be reduced at a minimal level to keep the minimal latency for the targeted application.

In a first step the stream of information is unidirectional. The time measurement of various calculations and transmission of data is achieved in the CPU associated to the HTFD ICT component.

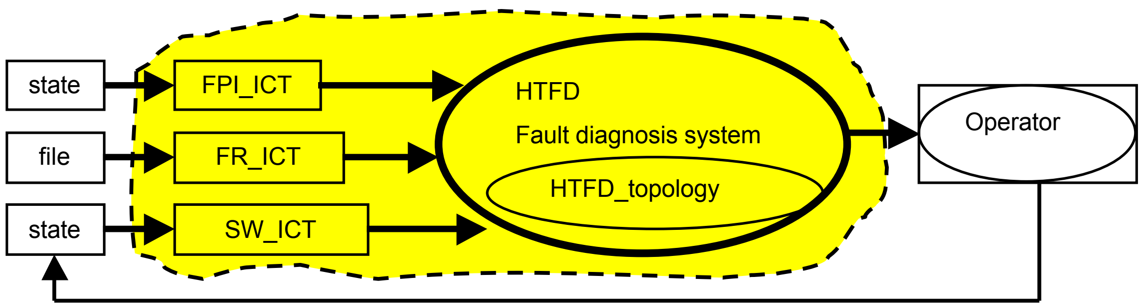

Figure 8: first step experiment simple presentation

The throughput is the capacity of the system in MB/s to transmit the information data. The latency gives the total time of transmitting the data from a node to another. If the throughput is increased too much, a risk of collision and losses of information may occur. This involves exchanges of extra messages between nodes and as a consequence an increase of the latency (see in [crisp D1.3]).

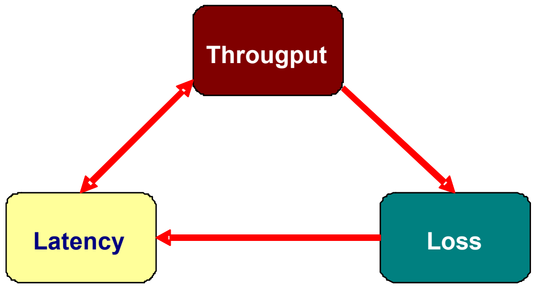

Figure 9: interaction between latency, throughput and loss of information

The main measurements during the experiment are the latency for the fault location. The analysis of the results will detail the time involved in the various step of transmission and local calculation. With the increase of FPI and FR ICT components sending information in a near short time, and the possible interaction of SW ICT components involving reconfiguration, the problem of congestion will be investigate and quantified.

4.5. Scenarios and strategies involved

The scenario 1 and scenario 5 described in the CRISP WP2.3 document (describing the HTFD simulation tool) will be used as reference cases for the experiment.

The experiment focuses on the analysis performance and data communication performance induced by the different ICT components.

A preliminary step will focus on a simple demonstration of the implementation of the different ICT component. This demonstration will take place in Grenoble (France) and will be composed of a few PC (near 7 CPU) representing the ICT components and physical links separating them.

A first step for experiments will take into account the proposed MV network (see scenarios) using 35 PC in the BTH premises.

Then the adaptation to the real condition for network devices will be investigate progressively (memory capacity and calculation power locally required and already available).

Scenario 1

All the conductor sections are MV lines. There is no DR in the network.
The neutral is grounded with impedance in order to limit the single-phase fault current.
A fault occurs in a derivation. No reconfiguration is expected in the MV cell, the EPS switch S7 should open.

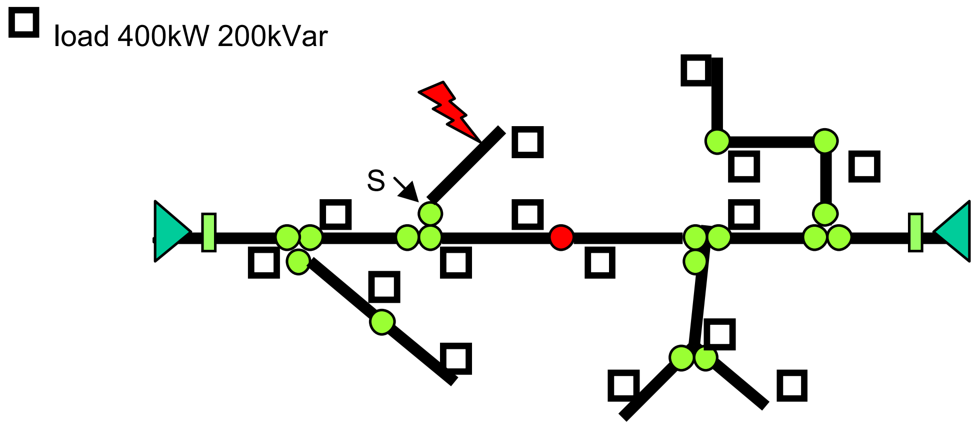

Figure 10: Scenario 1 diagram

Scenario 5

From the chosen initial situation this scenario describes two steps corresponding to two successive faults. This scenario has no distributed resource (DR) inside the simulated MV cell. The diagnosis tool must be adapted to update the configuration of the network (topology purpose).
All the conductors sections are MV lines.
The neutral is grounded with impedance in order to limit the single-phase fault current.
A fault occurs in the main feeder. A reconfiguration is expected in the MV cell.

Step 1: a fault occurs between CB1 and S1

The HTFD located in substation 1 should propose to open CB1 and to open switch S1 to clear the permanent fault. Then it should propose an appropriate sequence to close the switch S8 in order to supply as best as possible the level 1 cell (the appropriate sequence may be in this case : open CB2 – close S8 – close CB2, allowing CB2 to control a possible closing on fault).

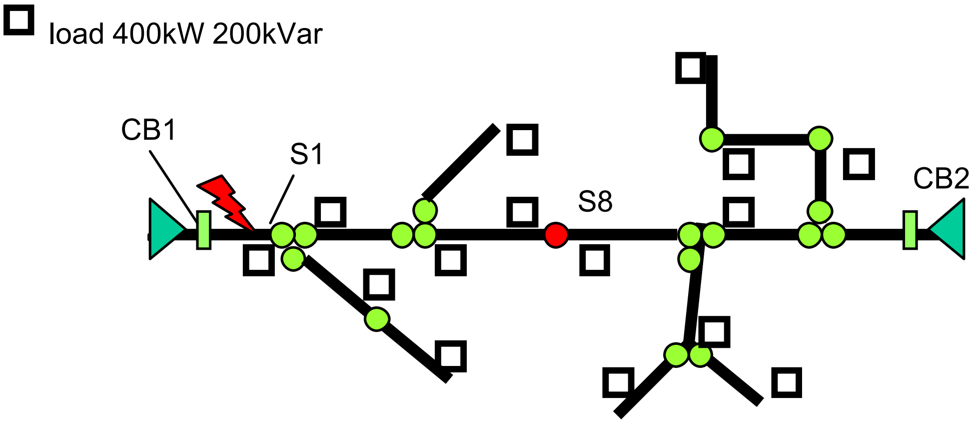

Figure 11: Scenario 5 step 1 diagram

Step 2: a fault occurs after reconfiguration

The cleared section of the network remains not supplied during a while: the new configuration is maintained up to the next fault occurrence. A new fault appears in the network at fault location 6.

The HTFD located in substation 2 should propose to open CB2 and then to open switch S4 in order to clear the permanent fault.

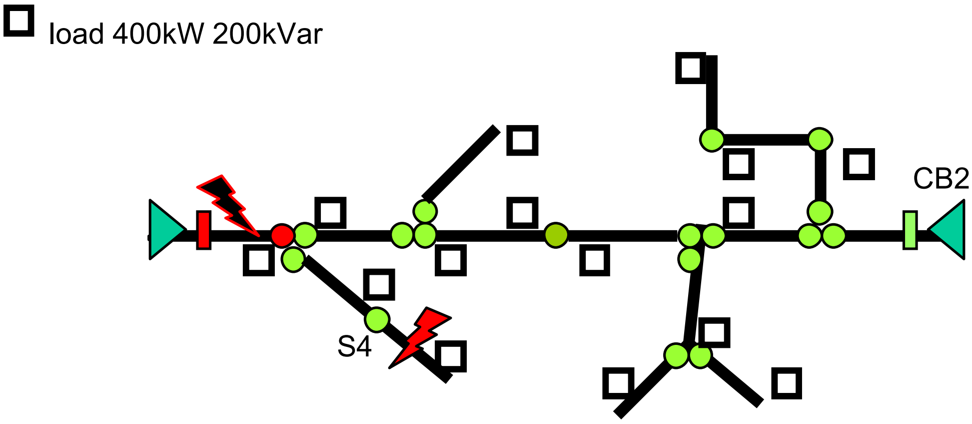

Figure 12: Scenario 5 step 2 diagram

4.6. Test program

The timing process of all the inputs of the distributed components will be programmed. The inputs of the HTFD ICT components will depend on the behaviour of the other ICT components.
The different sequences will be archived (time schedule and values changes) and then analysed for the different scenarios.

A part of the test will begin in BTH with a 35 CPU installation representing the information architecture. A simple demonstration of the experiment with the elementary ICT components is intended to be done in Grenoble. The files Comtrade (generated with Arene simulator in Grenoble for three-phase faults) in the scenarios 1 and 5 will be used as reference in BTH premises for the inputs of the FR ICT components.

In a first step, the measurements are achieved for unidirectional stream of information. The operator has time to make decision on the sequences of opening and closing circuit breakers and interrupters.

In a second step, an automated decision making of these operations may be developed (depending on the time results of the first step), involving to take into account of the operator and the circuit breaker as new kind of ICT components. In this second step the stream of information becomes bidirectional for the breakers and interrupters.

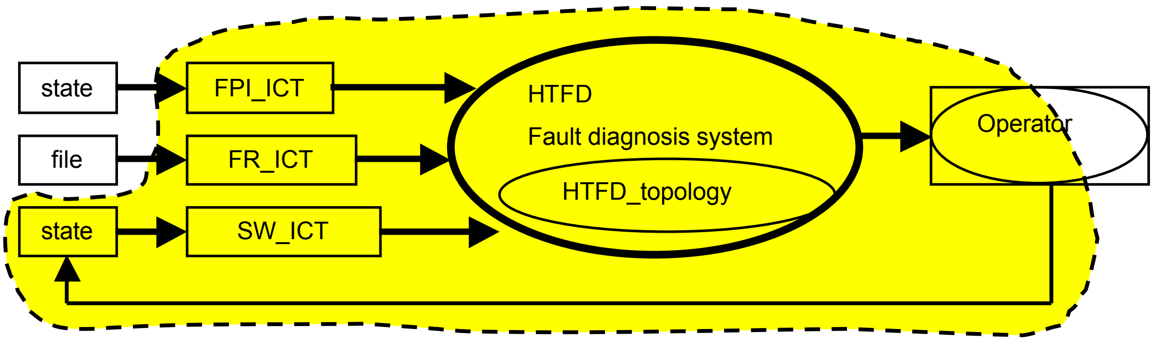

Figure 13: second step experiment simple presentation

5. Planning of activities experiment B

5.1. Phasing of activities

Phase 1: Program development for ICT components in C language in BTH (with Miguel contribution) [except main HTFD ICT component]

Phase 2: program development for HTFD ICT component in C language in Grenoble

Phase 3: Implementation of IP network with 35 CPU in BTH (with Miguel contribution)

Phase 4: Grenoble demonstration with a minimal configuration showing a case with the four kinds of ICT components (with Per and Bjorn contribution)

Phase 5: BTH and IDEA tests and analysis for experiments first step (35 CPU information system in the BTH premises), draft for results and analysis (D3.2)

Phase 6: Refinement for new tests (time results, CPU adaptation (cheap solution targeted), closed loop for SW ICT components)

Phase 7: depending on results from phase 5 & 6, closed loop with Arene real time to integrate the HTFD in the protection process, & associated tests.

5.2. Time plan

Phase 1: 2.5 month
Phase 2: 1 month
Phase 3: 4 month
Phase 4: 0.5 month
Phase 5: 2 month
Phase 6: 4 month
Phase 7: 3 month

5.3. Milestones and deadlines

Phase 1:
Start: August 04
End: mid-october 04

Phase 2:
Start: mid-September 04
End: mid-October 2004

Phase 3:
Start: mid-June 04
End: mid-October 04

Phase 4:
Start: mid-October 04
End: end of October 04

Phase 5:
Start: November 04
End: end of December 04

Phase 6:
Start: February 04
End: end of May 2005

Phase 7:
Start: June 05
End: end of August 05

Section C: Experiment C
Intelligent Load Shedding

Zoran Gajic, Daniel Karlsson

ABB

Control Versions:

Version	Date	Author	Description of Changes
1.0	2004-10-05	Zoran Gajic, Daniel Karlsson	creation
1.1	2004-10-06	J. Kester	some editorial changes
2.0	2005-02-22	J. Kester	suggestions for changes
2.2	2005-08-08	C.J. Warmer	prepare for final state

Summary

The document describes the setup of the CRISP 3C field experiment on power system response related to intelligent load shedding. The power system on the island of Öland in South-East Sweden, was selected by ABB and Sydkraft as suitable for the experiments, since it has a large amount of wind power and a relatively weak 50 kV system. The focus for the experiments is to study load and power system interaction, in the presence of a large amount of dispersed generation, during critical operational conditions. Three phasor measurement units will be install on Öland – one in the north, one in the south and one in the middle, at the connection point to the mainland. Voltages and currents will be recorded at the three measurement locations for 3 to 6 months. The outcome of the field measurements will depend very much on the power system events happening during this time.

Table of Contents Section C

References Section C

Label	Reference
Carlsson et al, 2005	P. Carlsson, Z. Gajic, D. Karlsson, N. Rahmat Ullah, S. Okuboye, C. Andrieu - *Intelligent Load Shedding*. CRISP deliverable D1.5.
Karlsson et al, 2004	D. Karlsson - *Intelligent Load Shedding to Counteract Power System Instability*. CRIS 2004 Conference, Grenoble
Karlsson et al, 2004	Cigré paper 277-04: “Intelligent load shedding to counteract power system instability” (Annex 1)

Acronyms and Abbreviations Section C

Acronym	Means
CT	Current Transformer
EMS	Energy Management System
GPS	Global Positioning System
ICT	Information and Communication Technology
PMU	Phasor Measurement Unit
PSS/E	Power System Simulator for Engineering
VT	Voltage Transformer

1. Introduction

The power system on the island of Öland in South-East Sweden, was selected by ABB and Sydkraft as suitable for the CRISP 3C field experiments, since it has a large amount of wind power and a relatively weak 50 kV system. The focus for the experiments is to study load and power system interaction, in the presence of a large amount of dispersed generation, during critical operational conditions. Three phasor measurement units will be install on Öland – one in the north, one in the south and one in the middle, at the connection point to the mainland. Voltages and currents will be recorded at the three measurement locations for 3 to 6 months. The outcome of the field measurements will depend very much on the power system events happening during this time.

2. Problem definition experiment C

The problem domain to be studied is related to intelligent load shedding, in systems with a large amount of dispersed generation. According to

- How do the wind power mills react to different power system conditions, such as
    - “normal faults” in the mainland power system
    - “normal faults” in the Öland system;
    - large disturbances and power oscillations – if they occur during the recording period.
- What is interaction between load and power supply system during stressed or faulty situations, such as
    - what is the load response to a supply voltage decrease;
    - what is the system voltage response to a load change.

The problem is to identify load and system interaction to be able to design efficient and “intelligent” load shedding schemes, in systems with a high degree of distributed generation.

3. Project definition experiment C

3.1. Goals of experiments

For the Öland experiments there are three very specific goals:

1) For faults occuring on Öland, resulting in loss of load for about half a minute, the system response to a load relief can be investigated.
2) For faults on the main land, resulting in weakening of the supply source, the load response to a voltage decrease can be studied.
3) For all kind of disturbances, the response from the distributed wind power can be studied.

3.2. Applied technologies

For the field test recordings phasor measurement units (PMUs) will be used. Recording of positive sequence voltage and current phasors will be made once every power system cycle, to a local PC with extended memory, for the whole recording period. The PMUs will be synchronized via the global positioning system (GPS). Since no communication is available the recordings will be put together after the finalization of the recording period.

3.3. Expected results

The results expected are much related to the disturbances and events happening in the power system during the recording period. Faults due to thunderstorms are expected a number of times, both in the Öland system and in the mainland system. Based on the material we hope to be able to in more detail specify

1) the voltage increase due to a load shedding;
2) the load reduction due to a supply voltage reduction; and
3) the response from the wind power mills to different disturbances, such as trip due to low voltage, oscillations due to short circuits or earth faults.

3.4. Integration with other CRISP activities

The experiments specified in WP3C are as such rather standalone. The results from the experiments – increased knowledge of supply and load interaction in the vicinity of a large amount of distributed generation – form, however, together with the tests and experiments in WP3A and WP3B a great knowledge base for future dispersed generation, concerning interaction and tuning.

3.5. Boundaries and dependencies

The main challenge is the “intelligent load shedding”, since there are practically no theoretical limits for the level of implementation. The most unintelligent solution is available already today – you shed load, with a distribution level (130 – 10 kV) circuit-breaker, based on a local underfrequency or undervoltage criterion. The level of intelligence can, from this starting point, be much improved both concerning the criterion – which can be more complex and sensitive, and based on wide area measurements (i.e. measurements coming from different parts of the power system) – and concerning the load reduction, as such – which can be much more detailed and selected in a more intelligent and local way. Dynamic pricing could be an excellent tool for load selection, either in a preparation level or on-line when the load reduction is requested, depending on the time available for corrective actions and available communication facilities.

4. Project description experiment C

4.1. ICT

The existing level of ICT in the area for the performance of the experiments is not very advanced. The experiments are rather aimed at investigating the potential and conditions for a more ICT based operation, e.g. concerning dynamic pricing. The communication infrastructure is not in place, but the experiments contributes to increased knowledge of the potential of dynamic pricing in different extreme operational situations. Dynamic pricing requires fast and reliable communication between power supplier and customer. Depending on the specific application the requirements on speed may differ, while the requirement on reliability is constantly high. The communication capability within the power system itself differs very much between different networks. In the Öland system, the communication facilities are very limited, but this fact does not affect the experiments as such, and the results are applicable in any system.

4.2. Power network

The power system on Öland is operated radially, with four outgoing 50 kV lines from the central supply substation. The wind power generation is approaching the total load on Öland, soon resulting in net export to the mainland. Minor wind power mills are connected to the local 10 kV distribution grids, while a large wind farm on the south part is directly connected to the 50 kV level.

4.3. Characterisation of experiment

The experiments, or field measurements, are rather simple, as it is more or less just to set up the recording equipment and wait for faults and incidents, since these incidents are much more powerful than any grid operator would allow for planned excitation of the power system. However, some switching activities, will be especially observed.

4.4. Information streams

The recording will go on for about 6 months during summertime, while we have the thunderstorm season in Sweden.

4.5. Scenarios and strategies involved

A utility top level manager introduced the term “Intelligent load shedding” after a severe disturbance that led to a system blackout. To his knowledge a load shedding system was installed, to take care of severe, rare disturbances, in such a way that a system wide blackout should be avoided. The load shedding system had obviously failed and the reaction from the management was immediate and powerful – stating that “we need a more intelligent load shedding system”.

Today we interpret “Intelligent load shedding” as

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

The aim is clearly to improve power system stability, i.e. keep the bulk power or transmission system energised together with as much of the load as possible. The way to improve power system stability is by *smooth load relief*, which can be achieved in a number of ways. The situations to activate smooth load relief, is when the power system *otherwise would go unstable*. “Intelligent load shedding” thus 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.

Smooth load relief

Today, most load shedding systems act on a feeder rated something like 10 or 20 kV. This way of cutting load is rather rough and insensitive. One criteria of selecting load suitable for load shedding has been to avoid areas with a lot of elevators. In this context it is obvious that the requested load relief can be fulfilled in a much more intelligent way.

Permanent load relief is used to mitigate voltage instability (short term or long term), frequency instability, or to mitigate cascading outages in case of overloaded system components. *Switched* load relief is used to mitigate power oscillations in the system – in this case also switch in of load devices has the requested effect. Fast (and smooth) reestablishment of the load is a main concern, for both permanent load relief and switched load relief.

Smooth load relief can be achieved by:

- switch off of specific (addressable) load objects, or groups of load objects,
- simple request for prepared load relief – the load objects to be prepared are continuously updated with respect to the operational situation,
- customer response to price changes, or

- change of supplying voltage.

Different levels of communication can be discussed, such as one-way, two-ways, just binary signals such as [switch off | switch in] or [raise | lower], or execute prepared load relief schemes. The next level comprises execution of a specific prepared action scheme, within a number of schemes, e.g. addressed by an integer number. The next level also includes a response from load side to certain information, such as change of price, e.g. if the price is changed a certain amount the load in a certain node will be changed with a certain number of MW. A prepared price ladder is in this case located at the customer node. The communication complexity also has to take into account the required speed for the load relief, for different purposes. A load relief request due to energy shortage is for example not as urgent as a load relief requested to counteract imminent voltage instability.

Load available to shed

An adaptive, sequentially updated "intelligent load shedding" system requires methods to keep track of the actual load available to shed. The idea is to have a good estimate of the effect of a certain load relief order. A first step could be to compare customer register information, describing type of customer, maximum load, etc., with typical load component set-up for each customer category. Combining this information with the present load level, weather conditions, time of the year, day of the week, time of the day, etc., a good estimate of the load composition, and thus the load available to shed for a certain feeder, is achieved.
Today's ICT gives new possibilities to keep track of the load available to shed. For example, in an electronic market setting the market concept could be extended to load shedding, i.e. load that is available informs about volume and cost related to an immediate short term shut down or load reduction in terms of a bid on a market.

Power system response to a load relief

The power system response to a certain load relief, in terms of voltage and/or frequency recovery, is an important parameter, to be able to shed the "right" amount of load for a certain disturbance. For voltage stability problems the benefit of a certain load relief is much related to the location of the load relief. Therefore the choice has to be something like the maximum of [power system benefit of a certain load shedding minus the cost for the load shedding]. This problem can also be stated as the minimum cost to achieve the required power system benefit. It is also understood that it might be cheaper to shed more load at a less favourable location, to achieve a certain system benefit.

Load response to a power system change

Power system changes that affect the load are often
- a change of transmission capacity, or
- a change of generation supply,

which are characterised by a change in supply voltage magnitude or frequency respectively.

Therefore, it is important to know the response of the connected load to a certain change in voltage magnitude or frequency. This load response has a major influence on the behaviour of the system, especially the time available for remedial actions is a critical parameter for the design of “intelligent load shedding” systems with smooth load relief.

Algorithms to identify the load to shed

Load shedding can be made either on a contractual base, with respect to the statements in the contract, between the power supplier (or grid operator) and the customer, or as an emergency non-discriminative action to save the system. Load shedding can be caused by long term problems, such as energy shortage or generation capacity shortage (peak-shaving), or by short term problems, such as imbalance between generation and load (frequency problems), power oscillations or voltage instability (network problems).
The problem of identifying an operational situation that calls for load shedding is discussed in the next section.
The problem of identifying the load to shed for a certain disturbance is related to a number of parameters, such as:

1) the power system problem area,
2) the severity of the problem,
3) the time available to take proper actions,
4) the load shedding infrastructure and preparation, and
5) the cost for the load shedding

Load shedding with respect to the power system problem

For energy shortage as well as generation capacity problems the time available to take actions is normally long and will most probably be taken care of on a contractual basis within the Energy Management System (EMS) of the dispatcher.

To handle disturbances, such as trip of generation and network outages, the general rule of thumb is that *the load shedding should take place within the area of the largest power deficit, with respect to the power transmission capacity into this area*. Note that this rule is valid both for generation shortage and for transmission capacity shortage. For each characteristic disturbance, the corresponding area for load shedding has to be identified. The disturbances planned for in this way can be general (such as loss of generation in the north) or specific (such as loss of a certain tie-line). To specify which load to shed within a specified area is more a matter of type of load in the area, communication infrastructure, and preparation for load shedding (arming, routines, contracts, etc.).

The severity of the problem

As the general rule of thumb, we can easily conclude that the more severe disturbance the more powerful (in terms of amount and speed) load shedding is needed. Suppose that the area of interest has a list of load to be able to shed, organised in order of priority. Then there are a number of principles on how to act:

1) Estimate the “severity” of the disturbance from power system events and measured and derived power system quantities. Calculate the amount of load necessary to shed, pick this amount from the list, and order load shedding. This approach can also be sequential; load is shed until the system recovers.

2) Each load available for load shedding, has its own load shedding algorithm, which is triggered by local or remote power system events and measured and derived power system quantities. The order and total amount of load to shed is prepared in advance by the settings of the trigger quantities for each load.

3) In some applications also the time delay can be used to shed the right amount of load. The loads to shed have the same fundamental settings, but different time delays. In this way load will be shed until the system recovers.

Different implementations and solutions will have different impact on the security and the dependability of the load shedding system.

Time available to take proper actions

To save a power system in transition towards instability by load shedding, the time to action is crucial, and also very different for different types of disturbances. It might be a very good idea to design a load shedding system to counteract rather frequent events, where the speed requirements on the load relief are moderate, and not solve very rare stability problems with high requirements on load shedding speed. (That is, prepare for long term voltage instability, but not for short-term voltage instability.) It has to be remembered that there is always a risk for misoperation, and the consequences have to be compared to the benefit of successful operations. Some figures of time available to counteract different disturbances are given below (these figures are very much dependent on the size of the power system – larger systems generally give more time for remedial actions):

	Disturbance:	**Time to action:**
1)	First swing instability (out-of-step):	fractions of a second
2)	Power oscillations:	fractions of a second, up to a few seconds
3)	Short term voltage instability:	a few seconds
4)	Long term voltage instability:	10 seconds to about one minute
5)	Frequency instability:	a few seconds

Load shedding infrastructure and preparation

Today load shedding is achieved by manually or automatically opening a circuit-breaker on 10/20 kV level. A first step towards “more intelligent load shedding” has been to equip larger loads with underfrequency and undervoltage relays, that automatically switches off the load on certain threshold levels. Such equipment is very distributed and does not require any communication, but the dispatcher does normally not know what help he will get from these systems in case of a disturbance, since he does not know which units are in operation. A few broadcasting systems that inform customers about tariff changes are also in use. The customer can then choose to connect such a signal directly to a load object that is selected for load shedding purposes.

The communication infrastructure performance influences the load shedding structure possibilities in terms of: selectivity, speed, one-way or two-ways, binary signals or complex messages, etc. as well as the possibility of “agent based negotiations” between the grid operator and the customer. Another aspect is the amount of preparations that can be made on beforehand –in different time scales – both concerning load connected available to be shed, and power system stress. (The load shedding system might be armed or disarmed with respect to the present power system operational situation; power flows, lines and generators in service, etc.)

Cost for the load shedding

There is always a cost related to load shedding, and different load objects have different costs. Three categories of costs can basically be calculated:

1) The costs for the power company (and/or grid operator) for not delivered energy (in combination with change in time for energy delivery) – this cost is normally very low if there are no specific fees for not delivered energy (such as the Kile system in Norway).

2) The direct costs for the customer that is exposed to the load shedding. These costs vary considerably, from almost nothing to very high costs and production interruptions in certain types of industry.

3) The third type of cost is the costs for the society, which also includes costs for insurance companies, delay in communications, etc. that are not regarded as customer costs. The costs for the society, due to electricity supply interruptions, are always higher or equal to the costs for the customers.

To be able to identify suitable load objects to shed the cost for a certain load shedding must always be compared to the alternative load objects to shed and to the benefit of the load shedding.

Detection of imminent instability situations

Detection of imminent instability operational conditions is crucial for the success of “intelligent load shedding”. The instabilities to detect are

- transient angle instability (first swing or out-of-step),
- insufficiently damped power oscillations (dynamic instability),
- short term voltage instability (no load flow equilibrium point after the clearance of a sever fault), and
- long term voltage instability (slow dynamics after a disturbance, or load increase).

Very often also the risk of cascaded outages – that will lead to instability – is a vulnerable situation that is important to detect and counteract.

4.6. Test program

Together with Sydkraft, the large utility in Southern Sweden, the radially fed island of Öland has been selected as suitable for field measurements and experiments (according to work package 3A), since it has a large amount of wind power and a relatively weak 50 kV system.

Description of the Öland power system

The Öland 50 kV distribution system is described in Figure 2. Existing and planned wind power farms are also marked, as well as the connection points for the recording equipment. From the supply point in LIN, the system is radially fed by two parallel 50 kV lines, feeding 50/10 kV transformers, connected to local distribution systems. In the south point of recording a rather large wind power farm is connected to the 50 kV grid via a 20/50 kV transformer. In the north point of recording a wind power farm is connected to one of the 10 kV feeders, that also feeds other load.

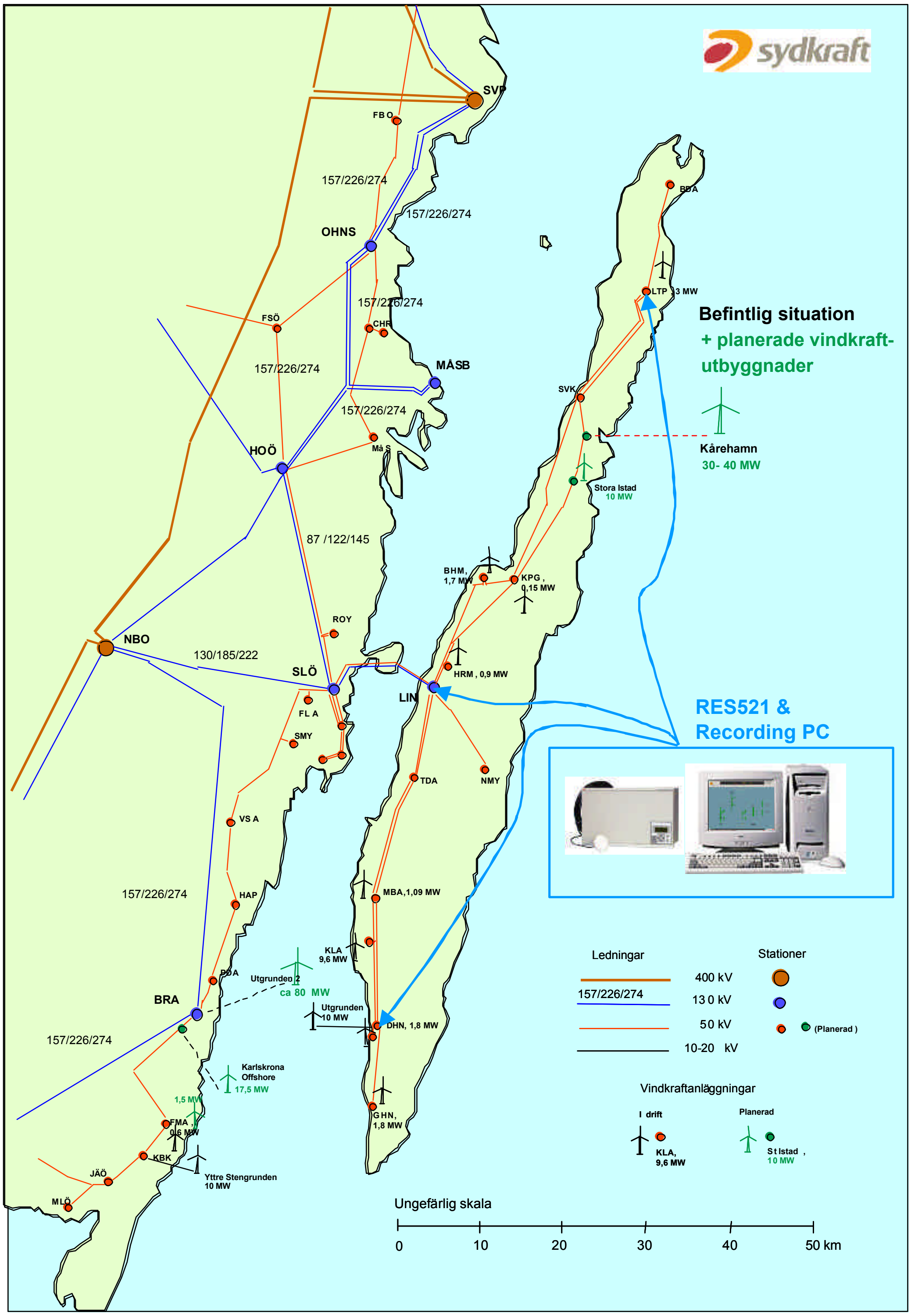

Figure 2. The test area of Öland, with wind power farms and recording nodes marked

Aims of the measurements

The aims of the measurements are to capture the load response due to changes in the supply voltages, and to capture the voltage response due to load changes, to fulfil the requirements specified in WP1.5. Both supply voltage changes and load changes can be either forced or natural. Also the wind power farm response to different network disturbances will be captured to fulfil the requirements according to WP1.2. To know and understand the behaviour of wind power farms during transient abnormal network conditions is essential to be able to specify adequate dynamic performance requirements for the connection of new wind power units and farms to existing networks.

Description of the measurements

Each recording equipment is connected to the substation Voltage Transformers (VT) and Current Transformers (CT), and measures two 3-phase voltages and four 3-phase currents. The recorded quantities are the positive sequence phasors (i.e. magnitude and phase angle) of the measured voltages and currents, the frequency and rate of change of frequency for the first voltage, and a number of settable trigger functions: abnormal frequency, abnormal rate of change of frequency, overcurrent and undervoltage. The speed of recording is settable to once every power system cycle, once every 2^{nd} power system cycle or once every 4^{th} power system cycle. The phasor measurement unit (PMU) sends data to the PC, which zip the data and store it on a hard disk. When there is a change of any trigger status the time for the change is printed to a file, to make it easier to find the interesting parts of the huge amount of data that will be recorded. The zipping and data storage will be made in a synchronised way, so that the data files from the three locations are corresponding, i.e. the first and the last data in a certain file from the three locations refers to the same time.

Methods to activate load and system dynamics

Active:

Switching the cables between SLÖ and LIN, e.g. both the cables in operation – switch off the 130 kV cable in LIN. This corresponds to a weakening of the transmission network and a related voltage decrease. Another alternative is to have the 50 kV cable in operation and the 130 kV cable disconnected. Switch in of the 130 kV cable in LIN gives a reactive power injection and a related voltage increase.

Tap-changer stepping in LIN, and/or Löttorp and/or Degerhamn. In Löttorp and Degerhamn perhaps two transformers, with different tap positions, can be used and voltage step-changes can be achieved by switching one transformer circuit-breaker.
Switching of a known load, e.g. the electrical heater at the creamery in Borgholm (6 or 8 MW).

Natural:

- Thunderstorms and lightning on the 50 kV network on Öland, should be able to trig wind power farm dynamics.
- Load switching for other reasons than our recordings
- Disturbances in the 130 and 400 kV systems on the mainland

Locations and points for connection of recording equipment

Recording locations:

Linsänkan, Degerhamn, Löttorp and a temporary installation in Borgholm

- All recordings are assumed to be three-phase. If only two-phase current is available, the common return wire is connected to the third current input on the RES521 Terminal.

Linsänkan:

Phasor 1: 50 kV voltage in bay 55 (T1)

Phasor 2: 50 kV voltage in bay 61 (cable towards Stävlö)

Phasor 3: 50 kV current in bay 55 (T1)

Phasor 4: 50 kV current in bay 61 (cable towards Stävlö)

Phasor 5: 50 kV current in bay 60 (line bay II towards Degerhamn)

Phasor 6: 50 kV current in bay 56 (line bay towards Köping)

The following is not recorded:

130 kV voltage;

line current 50 kV LIN-DHN I (the line end is open in DHN);

line current 50 kV LIN-BHM.

Degerhamn:

Phasor 1: 50 kV voltage in bay 60 (T3, wind power)

Phasor 2: 10 kV voltage in bay 9 (T1)

Phasor 3: 50 kV current in bay 63 (line bay II towards Linsänkan)

Phasor 4: 50 kV current in bay 60 (T3, wind power)

Phasor 5: 50 kV current in bay 58 (T1)

Phasor 6: 10 kV current in bay 9 (T1)

The following is not recorded:

line current 50 kV DHN-DHN C;

line current 50 kV DHN-GHN;

line current 50 kV LIN-DHN I (not connected in Degerhamn)

Löttorp:

Phasor 1: 10 kV voltage in bay 9 (T1)

Phasor 2: 10 kV voltage in bay 11 (T2 – no better alternatives)

Phasor 3: 50 kV current in bay 54 (line bay towards Sandvik II)

Phasor 4: 50 kV current in bay 58 (line bay towards Sandvik I)

Phasor 5: 10 kV current in bay 9 (T1)

Phasor 6: 10 kV current in bay 13 (line bay towards Böda – wind power)

The following is not recorded:
busbar voltage 50 kV;
line current 50 kV LTP-BDA;
current on T1:s 50 kV side.

Borgholm temporary installation to switch the electrical heater at the creamery:

Phasor 1: 10 kV voltage in bay 6 (T1)
Phasor 2: 10 kV voltage in bay 18 (T2 no better alternative)
Phasor 3: 10 kV current in bay 6 (T1)
Phasor 4: 10 kV current in bay 18 (T2)
Phasor 5: 10 kV current in bay 20 (Electric heater)
Phasor 6: 10 kV current in bay 21 (C1 – no better alternative)

The following is not recorded:
voltage on the 50 kV side;
voltage on the 50 kV side.

Miscellaneous

- The binary inputs can perhaps be used to measure the tap-changer position.
- The trigger conditions in RES521 should be used
- Recording of time instants for change of trigger conditions should be made.
- Recording on comtrade format should be evaluated.

Summary of the Öland Field Measurements

■**3 RES521 for continuous recording installed and commissioned 1st week of April**
Linsänkan + North end + South end – no communication available between the different RES521
10 kV and perhaps 50 kV voltage recording (2 x 3 phase voltage channels available)
Load, wind power generation and power oscillations current recordings (4 x 3 phase current channels available)
PC and external harddisk for data logging

■**Possible active excitation:**
Switch in 50 kV cable in Stävlö, then switch of the 130 kV cable in Linsänkan – or Stävlö
Tap-changer actions in Linsänkan – ramp up / ramp down
Load switching – e.g. Mejeriet – on Öland.

■**Possible natural excitation:**
Thunderstorms and other types of faults during the summer season
Unforced switching of major load objects

■**Aim of field measurements:**
Investigate the dynamic load response – to a voltage/source change – in the presence of distributed generation
Investigate the dynamic system response – to a load change – in the presence of distributed generation
Verify and develop the Sydkraft dynamic model of the island of Öland

■**Analysis:**
Utilize different types of manual loggers to find interesting time slots to investigate
Development of automatic methods to identify interesting time slots in the recordings, wrt voltage change or load change
Develop models to estimate the supply voltage response to a load change and vice versa
■**Related activities:**
Per Carlsson, methods for short time load control by pricing methods
Tomas Petru, Chalmers, dynamic wind power model development for PSS/E
Diploma work at Sydkraft for dynamic system model development
Diploma work at Chalmers for algorithm development for power oscillation damping by load switching
.

5. Planning of activities experiment C

5.1. Phasing of activities

The Öland field measurements can be split into three phases:

1) Recording equipment set-up and commissioning.
2) Measurement results description and evaluation.
3) Future potential for intelligent load shedding in the vicinity of distributed generation.

5.2. Time plan

The WP3C field experiments will be performed roughly according to the following time schedule:

Recording during the summer of 2003.

1) Result description and evaluation, during second half of 2003 and first half of 2004.
2) Future potential will be investigated during the second half of 2004 and first half of 2005.

5.3. Milestones and deadlines

June 01, 2003:	Equipment installed and commissioned – recording started.
October 01, 2003:	All data collected and analyses started.
October 01, 2004:	D3.1C submitted.
April 01, 2005:	D3.2C submitted.
April 01, 2006:	D3.3 submitted

Appendices

Cigré paper 277-04: “Intelligent load shedding to counteract power system instability”