

# **Advanced Architectures and Control Concepts for More $\mu$ Grids**

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## **WORK PACKAGE E**

### **DE2: Report on Interface Equipment Requirements for LV DG devices**

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## 1. Introduction

This report is aimed to review interface equipment requirements applicable to Low Voltage (LV) distributed generation technologies. This document is structured into two main different parts covering a brief summary of applicable products from Siemens' catalogue and the integration of IEC 61850 standard into electric engineering tools respectively. Finally, some annexes contribute with complementary information and examples.

A short review of MV and LV equipment and software tools is aimed to provide an example of the availability of commercial products suitable for  $\mu$ Grid construction and deployment from the electrical point of view. Those aspects resulting from the specific grid code requirements, the applicable legal normative and the internal organization and arrangements among parties contributing with  $\mu$ Grid equipment are out of the scope of the report.

The extension of the IEC 61850 standard out of the original substation environment into providing the basic framework supporting from DER modelling (IEC 61850-7-420) to other generation sources (IEC 61400-25 for wind farms or 61850-7-410 for hydro power) requires an update on other engineering applications and tools. This fact is exemplified considering the case of CAD tools used for electrical engineering, so far, derived from drawing tools where some "intelligence" is added to manage three phase electric systems.

Annex A describes a large PV installation in Germany; the interesting output of the case is related to the use of Siemens's SIMATIC/SIPROTEC control system –off the self product– to integrate advanced functionalities into the PV plant such as custom reactive power or harmonic current controls.

Annex B provides some insights on the local load controllers developed for the Kythnos island test site in Gaidouromantra. Some of the studies developed in the project have shown the importance of proper load controls to face sudden or specific events at  $\mu$ Grids; for instance, the stability after the transition from the grid connected mode into islanded mode may be compromised depending on the generation-consumption balance requiring some load shedding scheme for security reasons. This chapter describes some functionalities incorporated to the load controllers and aimed for this specific test case purposes.

## 2. MV & LV Equipment and Software Tools

This chapter focuses on the different equipment used in the network: switches for disconnection, protection, meter, converters, etc.; It also considers computer aided tools for engineering that integrate advanced functionalities such as protection configuration in traditional graphical design applications.

Siemens Power Transmission and Distribution Group (PTD) is a recognised product supplier, systems integrator and service provider for all tasks and activities involving transmission and distribution of electrical energy. It offers intelligent solutions for the transmission and distribution of power from generating plants to customers.

Siemens' service includes the setting up of complete turnkey installations, offers advice, planning, operation and training and provides expertise and commitment as the complexity of this task requires. Backed by the experience of worldwide projects, Siemens can always offer its customers the optimum cost-effective concept individually tailored to their needs.

In this chapter an overview about interface equipment for medium voltage (MV) and low voltage (LV) networks based on Siemens catalogue is provided; their specific requirements (where applicable) for use in  $\mu$ Grids and Multi- $\mu$ Grids systems are introduced.

$\mu$ SysCom is a communications equipment manufacturer. The company is a division of ZIV group, whom is considered a leading manufacturer of components and systems in protection, control and measurement equipment for electrical substations

Within ZIV group,  $\mu$ SysCom is focused on increasing the communications functionality of existing products. Additionally, it also addresses new markets on industrial applications that are different form the electric utility sector.

The commercial catalogue of  $\mu$ SysCom is the base for the section devoted to discuss some telecommunication alternatives and needs.

### 2.1. Requirements overview

This section provides an overview of technologies and interface equipment that should be considered in detail concerning  $\mu$ Grids. While LV equipment is required to connect different individual  $\mu$ Grid components such as generation units, responsible loads and intelligent

devices; in contrast, MV equipment is required considering the Multi- $\mu$ Grids aspect where it is assumed that different LV  $\mu$ Grids structures are combined and controlled as an intelligent MV feeder by means of the CAMC.

## 2.1.1. Distribution on MV level

### - MV equipment<sup>1</sup>

- Circuit breakers
- Switches, disconnectors, grounding switches
- MV HRC fuses, switch/fuse combinations
- Current and voltage transformers
- Protection relays
- Substation control and automation
- Special devices for neutral earthing (e.g. earthing resistors, earthing transformers)
- Surge arresters

### - Other MV equipment

- Special transformer (e.g. for neutral grounding)
- Reactors
- Capacitor banks

### - MV Power quality

- Flexible AC transmission systems (FACTS)
- Power factor correction units
- Harmonic filters

Typically, there are not any specific requirements for MV switchgear and transformers used for distributed generation (DG) installations or  $\mu$ Grids although some concrete functional characteristic may recommend slightly different attributes. For instance, if a  $\mu$ Grid is able of

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<sup>1</sup> Main equipment such as transformers, lines, etc. are not listed.

keeping the energy supply to the associated customers when the main MV is out of service, the switchgear would need a synchronization relay for the transition from the isolated operation back to the default interconnected mode.

### **2.1.2. Distribution on LV level**

#### **- Circuit breaker devices and fuse systems**

- Circuit breakers (air circuit breakers, compact circuit breakers)
- LV HRC fuses
- Fuse switch disconnectors
- Lightning current and surge arresters

#### **- Converters**

- AC/DC converters
- AC/AC converters

#### **- LV Power quality**

- Filter modules for harmonic suppression
- Power factor correction units

### **2.1.3. Monitoring, protection, and control equipment, special devices**

- Monitoring and protection relays
- Disconnecting protection
- Voltage controllers (LV)
- Soft starters for motors

### **2.1.4. Meters and measuring instruments**

- Meters
- Measuring instruments
- Transducers
- Test terminals

### **2.1.5. Power management systems**

- Visualization systems
- Event and status signal recording
- Measuring and optimizing the energy flow
- Systematic maintenance planning

### **2.1.6. Engineering software**

- Network planning and dimensioning tools
- Support tools for selective protection settings

Again, no specific requirements exist for LV switchgear and distribution boards with respect to DG applications.

A more detailed description of selected interface equipment and its requirements with respect to  $\mu$ Grids is done in the following sections.

## **2.2. MV equipment**

### **2.2.1. MV Circuit breakers**

Medium-voltage circuit breakers (Figure 2-1 and Figure 2-2) serve as incoming and outgoing circuit breakers for power distribution in medium-voltage switchgear. They are used as circuit breakers and load interrupters in networks, motors, generators, capacitors and transformers.



Figure 2-1: Vacuum circuit breaker<sup>2</sup>



Figure 2-2: Vacuum circuit-breaker/disconnector unit<sup>3</sup>

Mostly maintenance free vacuum interrupters are used for this providing a high reliability (Figure 2-3).



Figure 2-3: Vacuum interrupter

In combination with secondary relays, MV circuit breakers can provide definite and inverse time-overcurrent protection, time-overcurrent protection with additional directional function or differential protection. In larger distribution networks distance protection is also used.

<sup>2</sup> Siemens 3AH

<sup>3</sup> Siemens 3AH/3DC

MV circuit breakers shall comply with national and international standards such as IEC 60056, partially IEC 62271-100, IEC 60694, and BS 5311.

#### **2.2.1.1. Protective characteristics**

Secondary relays, whose characteristic curves are also determined by the current transformation ratio, are normally used as protective devices in medium-voltage systems. Static numerical protection devices are increasingly preferred.

#### **2.2.2. MV switch disconnectors**

MV switch disconnectors (Figure 2-4) are used in power distributions, for rare switching of loads, and switching of distribution transformers.

MV switch disconnectors shall comply with standards IEC 60129 and IEC 60265-1.



Figure 2-4: Switch disconnector<sup>4</sup>

#### **2.2.3. MV grounding switches**

MV grounding switches serve to protect personnel when working at equipment. Once the main equipment has been de-energized and isolated it is earthed before any maintenance is performed by the crew members.

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<sup>4</sup> Siemens 3DC

#### 2.2.4. MV HRC fuses

High voltage high-breaking-capacity (HV<sup>5</sup> HRC) fuses (Figure 2-5) can only be used for short-circuit protection. They do not provide any overload protection. A minimum short-circuit current is therefore required for correct operation. HV HRC fuses restrict the peak short-circuit current and clear the fault initially. The protective characteristic is determined by the selected rated current.

HV HRC fuses, mostly combined with switch disconnectors, are used for the protection of small to medium-size distribution transformers, motors, capacitors, voltage transformers, and small cable feeders.

HV HRC fuses shall comply with standard IEC 60282.

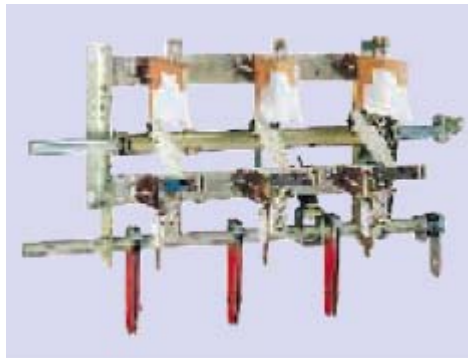


Figure 2-5: HV HRC fuses with fuse base link<sup>6</sup>

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<sup>5</sup> HV is used in the commercial and technical name for distinction from low voltage fuses.

<sup>6</sup> Siemens 3GD/3GH

### 2.2.5. Instrument transformers

Current and voltage transformers –CT & VT respectively– serve for measurement of electrical quantities in electrical installations (Figure 2-6). They provide transformation of currents or voltages into quantities that are better suited for protective devices. In addition they internally isolate high and low voltage parts from each other.

Current and voltage transformers shall comply with national and international standards IEC 60044-1, 60044-2, BS 7625, 7626, ANSI C57.13.

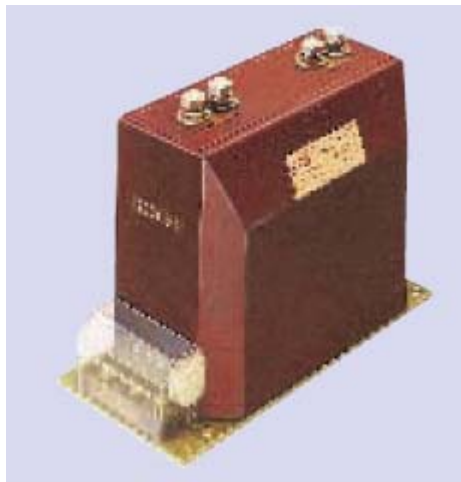


Figure 2-6: Block-type current transformer<sup>7</sup>

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<sup>7</sup> Siemens 4MA

### 2.2.6. Surge arresters

Surge arresters (Figure 2-7) protect the insulators of plants or plant sections against excessive voltage stress up to 42 kV (typically). Overvoltage limiters are used to protect high-voltage motors, dry-type transformers and cable networks up to 15 kV.



Figure 2-7: Surge arrester<sup>8</sup>

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<sup>8</sup> Siemens 3EE2

## 2.2.7. Protection relays

Besides HV HRC fuses, protection relays form a second important group of protection devices for MV circuits (Figure 2-8). They are often used in combination with switch disconnectors for protection of smaller distribution transformers, MV circuit breakers with secondary protection relays and current transformers (and voltage transformers if necessary).



Figure 2-8: Numerical protection relays<sup>9</sup>

According to ANSI/IEEE C 37.2 IEEE Standard Electrical Power System Device Function Numbers there are a number of different protection functions which relays can be selected and set for.

The most important protection functions in MV networks with their corresponding ANSI/IEEE numbers are:

**Table 2-1: Excerpt of ANSI/IEEE relay codes**

| ANSI / IEEE Code | Protection description                              |
|------------------|---|
| 21               | Distance (mainly in networks covering a wider area) |
| 27               | Under-voltage                                       |
| 25               | Synchronism check                                   |
| 50               | Instantaneous over-current (definite and inverse)   |
| 51               | Time delayed over-current (definite and inverse)    |

<sup>9</sup> Siemens Siprotec 4

| ANSI / IEEE Code | Protection description                          |
|------------------|---|
| 67               | Directional over-current (definite and inverse) |
| 87               | Differential (current)                          |

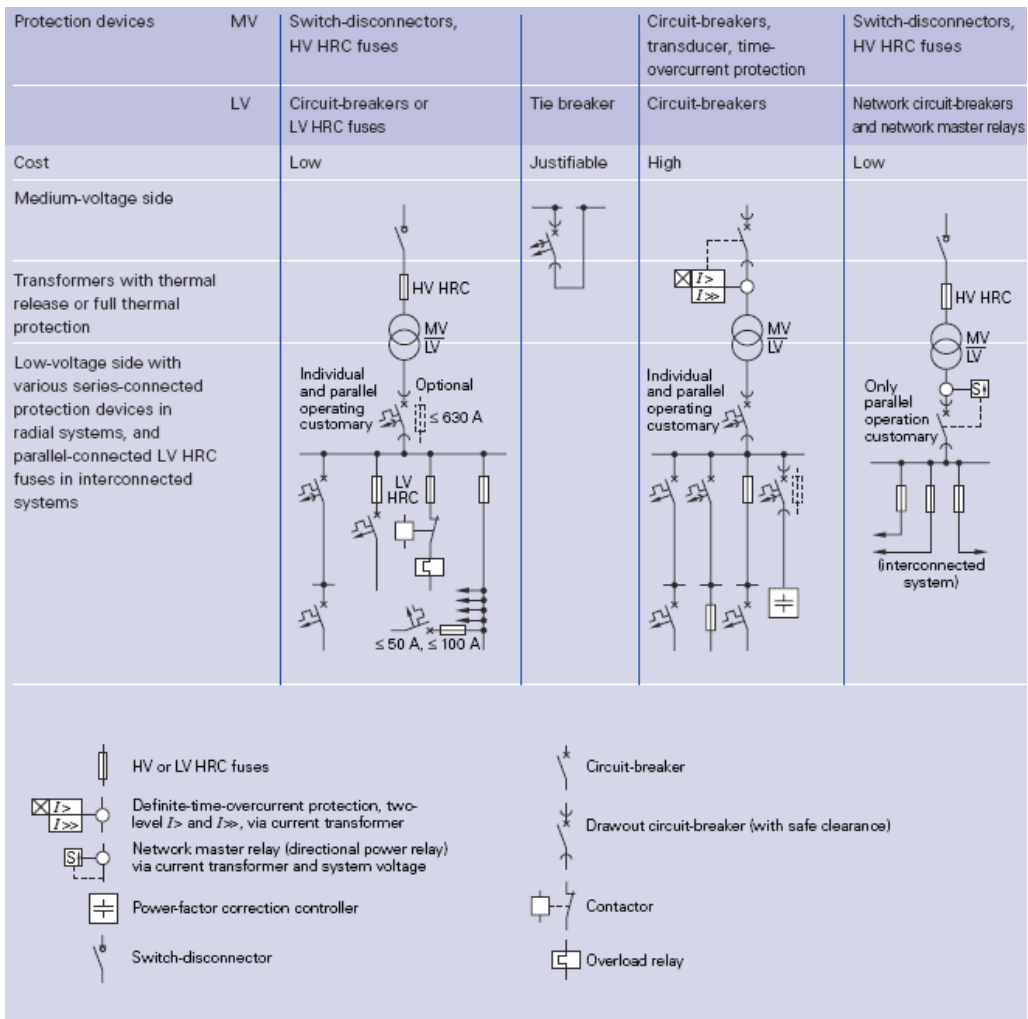


Figure 2-9: Overview of protection grading schemes

In addition to the fundamental protection functions, nowadays protection relays mostly offer a variety of further implemented measuring, communication and other functions (Figure 2-10 as example for Siemens SIPROTEC series), such as e.g.

- Breaker control
- Measurements during operation
- Display of measuring and metering data

- Fault recorder
- Communication via copper or LWL lines with standard protocols (e.g. RS232/485/LWL, IEC 61850, IEC 60870-5-103, PROFIBUS FMS/DP, DNP3.0, MODBUS RTU)
- CFC (continuous flow chart) logic for implementation of interlocks etc.

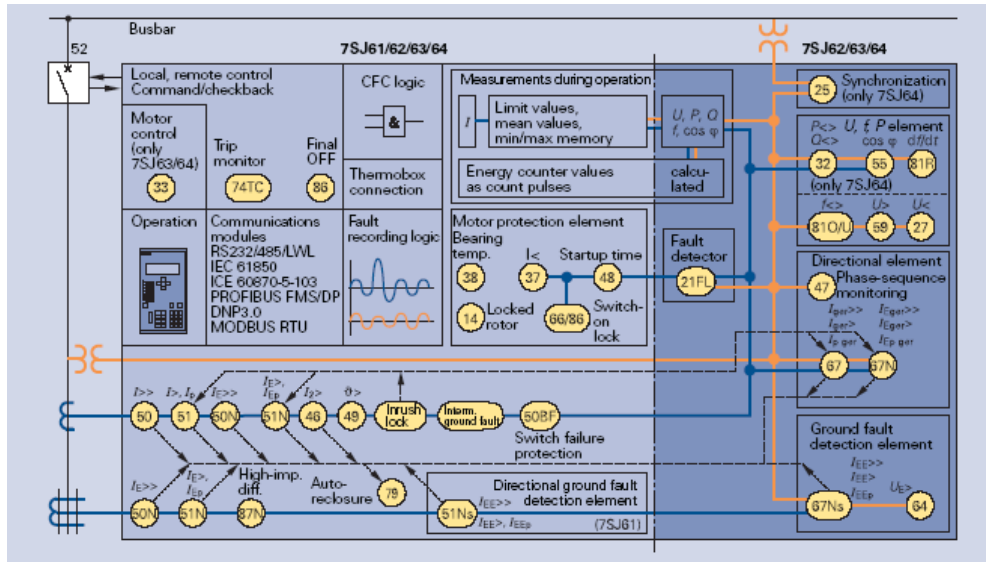
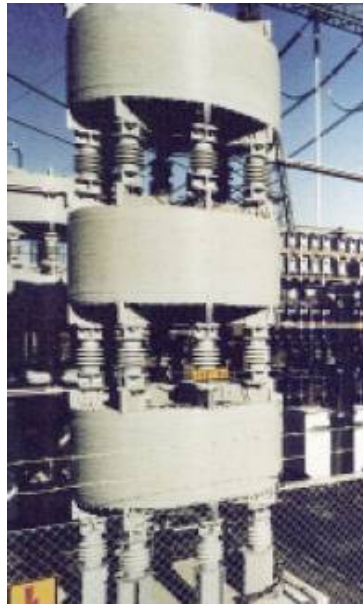


Figure 2-10: Relay functions<sup>10</sup>

<sup>10</sup> Siemens Siprotec 4

### 2.2.8. Reactors

In medium voltage networks with DG units connected reactors (Figure 2-11) are mainly used for current limiting purposes, in order to reduce the short circuit current to levels within the rating of the equipment on the load side of the reactor.



**Figure 2-11: Three-phase stacked current limiting reactor (Trench)**

Another application of MV reactors is to act as filter reactors in conjunction with capacitor banks to form series tuned harmonic filter circuits, or in conjunction with capacitor banks and resistors to form broadband harmonic filter circuits. However, these tasks are often performed on the LV side of the network.

Neutral Grounding Reactors limit the line to ground fault current to specified levels. Single-phase neutral grounding (earthing) reactors (arc suppression coils) are intended to compensate for the capacitive line-to-ground current during a single-phase ground-fault. Mostly such a device is connected to the power transformer neutral point in the transformer substation. In some cases it might become necessary to locate this special kind of reactor in the subnetwork where DG units are connected by means of a grounding transformer.

### 2.2.9. Neutral earthing resistors

The neutral earthing resistor is used in power distribution stations for neutral earthing of generator and transformer windings, usually of the neutral point. Concerning  $\mu$ Grids networks, they will be mostly applied in the transformer substation.

### 2.2.10. MV power quality equipment

MV Flexible AC transmission systems (FACTS), power factor correction units, and harmonic filters are further devices that might in some cases be necessary or useful in MV distribution networks (Figure 2-12). However, they are not regarded as essential equipment in  $\mu$ Grids networks; therefore they are not dealt with in detail in the frame of this report. Intelligence that may be necessary for active distribution networks can be integrated in power converters of DG units.



**Figure 2-12: Example SIPLINK – a MV DC Coupler in Distribution systems for coupling of galvanic separated parts of the network with active power flow control**

## 2.3. Low voltage equipment

### 2.3.1. LV Circuit breakers

LV Circuit-breakers (Figure 2-13, Figure 2-14) serve as incoming and outgoing circuit breakers for power distribution in low-voltage switchgear. They are responsible (together with their built-in primary tripping devices) for overload and short-circuit protection in systems, motors, generators and transformers.



Figure 2-13: LV air circuit breaker<sup>11</sup>



Figure 2-14: LV compact circuit breaker<sup>12</sup>

A large variety of additional features is available at up-to-date LV circuit breakers which supports their application in networks with distributed generation. Among those are particularly:

- a selection of high-sophisticated trip units offering many possibilities for setting the breaker according to the requirements of the plant
- communication modules enabling the circuit breaker to interact with higher level power management systems (see below)

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<sup>11</sup> Siemens Sentron 3WL

<sup>12</sup> Siemens Sentron 3VL

### 2.3.2. Fuses / fuse switch disconnectors

Low voltage fuses (Figure 2-15) provide secure protection for electric systems, cables and lines as well as for electric devices. A range of standardized types exists, starting from small types (D0 system, e.g. NEOZED<sup>®</sup>) over medium-sized types (D system, e.g. DIAZED<sup>®</sup>) towards large types (LV HRC), and special types for solid-state consumers (e.g. SITOR<sup>®</sup>).



Figure 2-15: LV fuse switch disconnector<sup>13</sup>

Fuse switch-disconnectors are able to make, conduct and break the specified rated current (including a certain degree of overload). If a short circuit occurs, the fuse switch-disconnector must be able to conduct a specified short-circuit current during a predefined time. The switch-disconnector is opened (OFF) and closed (ON) by operating the handle unit. In the "open position", it meets the requirements for an isolating function.

Overload and short-circuit protection of downstream system components and devices is provided by the LV HRC fuses integrated in the handle unit.

### 2.3.3. Lightning current / overvoltage protection devices

*Surge protective devices* (SPD) can be distinguished into lightning current and overvoltage protection devices. They protect sensitive equipment against damages produced by overvoltages. According to their causes, overvoltages are filed in two categories:

- LEMP (lightning electromagnetic impulse) – overvoltages that are caused by atmospheric impact (e.g. direct lightning strike, electromagnetic lightning fields)

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<sup>13</sup> Siemens 3NP4

- SEMP (switching electromagnetic impulse) – overvoltages that are caused by switching operations (e.g. breaking short circuits, operational switching of loads).

The determination and selection of an SPD is done according to the lightning protection zone or the withstand surge voltage categories for low voltage equipment. For this four withstand surge voltage categories and three requirement classes have been defined (Figure 2-16).

SPD shall comply with the standards:

- VDE 0675-6, Germany, 1996
- IEC 61643-1, International, 1998
- CEI EN 61643-11, Italy
- ÖVE/ÖNORM E 8001, Austria

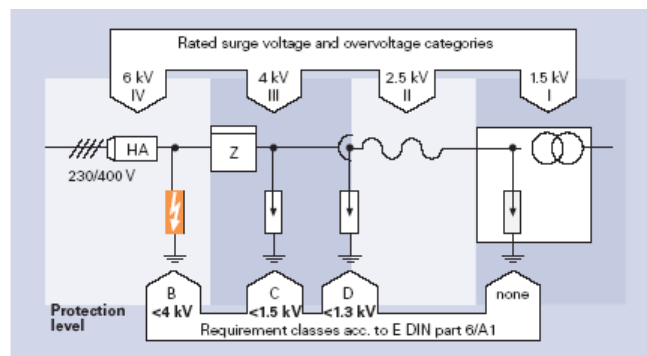


Figure 2-16: Requirement classes of LV arresters

### 2.3.4. Converters

Converters for  $\mu$ Grids applications need to have the following main features:

- Islanding capability
- Low line reactions
- Single or multi-quadrant operation (depending on application)

Inverter types that are applicable for  $\mu$ Grids are:

- Self-commutated converters
- Voltage-source inverters (VSI) with pulse width modulation (PWM)

Line-commutated converters are of minor interest for  $\mu$ Grids applications due to their missing islanding capability.

## 2.4. Monitoring, protection and control equipment

### 2.4.1. Meters and measuring instruments

Measuring instruments are used for measuring the consumption of electricity, gas, heat and water for purposes of billing. In this regard, modern energy meters should be able to handle differing regional tariff structures as well as complex tariffs in industrial applications.

Usually in electricity supply, meters (Figure 2-17) serve for monitoring of currents, voltages and power values in distributions, in order to know the system utilization so that overloads do not occur.



Figure 2-17: Power meter<sup>14</sup>

Beyond these basic features, metered data can be used for online recording, transmission via network and integration into a Power or Energy Management System. Thus the systems are able to balance generation and consumption locally providing all economic and ecological benefits.

Besides the “classic” measuring and metering values voltage, current and power there are several further values that can be acquired, as e.g. phase angle, unsymmetrical conditions, harmonics etc. By means of these data a comprehensive monitoring and control of the distributed generation system is possible.

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<sup>14</sup> Siemens SIMEAS P

### 2.4.2. Special devices

Besides general monitoring and protection relays, DG units in public electricity networks shall have a *coupler circuit breaker with disconnecting element* at the connection point to the grid. This shall provide a disconnection from the public grid in case of non-permissible voltage and frequency values in order to ensure that:

- The operating staff is well protected during maintenance work on the network.
- Unintentional in-feed into a subnetwork being separated from the public grid is not possible.
- Supply into the public grid after a fault or at an auto-reclosure situation is prevented to avoid damages at the generating equipment at return of voltage.

In order to provide these preconditions, the monitoring and protection features shall include as a minimum:

- Under-voltage/over-voltage relay             $U<, U>$
- Under-frequency/over-frequency relay       $f<, f>$
- Vector (or load) jump relay

In addition to this, the tie circuit breaker shall be capable for *synchronization*.

At generating units supplying directly into the public grid a *synchronizing device* shall be foreseen in order to ensure that the synchronizing conditions are fulfilled. It shall contain a double frequency, a double voltage, and a zero-sequence measuring device. An automatic synchronizing device is recommendable.

In networks with DG such as PV or wind energy plants, the system voltage between the worst case operation points

- Low load / full generation → highest voltage
- High load / no generation → lowest voltage

can differ considerably. This can possibly require additional measures at the distribution transformers, as e.g. *automatic voltage controller*, in order to keep the voltage in the permissible margins.

## 2.5. Telecommunication equipment

Telecommunication equipment can be seen as an important  $\mu$ Grid enabler. When talking about telecommunications, two different functions are required inside a LV grid:

- Networking infrastructure for automation: Following the market trends, an Ethernet LAN seems to be the LV network automation basis. It should also be noted that similar features to those found in IEC 61850 substations are required for  $\mu$ Grid networking infrastructure. Synchronization must also be taken into account as power network events must be tagged very precisely.
- Secure Remote Access:  $\mu$ Grids are not intended for islanded operation only but should also be connected to the mains. In order to do so, appropriate telecom equipment need to be deployed. In those cases, where the Utility has not their own telecom infrastructure (fiber optics / private radio), the latter may rely on existing mobile network carriers telecom infrastructure. For such telecom transport media appropriate security mechanisms are needed.

### 2.5.1. Networking infrastructure for automation

$\mu$ SysCom (ZIV group) provides the networking infrastructure that allows an Ethernet LAN deployment inside  $\mu$ Grids. The commercial catalogue also introduces GPS based equipment to synchronize all integrated IED's.

#### 2.5.1.1. SWT: Gigabit Ethernet / Fast Ethernet switches

During last years, the International Electrotechnical Commission (IEC), has created an standard that strives for interoperability between the different electronical devices in charge of automation within electrical substations: IEC-61850. This standard promotes the use of Ethernet technology in local area communication networks.

$\mu$ SysCom has developed the SWT family of Ethernet switches for such application. SWT Ethernet Switches have been designed to fully accomplish the most hazardous performance requirements for implementing Ethernet networks in electrical facilities.



**Figure 2-18: Ethernet Switch (19" Rack)** <sup>15</sup>



**Figure 2-19: Ethernet Switch (DIN)** <sup>16</sup>

μSysCom SWT managed switches include the following features:

- Full duplex – wired speed
- Automatic configuration of IP address
- NTP/SNTP Client
- VLAN support according to 802.1Q (also Q in Q)
- Broadcast Storm Control, configurable by the user for ingress and egress traffic
- Spanning Tree Protocol STP and RSTP according to 802.1D
- QoS (Quality of Service). 3 priority queues for each port are supported
- Port monitoring
- Management via CLI, TELNET, SNMP (RMON MIB)
- Remote Monitoring (RMON RFC 2819). 4 groups of monitoring elements available: Statistics, History, Alarms and Events
- User friendly web page; easily configurable
- Configuration changes applicable at runtime

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<sup>15</sup> μSysCom 3SWT

<sup>16</sup> μSysCom 3SWT

### 2.5.1.2. GPS: Time clock synchronizer

The distributed nature of electronic equipment in power systems adds complexity when analyzing system wide events. Precise time accuracy, distributed throughout the network, is critical for system synchronization and provides useful sequence of events enabling proper analysis.

In this context, NTP (Network Time Protocol) is one of the most used protocols for synchronizing the clocks of computer systems over packet-switched, variable-latency data networks, getting 1 ms precision times inside an Ethernet LAN.

μSysCom has developed the GPS NTP synchronizer; it uses the GPS satellite system as a stratum 0 NTP server to synchronize itself, and then works as a stratum1 NTP server.



Figure 2-20: GPS NTP synchroniser<sup>17</sup>

ZIV (μSysCom) GPS NTP synchronizer includes the following software features:

- Automatic configuration of IP address
- Internal GPS clock
- Stratum 1 NTP Server
- Compatible with SNTP
- Management via CLI, TELNET, SNMP (RMON MIB)

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<sup>17</sup> μSysCom GPS – NTP Sync

- Remote Monitoring (RMON RFC 2819). 4 groups of monitoring elements available: Statistics, History, Alarms and Events
- User friendly web page, easily configurable
- Configuration changes applied at runtime
- Firmware upgradeable

### **2.5.2. Secure Remote access**

In this section two different options are introduced.

- EMR wireless routers: Having deployed an Ethernet LAN, the most straightforward option is to use a router to provide remote accessibility to the network components measurements and control actions. Nevertheless, security requirements are to be taken into account, so features such as IPSec are highly recommended when integrating elements into the Utility IT infrastructure through 3rd party network carriers.
- SIP product family: SIP is a very powerful product family as it will allow both, an Ethernet LAN and an asynchronous serial device to share the same wireless connection.

#### **2.5.2.1. EMR: Wireless cellular routers**

In last decades we have faced an important increase in the mobile communications market. Current estimates indicate that there are, at least, 1.500 millions of mobile communications subscribers in the world.

Cellular mobile communications systems are able to provide telecommunication services to their subscribers in extensive geographical areas, having the capacity of maintaining the communication link while the subscriber moves. Nowadays, there are several mobile technologies, such as GPRS, EDGE, UMTS and HSDPA that provide data bearer capabilities at a very competitive cost.

The conjunction of mobility and data communications make cellular mobile communications systems the ideal solution for multiple applications. EMR cellular router brings over UMTS/EDGE/GPRS/HSDPA data capabilities to Ethernet networks, so that remote sites can be easily connected to the corporate LAN.



**Figure 2-21: Wireless network router<sup>18</sup>**

ZIV ( $\mu$ SysCom) EMR WAN routers incorporate the following software features:

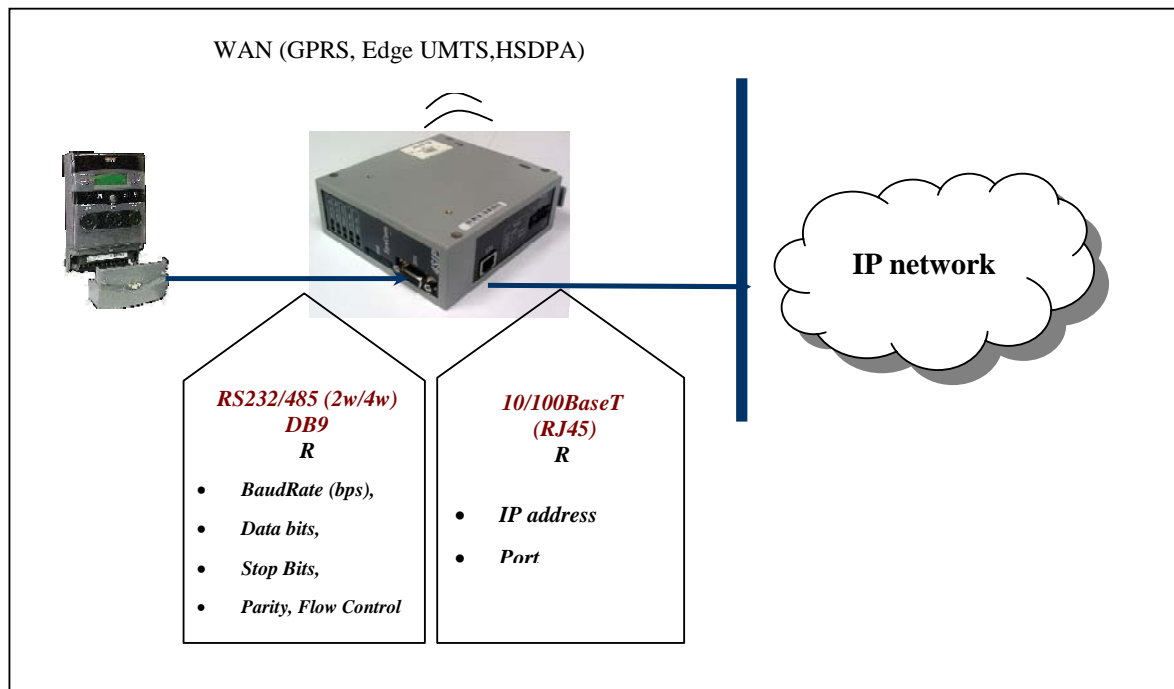
- Flexible interface configuration
- WAN connection to the cellular networks – “always on”
- Static routing
- DHCP Server / Client
- NAT for IP masquerading and Port Forwarding
- SNMP agent
- NTP client
- Firewall – flexible and easy configurable Filtering Rules
- Redundancy solution – VRRP
- VPN Support: IP over IP tunnels; GRE Tunnels; IPSec Tunnels (IKE); DPD Dead Peer Detection functionality; NAT -Traversal
- Wide range of Statistics

#### **2.5.2.2. SIP: Intelligent Serial to IP converter**

$\mu$ SysCom SIP is an intelligent Serial to IP converter that allows connection of asynchronous RS232/485 serial devices to a 10/100 Base-T Ethernet based network. It also provides a wireless connectivity so a remote access is also possible as depicted below.

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<sup>18</sup>  $\mu$ SysCom 3EMR - GPRS



**Figure 2-22: Serial to Ethernet / Wireless bridge / gateway**

SIP allows an easy integration of non IP devices onto an IP network. An additional wireless WAN connection is available for those cases where mobility is a must and mobile network operator data services (such as GPRS, Edge, UMTS, HSDPA) are required.

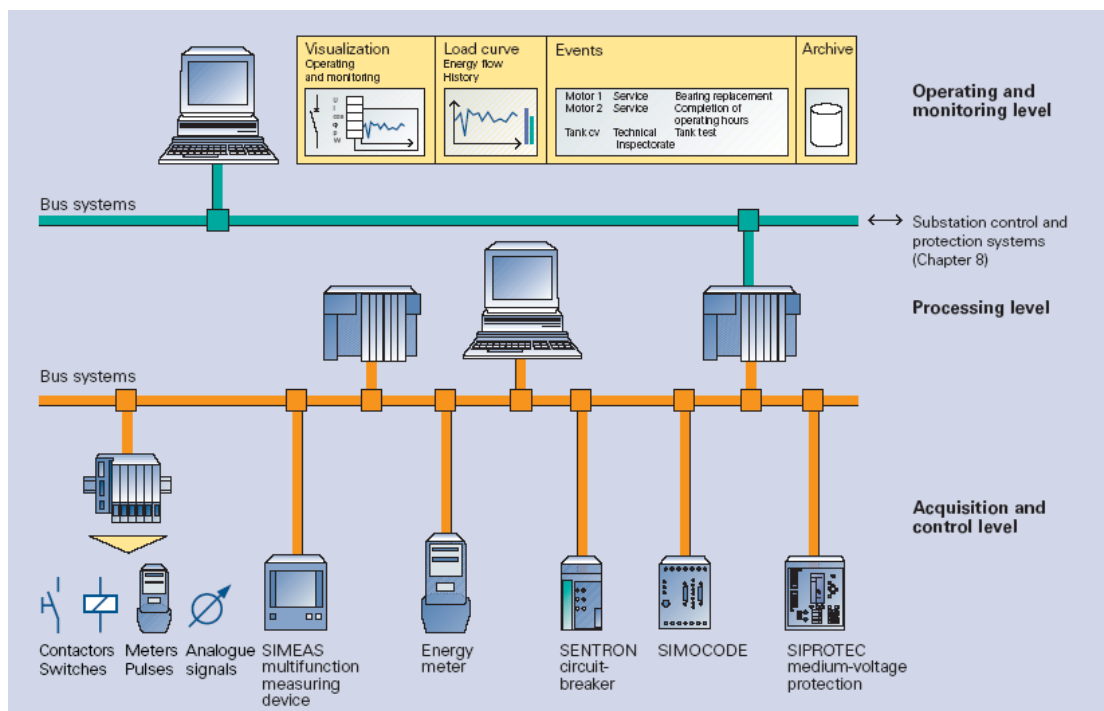
$\mu$ SysCom SIP has been specially designed taking into account the particularities of the electrical sector, and therefore supports the transport of specific protocols, such as IEC 60870-5 101/102 serial protocols. The following SW features are available:

- Flexible Web based interface configuration
- Easy configuration of serial to IP connections
- Optional WAN connection (GPRS/Edge/UMTS/HSDPA)
- Optimized for transporting IEC 60870-5 101/102 serial protocols over IP networks
- DHCP Server and Client inside
- NTP Client
- Wide range of statistics
- SNMP management
- Firmware upgradeable

## 2.6. Software applications and miscellaneous

### 2.6.1. Energy management systems in electrical power distribution

Power management (Figure 2-23, Figure 2-24) in general implements the connection of various energies (electricity, gas, water, heating, cooling, etc.) to various software packages. Applications such as status visualization, consumption recording with the corresponding load curve presentations and assignment to cost centres, load management, forecasts, as well as reporting and control functions, recording and managing of maintenance information can be implemented. A consistent operating and monitoring concept forms the basis for comprehensive power management.



**Figure 2-23: System structure for the communication in the energy distribution (Siemens)**

A visualisation for event-oriented operating and monitoring is used at the level of low and medium voltage electrical power distribution. All information about faults and events aids in troubleshooting. Complete and detailed maintenance information is important for the execution of maintenance works. The electrical power supply is monitored only with regard to observance of limits and the switching of equipment (on- and off-switching). The electrical energy demand is forecasted. All information and actions focus on smooth-free operation, fast fault clearance, and the expedient execution of maintenance work.

Bus systems are used for the data transmission and communication in the electrical energy distribution. This communication is not only used to record switch position, messages and measurements, but also to perform switching operations. The communication with modern circuit breakers allows a direct online parameterization of the setting values. Furthermore, all recorded measured values can be read out.

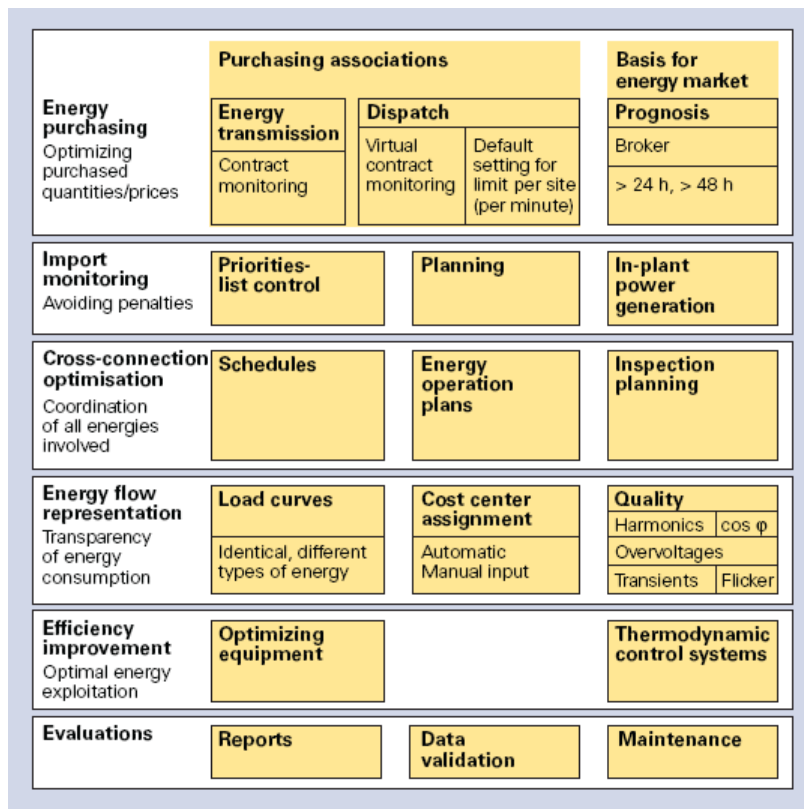


Figure 2-24: Power management modules

Although a power management system is for sure not typical interface equipment as is the issue of work package TE3 “interface equipment requirements”, but, this system demands certain features from the hardware interface equipment of the network.

### 2.6.2. System Planning

Integral power system solutions are far more than just a combination of switchgear, transformers, lines or cables, together with equipment for protection, supervision, control, communication and whatever more. Of crucial importance for the quality of power transmission and distribution is the integration of different components in an optimized overall solution in terms of:

- System design and creative system layout, based on the load centre requirements and the geographical situation
- Component layout, according to technical and economic assumptions and standards
- Operation performance, analyzing and simulation of system behaviour under normal and fault conditions
- Protection design and coordination, matched to the power system.

Some of the tasks that have to be performed for system planning are depicted in Figure 2-25.

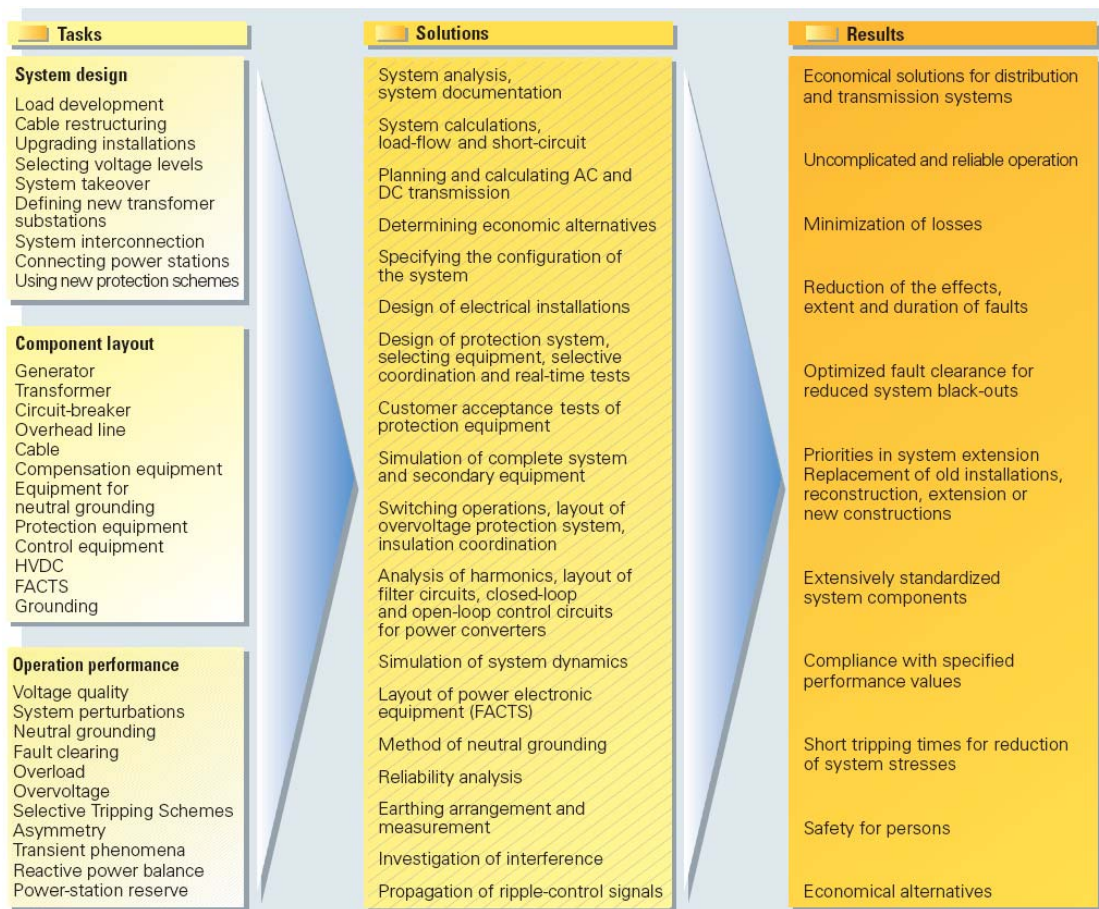


Figure 2-25: Tasks of system planning

### 2.6.3. Protection design and coordination

Apart from all the intelligence that is required to operate Microgrid networks basic tasks of protection have to be applied:

- Protection of persons against the effects of short-circuits

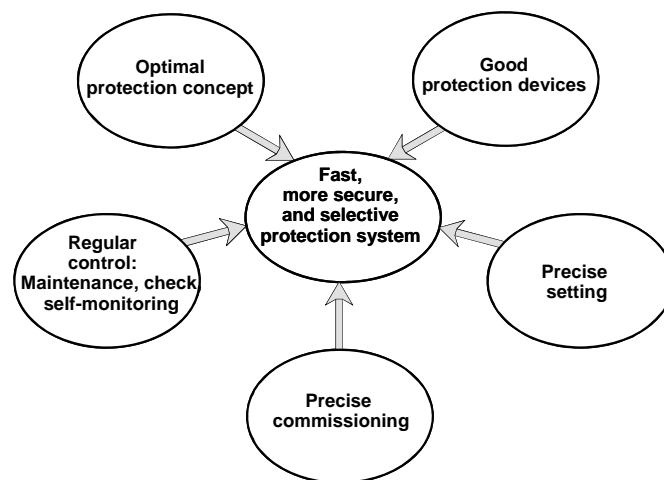
- Protection of operational equipment from destruction and damages
- Maintaining the power system operation in case of failures

### 2.6.3.1. Principles of protection coordination

Relay operating characteristics and their setting must be carefully coordinated in order to achieve selectivity. The aim is basically to switch off only the faulted component and to leave the rest of the power system in service in order to minimize supply interruptions and to assure stability (Figure 2-26). For this protection has to be:

- Fast (to avoid damage that is over proportional to time)
- Selective (switch off only faulted part)
- Sensitive (protection should be as sensitive as possible to detect faults at the lowest possible current level) and
- Available (operation without any failure i.e. by digital protection with self-monitoring).

At the same time, however, it should remain stable under all permissible load, overload and through-fault conditions.



**Figure 2-26: Planning of power system protection**

Aspects of protection coordination comprise:

- Selection and coordination of relay features by themselves
- Selection and coordination of relay features due to system devices, given Network configuration and client
- Selective grading and parameterising of main and backup protection

- Application of tele-protection schemes ensuring fault clearance for 100% of protected line and avoiding unselectivity
- CT- and VT-dimensioning according to relay requirements

With digital tools for network calculation it is necessary to perform steady state and transient simulation of protection and power system such as calculation of important load flow scenarios, voltage profiles (voltage drop  $\diamond$  U/I-fault detection), minimum and maximum short-circuit currents and transient stability with maximum fault duration and relay-dead time). Minimum short-circuit currents (two- and one-phase) and maximum load currents (minimum load impedances) determine the pick-up values. Maximum short-circuit currents determine the maximum permissible fault duration.

More generally it has to be taken into account:

- Which neutral earthing method?
- Which break times are permissible?
- Which target time at the supplies?
- How will the system develop in the future?
- How important are the customers?
- Which information is required?

### **2.6.3.2. Revision of conventional protection concepts for $\mu$ Grid protection**

$\mu$ Grids are characterized by a high number of subunits connecting DG units to LV and MV networks. As a consequence, conventional selective protection concepts lead to high fault clearing times or unselective trippings which become unacceptable under operational and economical aspects. A revision of conventional protection concepts i.e. with new protection grading principles is necessary.

For ring networks with numerous subunits and converter connected DG and radial network with direct connected DGs an investigation has shown that the use of inverse time characteristics according to an advanced manner can lead to significant shorter delay times ensuring selectivity simultaneously. The benefit becomes the more obvious the higher the number of subunits which is typically for networks with DG infeed ([Ref-4]).

## **2.6.4. Engineering software**

### **2.6.4.1. Network planning and dimensioning tools**

For the planning of DG networks it is required to check whether the system supply conditions are met. This requires, according to the conventional method, several calculations of the different operational modes in order to determine the voltage drop with full respectively no generation. An *Automated examination of the voltage drop* of DG plants would help to reduce the effort considerably.

Moreover, the harmonic distortion of the system produced by DG plants has to be examined. Not only the THD but also the content of the individual harmonics have to match the requirements. This requires extensive examinations with a computer simulation program. An *Automated examination of the prospective harmonic distortion* of DG plants combined with a comparison with the requirements would be an interesting tool, therefore.

A combination of these tools: *Automated examination of the voltage drop* and *automated examination of the prospective harmonic distortion* in form of an “electronic data sheet” of the DG plant would further reduce the effort on necessary examination of such systems.

### **2.6.4.2. Support tool for selective protection settings**

The determination of appropriate setting parameters for the protection equipment and coordinating it with the higher-level protection requires relatively large effort when doing it manually. An add-on on software exiting programs *Automated protection setting* for DG plants would help to decrease the effort in cases where a standardized DG plant configuration is to be examined.

### 3. Computer Aided Design Software Tools

This chapter focuses on the desirable features that should characterise computer aided design tools used for electric power system installations. In general terms, several design tasks could be considered as base for a detailed analysis, from HV/MV substation to MV/LV industrial distribution substations but also extending into DER installations; as alternative a group of different tasks are taken into account irrespectively of the concrete field to provide an overview of the problem and identified needs.

#### 3.1. Requirements overview

The general procedure for electrical installations design includes several distinct elements summarised in:

- One-Line Schematics: This representation identifies the basic configuration of the installation, how it is exploited, etc. Usually, the one line includes basic information about the control system, protection relay codes, etc.
- Electrical engineering works general floor plan: It documents the physical layout of the electrical equipment; for instance, in the case of a substation, bushings, incoming and outgoing lines, transformers, switchgear, disconnectors, distances, auxiliary elements, etc. are depicted in their physical locations in accordance to the adopted shape (U, L, Y...).
- Civil engineering works floor plan: It covers the physical layout of the whole installation: terrain, foundations, trenches for power, control & signalling cabling, oil spill recovery trenches and tanks, sheltering elements, housing for in-door equipment, security fences, etc.

From the theoretical point of view, the full integration of all involved processes would be required but difficult to achieve. Floor plans for the general electrical and civil engineering are relatively easy to merge in a single step because there is a large experience in the use of CAD systems for building with several tools available (AutoCAD®).

The most outstanding feature of these applications devoted to support civil engineering is based on the inclusion of high level objects and entities (i.e. door, wall, window, and so on) with their own behaviour and managing rules.

The applications used for electrical engineering design are less mature and, in most cases, each task has to be handled with a different software environment, material list end up in MS Excel listings, graphical representations of the one-line, three-line schematics are just mere plots with primitives (line, arc, box...) with no intelligence behind, relays are configured using the manufacturer proprietary solution, etc.

Therefore, the general floor plans are left out of consideration, and the set of requirements for an integrated tool supporting the electrical engineering part of the design phase are targeted.

The general application is structured in modules that complement each other, each of the considered modules contain other sub-modules. The proposed architecture is intended to be indicative of one potential layout satisfying some functional requirements; other layouts are also possible after a more detailed software specification is conducted.

### **3.2. Engineering Software**

There are several electrical installations that could be taken as example for guiding a general configuration, for instance, in case of an industrial installation feed from MV or a HV/MV substation.

The first example is relatively simple: compact substations manufacturers (either global like ABB, Schneider Electric, Siemens, etc. or either local such as Ormazabal at Spain...) supply their customers with design supporting tools. This type of tools, provide, under a graphical environment, help in the process to design the desired plant.

Figure 3-1 shows one of the outputs of amiKIT (see [www-9]) where the different cubicles of the installation are outlined. The engineering design is relatively complicated because the tool integrates the intelligence to guide the user along the process and deduces some constraints from provided information (i.e. from the province: the local distribution company name, available voltage levels and applicable constraints, etc. are derived).

In the particular case of this tool, estimated budget, list of materials, CAD drawings, project drafts and other features are provided as well as export capacity into MS Office components. In any case, the final project for the installation has to be adapted and reviewed by the engineering or architecture company using the application.

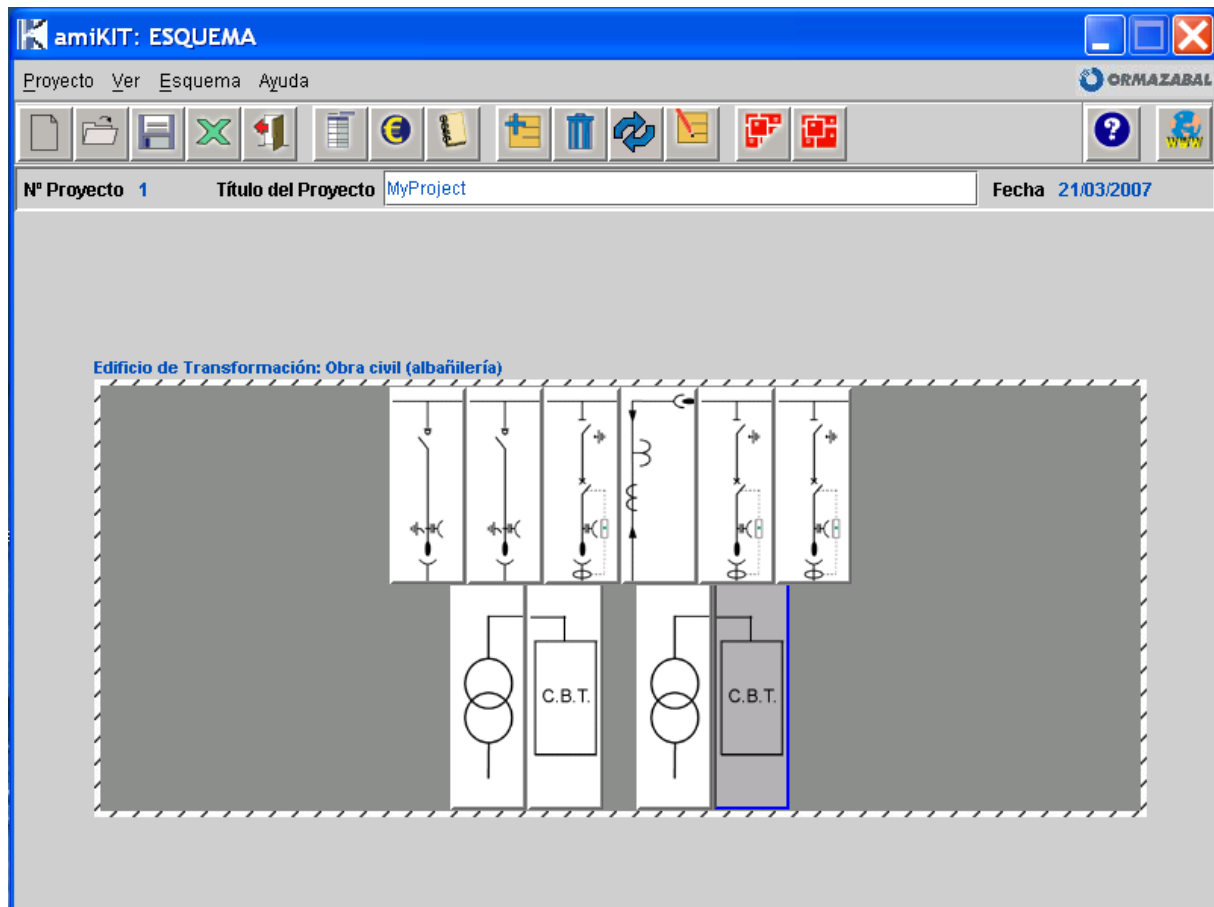


Figure 3-1: AmiKIT<sup>19</sup>: Floor plant of HV metal clad cubicles

In summary, when the engineering tool is provided by a single company offering a complete catalogue of solutions for every single need, it is possible to use it. Some elements are still missing but the process is almost done.

When a larger project is aimed, when products and solutions from several purveyors are required, when a more processes are involved, then some advanced application is needed. This is the case of DER installations or substation design where local controls, interlocking mechanisms, protection relays configuration, etc. are integrated in the project.

### 3.2.1. Environment

A brief analysis of the existent tools and their features demonstrates that although there are applications managing the CAD part they do lack of support for advanced modelling, while

<sup>19</sup> Customer support tool provided by Ormazabal for the Spanish market.

those integrating adequate data models do not include the graphical design part and electrical engineering tasks.

### **3.2.1.1. CAD Tools**

In the market there are many available tools for CAD, from the well known AutoCAD® ([www-4]), MicroStation® ([www-5]) to many other smaller products.

The interesting issue of general CAD applications is that some intelligence is built on top of them to support advanced engineering tasks. The basic feature of any CAD application is drawing through the use of basic plot primitives: lines, arcs, etc. completed with scaling, multilayered views, hidden layers, and so on.

Over these basic elements, some domains have evolved these tools integrating some higher level objects that improve significantly the engineering tasks. A clear example is architecture: special modules are added on top of the basic CAD tool to provide access to entities such as walls, doors, windows, etc. These advanced elements behave properly, if two walls are crossed at the graphical interface there are not two separate walls any more, a corner is automatically added, its properties defined considered walls width, etc.

In the electrical engineering domain something similar is found with a few products able of handling single phase and three phase representations properly (AutoCAD Electrical, Electrical Designer -[www-2]- and others) with more or less functionalities apart from the basic drawing.

### **3.2.1.2. IEC 61850**

IEC 61850 Standard was developed by WGs 10, 11 and 12 belonging to IEC Technical Committee 57. These working groups focused on communications within substations, as opposed to distributed Telecontrol, which was the focus of Working Group 3, or communications between control centers, as in Working Group 7. Communications within the substation were divided into three levels: station, process, and unit. Initially each Working Group handled a different part of the architecture, but in later years they formed joint task forces to address mutual issues. The initial specifications focused on a “top-down” approach, characterizing the interactions between substation components at requirements level:

- 61850-1 Introduction and Overview
- 61850-2 Glossary
- 61850-3 General Requirements

- 61850-4 System and Product Management
- 61850-5 Communications Requirements

These WGs also had within their scope the task of developing a standard file format for exchanging information between proprietary configuration tools for substation devices. This standard is based on Extensible Markup Language (XML), and draws on the data modelling concepts found in the other parts of IEC 61850, and the capability of the IEC 61850 protocols to “self-describe” the data to be reported by a particular device.

- 61850-6 Substation Configuration Language

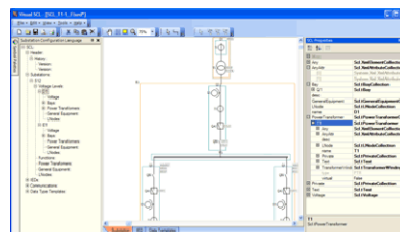
The IEC61850-7-420 standard has been recently published based on a previous work distributed as “Utility Communications Architecture (UCA®) Object Models for Distributed Energy Resources (UCA-DER)”

The IEC 61850-7-420 grows over the base established by the IEC 61850 standard taking the logical node, logical device, common data classes and remaining available modelling entities as base for the information models of several DER technologies.

- 61850-7-420 Communication systems for distributed energy resources (DER) – Logical nodes

IEC 61850-7-420 is recent and there are not any tools supporting it, IEC 61850-6 is more mature and there are applications as Visual SCL ([www-3]) or Kalki SCL Manager ([www-7]) integrating the standard data model.

Visual SCL is a graphical tool that implements the SCL standard allowing the engineer to concentrate on the engineering of substation automation tasks instead on the concrete details of the XML syntax. Objects representing busbars, transformers, etc. are directly managed and placed on the single line representation.



**Figure 3-2: VisualSCL single-line substation schematic**

The SCL syntax is maintained, cross references established, attributes filled with ad-hoc forms and some graphics functionalities introduced.

### **3.2.2. Requirements**

The comparison between those tools aimed for CAD within the electrical domain and those supporting the IEC 61850 offer a clear conclusion: it is easier to further develop CAD applications up to cover the appearing needs than achieve an acceptable functionality on SCL applications.

This approach is perfectly admissible because it exactly describes the traditional business model for third parties developing add-ons for off-the-self CAD applications. The main CAD product is customized by some external developer linked through a partnership program and aims to a given, small or not, market niche.

A detailed review of the functionalities offered by AutoCAD® Electrical (Autodesk® product) and those coming with third parties such as Electrical Designer reveals, apart from a clear parallelism between both, the inclusion of advanced modules and tools able to manage electrical projects.

#### **3.2.2.1. Data Model**

The IEC 61850 seems to be the new coming standard, not only for substation communications but for some other applications (hydro power plants, wind farms, DER plants ...).

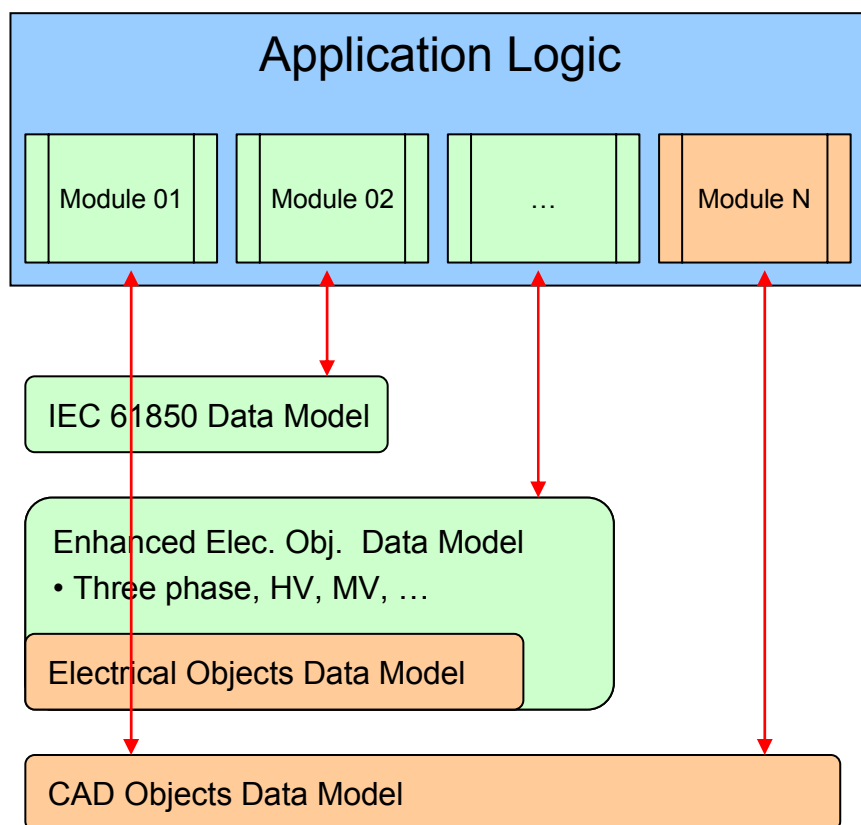
Those tools aimed to support the electrical engineering tasks integrated with CAD environments have evolved a set of high level objects with integrated logic. These objects are far more complex than the simple symbol libraries because they behave as single entities with their own relations, characteristics... but are still far from providing the required levels of intelligence.

Figure 3-3 represents the layered scheme of complementary data models required for advanced engineering tools. The base layer is composed by the traditional CAD primitives; on top of this some basic electrical objects are represented.

This second tier requires some improvements: for instance, to enhance three phase proper support depending on the source add-on used as base for development because AutoCAD® Electrical management of three phase networks seems to be limited (only mentioned at motor control module) while Electrical Designer handles three phase networks.

In the same line of development, most of this sort of applications and integrated data models are aimed to the most common low voltage domain while the capacity to manage medium voltage and high voltage installations is reduced. A clear improvement is needed in this area because the engineering is not only devoted to the control cabinets of larger installations but to the installation itself.

Finally, on top of the base of electrical equipment object models, the IEC 61850 should be incorporated. The standard data model does not consist of many different instances but higher level concepts like substation, voltage level, bay, etc. are a must.



**Figure 3-3: Internal data model needs**

It is worth mentioning that the different layered data models may, or may not, be completely crossed; A given module for editing some substation properties do not require any use of the basic CAD drawing entities but, on the other hand, adding one transformer bay transverses the full tree.

### 3.2.2.2. Data Storage

No special requirement is defined for the data repository. It is assumed that relational data bases (RDB) are in use as they are in today tools and applications.

This approach based on conventional and well matured RDB for providing the back end data storage is aimed to allow easy access to data, externalize the storage format issue and provide an entry point for the integration with other corporative modules. An integrated set of relations between tables, primary keys and other RDB management facilities contribute the overall data organization and coordination.

### 3.2.3. Modules

#### 3.2.3.1. Import Module

There is a clear need to integrate a suitable import module into the application. A normal use case for the application would be based on one engineering company receiving the customer specification, a relatively old CAD file describing a substation one-line and some complimentary information. With this information, the work is expected to start from scratch;

It would be desirable to integrate some import facility able of interpreting simple drawing lines and tags into wires, boxes with relay protection codes into concrete relay objects, etc. In the rare case the System Specification Description (SSD) is available it is integrated into the tool as input data.

The SSD file is updated with the editor because it constitutes the full substation specification, including single line drawings and functionalities identified with their respective logical node.

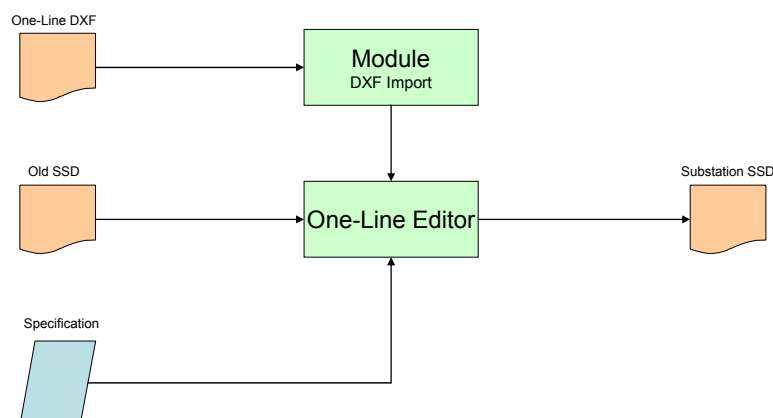


Figure 3-4: Import module need

### 3.2.3.2. Design Modules

The engineering tasks included into the basic application are developed as individual modules to provide the maximum flexibility.

Following the substation design case: the SSD data is completed with existent products taken from off-line or on-line catalogues, IED capability files should be integrated to assign a given logical device to a physical device, other data as customer preferences should be treated and incorporated to the final model, IED configured into Configured IED Description (CID). As result of many sequential and simultaneous processes the final Substation Configuration Description (SCD) is obtained.

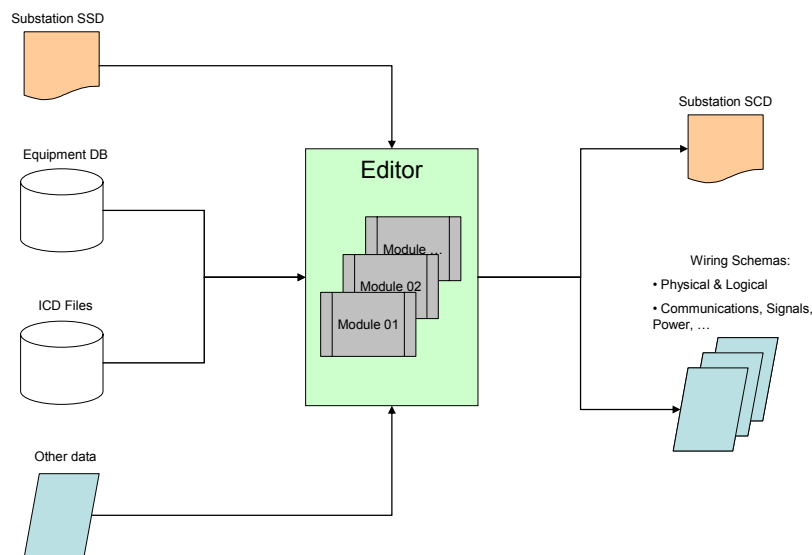


Figure 3-5: Some targets for the installation electrical engineering

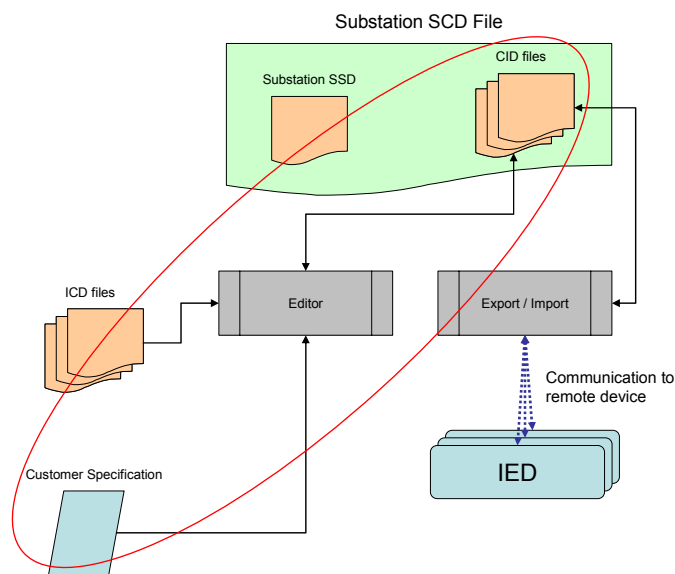
This IEC 61850 specified file is just part of the overall design because there are many other tasks that are required to implement such a specification:

- Catalogue of HV, MV and LV products
- Terminals require labelling, automatic numbering, error checking, physical layout in cabinets or trenches, etc.
- Terminals are integrated into cables, also requiring labelling, numbering, etc.
- PLC I/O design, ladder programming, export to some sort of format understood by the PLC and even import capacity from PLC into the database.

- Wires may belong to the electrical system, to the auxiliary power system, to control system, to communications network, etc.
- ...

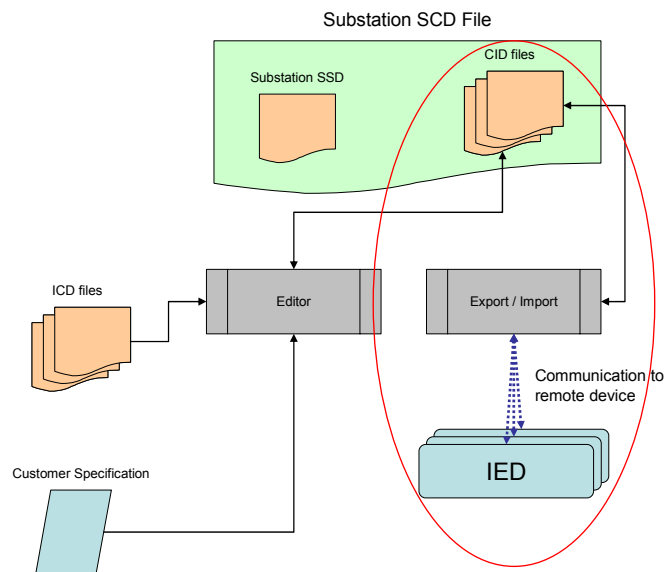
Above list is not intended to provide a complete relation of modules, functionalities or needs; it just aims to outline some concurrent issues.

For most of the cases (substation design, DER plant design, etc.) there is a need to configure the IEDs; this information is built from the IED capability file, completed with the local utility and produces the IED configuration files (CID) as seen in Figure 3-6.



**Figure 3-6: IED configuration edition**

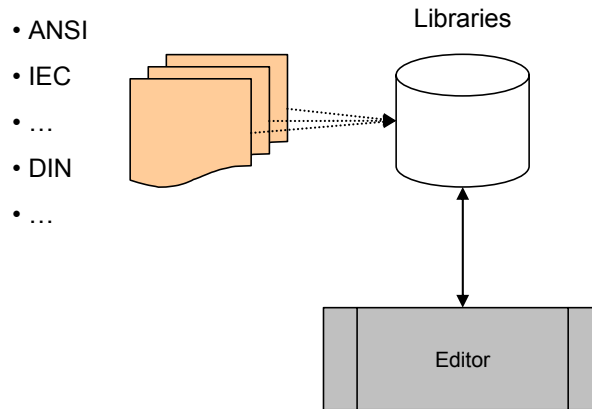
Logically this information belongs to the complete SCD model but needs to be extracted from it and transferred back to the IED providing the service. This second step requires a special care for medium term maintenance (Figure 3-7) of the SCD file because any change performed on the local installation may remain hidden producing unexpected results in case of later updates to the IED.



**Figure 3-7: IED configuration maintenance**

**3.2.3.3. Data Editors**

The engineering process includes not only the design of the installation, cablings, controls, etc. but also involves the selection of specific equipment able to satisfy a given requirement.

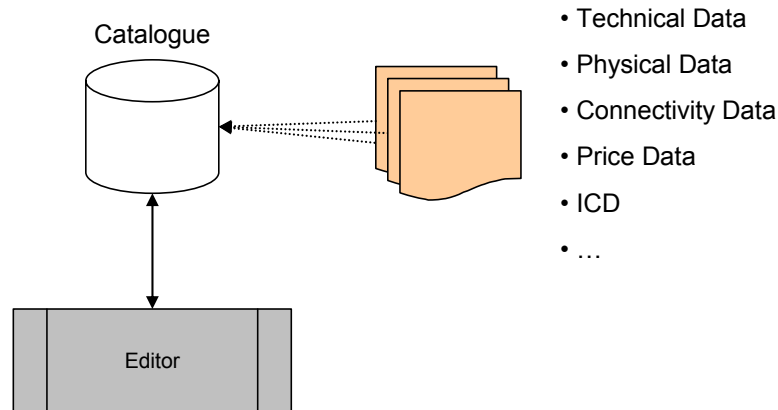


**Figure 3-8: Library editor**

These requirements could be as simple as the set of symbols preferred by the final customer (ANSI, IEC, etc. or even custom) managed by means of external libraries (Figure 3-8).

The specification defines functional requirements and it could be incorporated to the project in terms of engineering. For instance one instantaneous over-current function may be needed, and the connections from the relay function to the current transformer and to the

breaker may be added to the project. These elements, type, characteristics, etc. also form part of the overall project and should be specified.



**Figure 3-9: Catalogue editor**

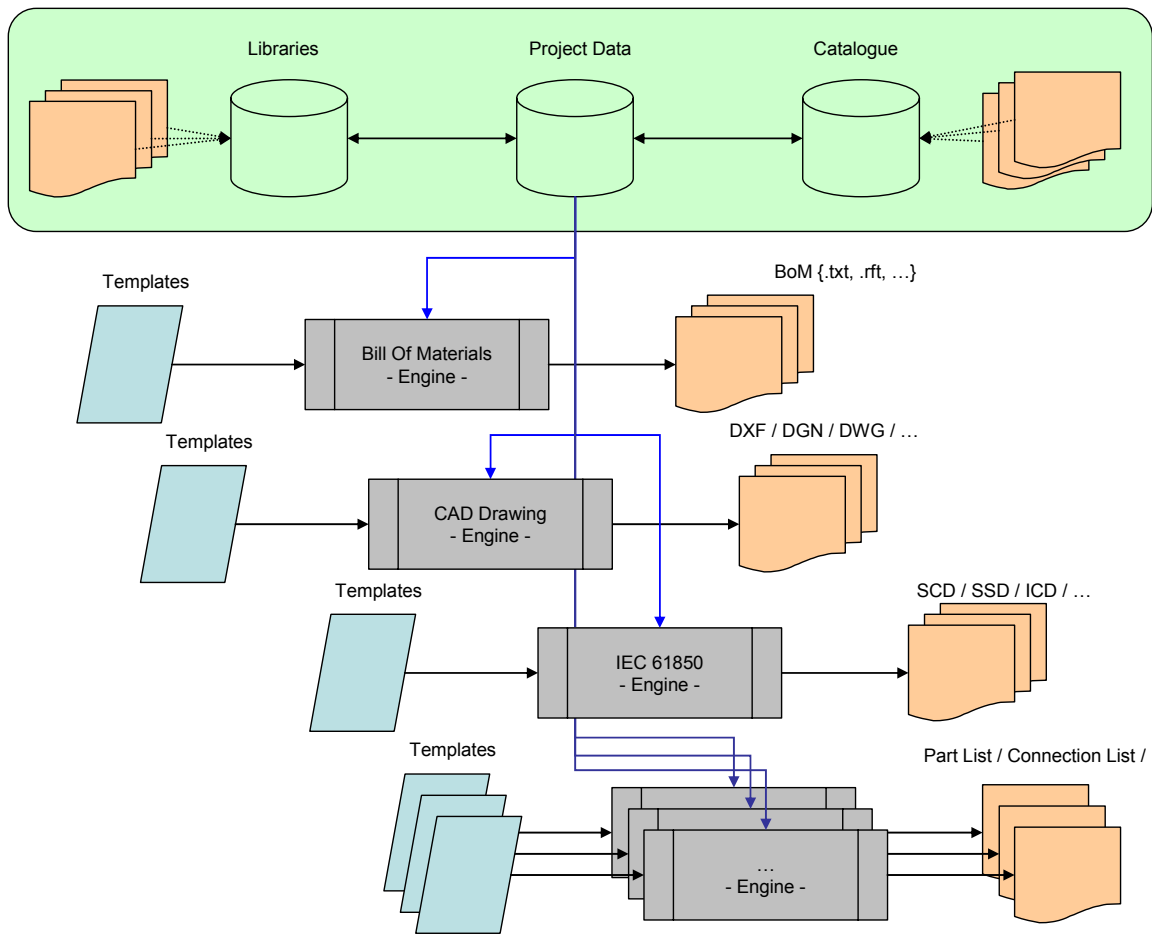
Figure 3-9 depicts a catalogue editor that allows considering different products from distinct purveyors. It is worth noticing that the type of data hold by the catalogue will vary depending on the features of the software tool.

Substation equipment ICD data is required to complete the IEC 61850 set of files but connectivity data would be required if advanced coherence wiring checking is done, physical sizes if cabinet layouts are considered as part of the outcomes.

#### **3.2.3.4. Documentation modules**

In the same way that design application is built as a group of concurrent modules, documentation applications is also formed by several compatible modules in charge of generating the different elements that constitute the installation information:

- Bill of Materials: This report may be based on mere plain text listing or more complicated word processor formats (rtf...) with properly designed templates.
- CAD Drawings: High level single phase schematics, detailed single phase schematics, three phase, cabinet deployment layouts, etc.
- IEC 61850 related files: SCD, IDC, SSD...
- Others like wire labels, wire lists, cable lists, etc.
- ...



**Figure 3-10: Documentation modules**

It is worth noticing that, in case the database internal design is accessible and documented, some, if not most, of these documentation modules could be based on existent third party tools and applications (i.e. Crystal Reports®).

**3.2.4. Other modules**

The whole software package would be completed with some additional components aimed to help during the engineering process such as:

**3.2.4.1. Error checking**

A significant part of the effort during the engineering phase is applied to the correction of errors, specially when several task are executed in parallel. One-supposed-to-be-small change may derive into serious consequences in other parts of the project or, even worse, remain hidden until a latter stage.

In this sense, there is a clear need for tools in charge of checking automatically for errors, ensuring the coherence across all the concurrent development lines. These tools may be based on simple searches for duplicate entries to more complex pattern matching, from accounting the number of free terminals on a given device to the number of wires in a single cable, in any case there will always be something susceptible to be verified.

In general terms, each company experience and internal organization may lead to slightly different needs in terms of data assessment that could be solved applying custom modules to the database data.

### **3.2.4.2. Layout**

Some commercially available products offer some sort of automatic layout engine able to help into producing the cabinet wiring layout. So far, this type of applications are quite immature but complex electrical engineering designs need to define the internal (cabinets) and external (other elements) layouts of various systems: communication (physical layers), power, control, signals, etc.

### **3.2.4.3. Repository**

A consistent repository management module is clearly foreseen; on one hand, the learning effort resulting from the introduction of a new software tool for electrical engineering is only compensated after several years, when designers are fully used to the application and provide the maximum performance using it; on the other hand, developed projects for the same customer are likely to be quite similar in terms of specification and this leads to the fact that several projects will share philosophy (protective relay scheme, signalling...).

Therefore, it is clear that, following the new design integrated application, there will grow a large know-how database, suitable to be exploited with some form of copy-paste of components. The coherence checking modules will assist the engineering team to early correct any made mistake.

## 4. References

- [Ref-1] Siemens AG, *Totally integrated power*, second revision edition, Siemens AG, Berlin and Munich, Germany, 2005.
- [Ref-2] Trench, Brochure *Reactors*, Canada, 2006
- [Ref-3] C.Nietsch, C. Schwaegerl et al.: '*Netzverträglichkeit von PV-Kraftwerken*', OTTI PV Kloster Banz, 2007
- [Ref-4] J. Jäger, T. Keil, L. Shang, R. Krebs: 'New protection coordination methods in the presence of distributed generation', IEE Amsterdam, 2004
- [Ref-5]

## 5. Web Sites

[www-1] <http://www.abb.com/>

[www-2] <http://www.aceri.com/>

[www-3] <http://www.ase-systems.com/>

[www-4] <http://www.autodesk.com/>

[www-5] <http://www.bentley.com/>

[www-6] <http://www.iec.ch/>

International Electrotechnical Commission – IEC

[www-7] <http://www.kalkitech.com/>

[www-8] <http://www.schneider-electric.com/>

[www-9] <http://www.ormazabal.com/>

[www-10] <http://www.siemens.com/>

[www-11] <http://www.ziv.es/>

[www-12] <http://jade.tilab.com/>

## 6. Glossary

| Term      | Stands for                                | Notes  |
|-----------|---|--|
| CAMC      | Central Autonomous Management Control     | More $\mu$ Grids project term defining an intermediate control hierarchy bellow the DMS.   |
| CID       | Configured IED Description                |  |
| DG        | Distributed Generation                    |  |
| DMS       | Distribution Management System            |  |
| DSP       | Digital Signal Processor                  |  |
| EMC       | Electromagnetic compatibility             |  |
| FACTS     | Flexible AC transmission systems          |  |
| GPS       | Global Positioning System                 |  |
| HRC       | High Rupturing Capacity                   |  |
| HV        | High Voltage                              |  |
| ICD       | IED Capability Description                | File based on SCL  |
| IEC       | International Electrotechnical Commission |  |
| IED       | Intelligent Electronic Device             |  |
| ILC       | Intelligent Load Controller               |  |
| IP        | Internet Protocol                         | One of the stacked protocols at TCP/IP networks; Used in general to identify the whole set of protocols and associated functionality |
| IPsec     | IP Security                               | Standard for authentication and encryption over IP.  |
| JADE      | Java Agent DEvelopment Framework          |  |
| JADE-LEAP | JADE Light Extensible Agent Platform      | Reduced version of JADE platform aimed towards embedded –limited– devices.   |
| JVM       | Java Virtual Machine                      |  |
| LAN       | Local Area Network                        |  |
| LV        | Low Voltage                               |  |
| MAS       | Multi-Agent System                        |  |
| MV        | Medium Voltage                            |  |
| MGCC      | MicroGrid Central Controller              | Energy management system in charge of controlling a $\mu$ Grid as to fulfil any given target.  |
| NTP       | Network Time Protocol                     |  |

| Term | Stands for                           | Notes                        |
|------|--------------------------------------|------------------------------|
| PLC  | Power Line Communications            |                              |
| PR   | Performance Ratio                    |                              |
| PV   | Photo Voltaic                        |                              |
| PWM  | Pulse Width Modulation               | i.e. for motor speed control |
| RDB  | Relational Data Base                 |                              |
| RFC  | Request for Comments                 | IEEE term.                   |
| SCD  | Substation Configuration Description | File based on SCL            |
| SCL  | Substation Configuration Language    | IEC 61850-6 Standard         |
| SPD  | Surge Protection Device              |                              |
| SSD  | System Specification Description     | File based on SCL            |
| THD  | Total Harmonic Distortion            |                              |
| VPM  | Virtual Private Network              |                              |
| VSI  | Voltage Source Inverter              |                              |
| WAN  | Wide Area Network                    |                              |

## 7. Annexes

### 7.1. Annex A: Network integration of a 5 MW solar park

#### 7.1.1. Introduction

In 2004, one of the world's biggest PV-plants with 5 MWp electric power was built close to Leipzig in Germany. GEOSOL, Shell Solar, Siemens and West Fonds constructed the "Solarpark Leipziger Land" on a coal dust landfill. This solar park has a total surface area of 16 hectares and comprises 33,264 solar modules.

During the last years the number of bigger PV-plants (>1 MVA) has increased significantly. The infeed of generating power from PV-plants with installed capacities of more than 5 MW possibly alters the direction of power flow and takes considerable influence on the local network quality.

#### 7.1.2. Idea

Due to the restricted bearing capacity of the soil in this coal dust deposit, the location of the containers was transferred to the outer sides of the basin and the 20kV substation was placed outside this area. Four inverter containers with 3 x 400kVA *SINVERT solar M/S/S* inverters each take in the PV-input of 2 x 1.25MVA transformer stations at one site and feed into the 20kV system via decentralized located 20/0.4kV transformers (Figure 7-1).



Figure 7-1: Solarpark Leipziger Land

In the 20kV switchgear building located outside the basin, the circuit breakers with transformer feeder protection, the 20kV connection with measuring system and the 20/0.4 kV station-service transformer of 50KVA, as well as the control via intelligent SIPROTEC protection and bay controller devices have been installed (Figure 7-2).

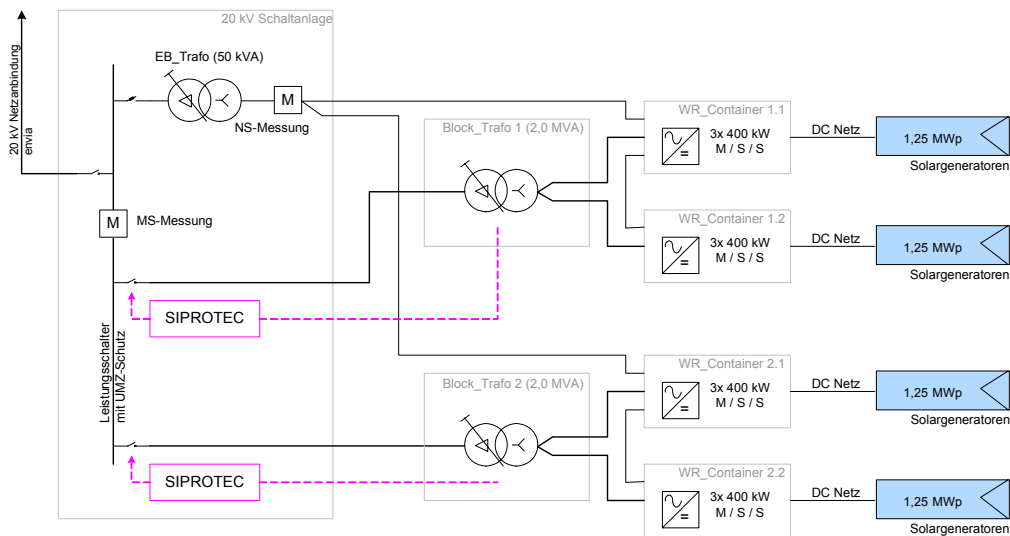


Figure 7-2: PV plant conception

### 7.1.3. Technology and Operation

The PV-plant has been equipped with twelve *SINVERT solar 400* inverters in master-slave operation, which directly feed on two 20/0.4kV GEAFFOL transformers (2 MVA). The intelligent controlling of inverters and a central SIMATIC control system ensure the compatibility of PV-power infeed with the network, see Figure 7-3 [Ref-3]:

- Phase-symmetry control ensures the symmetric infeed into the system; avoidance of negative-sequence and zero-sequence systems
- $\cos\phi$  control backs the voltage quality on site and, if required, provides capacitive or inductive reactive power
- VAR control
- The active harmonic current control reduces the harmonic current load on the connecting point and renders possible a higher PV-input even in pre-loaded systems
- Automatic overnight disconnection via the SIMATIC/SIPROTEC control system reduces losses and increases the overall efficiency (Performance Ratio PR) of the PV-plant

- Isolated operation during approach and synchronic connection of the transformers to the system avoids voltage dips and permits operation even at weak dead-end feeders
- Restriction of the infeed when reaching the maximum voltage, e.g. at light load during weekends and high PV-power, reduces frequency of disconnection, protects the material, increases overall efficiency (PR) and avoids sudden power variations in the network
- The central operating and monitoring system (PV-WinCC) and the SIMATIC control system are capable of intercommunication and, even today, allow a bidirectional, redundant connection (via internet, ISDN and GSM) to a central network automation in the future.

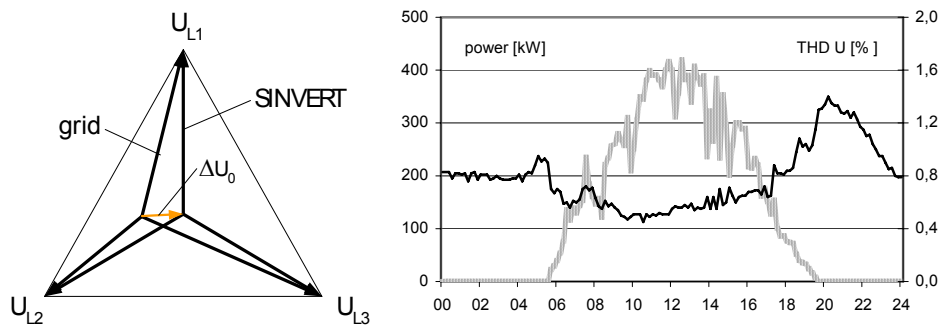


Figure 7-3: Symmetry control and THD improvement at the connection point to the grid

#### 7.1.4. Perspective

The tuning of all components of the PV-plant under consideration of intelligent automation technology and the tuning of the operational equipment on the basis of local network analysis permit a technically reliable and economic operation with high overall efficiency throughout the life cycle of the plant and ensure high system compatibility.

To achieve a higher interference with decentralized generation, it should be aimed at approximating the behaviour of static inverters and synchronous machines (infeed not via increase of voltage, but virtual modification of the angular displacement).

## **7.2. Annex B: Operational and control requirements of load controllers**

### **7.2.1. Introduction**

This section provides the control and operational requirements as well the experience of the load controller development and installation in Gaiduromantra in Kythnos Island. The main characteristic of this controller is that it is designed to become part of a Multi Agent System (MAS) Environment and the Jade Library ([www-12]).

### **7.2.2. Description of the system**

The Power Systems Laboratory of the National Technical University of Athens (NTUA) in cooperation with ANCO S.A., have designed and developed an Intelligent Load Controller (ILC), which will be field tested in the Kythnos Microgrid. More specific ANCO developed the hardware platform and NTUA developed the Java based control algorithm. The software allows the implementation of Intelligent Agents' Technology. Namely, every ILC will be controlled and represented in the system by an intelligent agent.

The ILC is a system that can be used to monitor the status of a power line and take Voltage, Current and Frequency measurements. In addition it can remotely control up to 256 PLC A10 devices (load switches) connected to the power line. As far as the houses on Kythnos Island are concerned each ILC will control two PLC switches. Main objective of this application is to control the operation of non-important loads. Each house in the settlement is equipped with a water pump, which is responsible for replenishing a water tank and in this way supplying water to the residents of the house. In case of power shortage, the water pump is considered as non-important load and therefore, it should be disconnected if needed. Therefore, the first PLC Switch controls the water pump, while the second PLC Switch controls a power socket and any load connected to it.

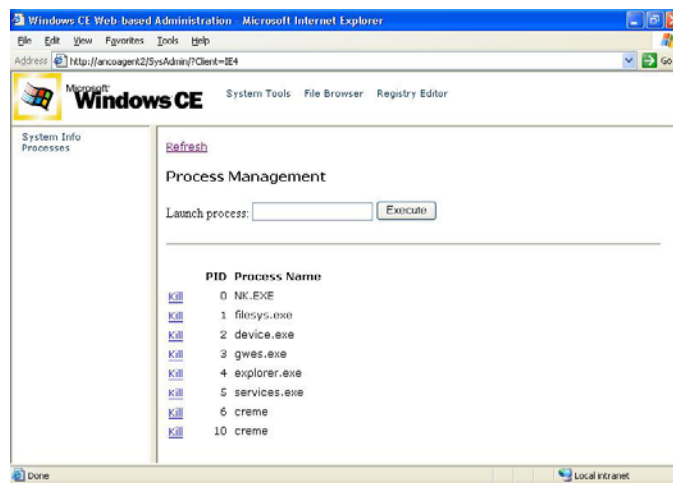
Additionally, the ILC features a Wi-Fi interface that enables it to wirelessly connect to a Local Area Network. This eliminates the need of a data-cabling infrastructure and simplifies the installation of the units.

The core of the unit is an integrated computer module that runs the Windows CE 5.0 operating system. The integrated computer module is driven by the powerful Intel® Xscale™

PXA255 processor at 400MHz and features 64MB of RAM and 32MB FLASH Memory (instead of a hard disk drive). Thus, it is suitable for demanding applications.

The operating system supports the installation of a Java Virtual Machine. Therefore, an agent environment based on the JADE platform can be easily embedded in the controller. In this way, along with the MGCC installed in the System House in the Kythnos Microgrid, we are provided with the opportunity to perform the first actual field test of the Intelligent Agents' Technology in a Microgrid.

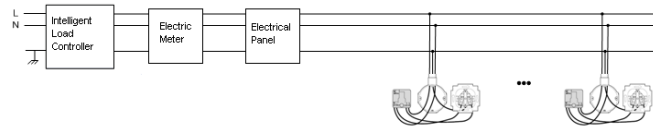
The ILC hosts an integrated Web Server, as shown in Figure 7-4 through which we are able to control the operation of each controller.



**Figure 7-4: ILC Integrated web server**

During the installation in the Kythnos Microgrid, a broadband internet connection will allow for remote control through a Virtual Private Network (VPN). As a result, commands can be sent and data can be exchanged among the ILCs, the MGCC and authorized users who are not required to be situated on the island of Kythnos. It should be noted that an ILC communicates with the MGCC through a Local Area Network and the Wi-Fi interface they both feature.

Figure 7-5 shows how the ILCs are connected in the electricity grid. Each ILC unit is connected to the power line outside the house, before the electric meter and the house's electrical panel. After the electrical panel and near the loads, the PLC switches are installed. Each PLC switch has a unique address, so that it can be commanded by the Intelligent Load Controller.



**Figure 7-5: Typical installation of an ILC Unit**

### 7.2.3. Power Line Measurements

The Intelligent Load Controller built-in software provides the following functionalities regarding the power line measurements:

- Frequency measurement.
- Voltage RMS measurement.
- Current RMS measurement.
- Sag events detection and announcement.
- Over-voltage events detection and announcement.
- Over-current events detection and announcement.

The values are calculated by sampling the power line at a rate of 3,500 SPS (samples/second). As far as the events detection functionalities are concerned, the controller announces the event start and termination, records the duration of the event and, depending on the event, records the maximum or minimum value measured. It is important that, with the software we have developed, the controller is capable of processing these measurements. As a result, the agent who is implemented in the controller is able to identify only certain events, take the relevant actions.

### 7.2.4. Operational Requirements

#### 7.2.4.1. Environment

The controller is designed mainly for outdoor usage therefore it should take into account any regulation that is related with external usage of electrical equipment. We have considered two main issues:

- Water/humidity resistance
- Temperature

The outdoor installation near the sea requires capability of IP65 insulation against humidity and rain, however the extreme temperatures in the Greek islands ( $>40^{\circ}$ ) should also be considered.

### **7.2.4.2. Electrical Network**

The controller is designed to operate not only to grid-connected mode but also to island mode like the network in the island of Kythnos. This means that it should operate in voltage and frequency levels that are not often in the ordinary grids. Especially regarding frequency a value between 52-53 Hz is quite common in this network especially in case Gaidouromantra when the batteries are full, the PV has full production and there is no load. Regarding voltage quality and voltage dips we have not noticed any specific problem and the only requirement is to be able to handle voltage levels and dips that are acceptable by the local regulations.

### **7.2.4.3. Platform**

The core of the software will be the Jade Library therefore the controller should have load the proper Java Virtual Machine (JVM). Furthermore the Jade-Leap library has been used.

### **7.2.4.4. Communication**

The java based library is using TCP/IP protocol for the communication and the physical mean should be the most appropriate according to each installation. For example in the Kythnos application Wi-Fi has been used.

## **7.2.5. Control requirements**

### **7.2.5.1. Load Control**

The load controller is using PLC switches that can handle up to 16A load. For the Kythnos Island this is the absolutely acceptable however for other application this might create limitations and can be solved by using an intermediate relay however this way the current measurements do not reflect the actual load. Furthermore there are limitations on the current the DSP processor can measure.

### **7.2.5.2. Measurements**

As mentioned before the ILC is capable of measuring various values as well sag and over-limit events. However within our application the events have been used only in the laboratory. This is a part of the future work since not only fast dialogues are needed but also different algorithmic approach introducing preventive operation.

### **7.2.5.3. Response time**

The application was developed in the MAS principle of operation using Java, however this creates problems in response times. The average response time if the system taking into account that there might be some negotiation dialogues between the agents is approximately 1-2 sec. in order to achieve better response duration different approach should be selected avoiding JVM.

### **7.2.6. Conclusion**

The ILC controller has a suitable configuration for the test field in Gaidouromandra, however in order to use it in different applications certain modifications modification should be done. The most important are:

- The controller should be flexible enough to handle various loads
- The capability to achieve fast response times may require modification in the usage of the Jade as well the adopted algorithmic approach.

## **7.3. Annex C: Electrical Designer description**

### **7.3.1. ELECTRICAL Designer Current Version: 2008**

Developer: ACERI S.A.

Country: Spain

Categories: Electrical; Electronic Schematics

Product Summary: Ideal software for electrical engineering design and drafting.

Product Language(s): Chinese, Dutch, English, French, German, Korean, Portuguese, Spanish, Russian

Works With: AutoCAD 2008; AutoCAD Electrical 2008; AutoCAD 2007; AutoCAD 2006; AutoCAD Electrical 2007; AutoCAD 2005

Price: Contact Developer

### **7.3.2. Target Customers**

Engineering companies

Cabinets and panels builders and mounters

Electricity companies (manufacturers and transformers)

Automation companies

Large facilities maintenance

Process and power companies

Machine builders

### **7.3.3. Product Description**

ELECTRICAL Designer is the ideal software for electrical engineering design and drafting within AutoCAD®. It is easy to install, learn and use and with its dedicated electrical engineering functions. ELECTRICAL Designer gives the user a better quality of drawings supported by extensive documentation and error checking facilities. Drawings are produced more quickly, efficiently and with a greatly reduced risk of costly errors. It includes as standard, ANSI, BS, IEC, DIN and JIC libraries.

#### **7.3.3.1. Main Features:**

Project, Library and Catalogue Management

User-definable automatic numbering of circuit elements, wires and terminals.

Cross Reference Analysis.

Automatic generation of bills of materials, parts lists and connections lists.

Technical data reannotation into drawings

Semi-automatic generation of cabinet layouts

Automatic generation of terminal Drawings

Automatic drawing plotting

Terminals and Cables Editor

Connections and Terminals Lists

Libraryshow

Customisable by users

Uses standards (dbf and dwg files)

#### **7.3.4. Benefits**

Easy to learn and operate, fast Return On Investment

Improves drawing quality and productivity

Produces superior quality drawings and documentation.

Reduces risk of costly and time consuming design errors.

Information is produced in standards formats: DWG & DBF files

Connection to materials databases

Management and Project Control

Extensive schematics components and panels libraries supplied.

#### **7.3.5. Features**

Project, Library and Catalogue Management

User-definable automatic numbering of circuit elements, wires and terminals.

On-line Cross Reference Analysis.

Automatic generation of bills of materials, parts lists and connections lists.

Technical data annotation within drawings

Semi-automatic generation of cabinet layouts

Automatic generation of terminal Drawings

Point to point connections and Terminals Lists

Automatic drawing plotting

Terminal and Cable Editing

Library shows

### **7.3.6. Industry Standards**

ANSI, DIN, IEC, BS, JIC, NEN and others

### **7.3.7. Documentation**

Box: A box including users manual & tutorial manual, as well as the CD including the software and the electronic tutorial

Download: Complete software & sample data. Complete documentation in PDF format. Tutorials both in PDF and AVI formats.

### **7.3.8. Relation to Autodesk Products**

Works With: AutoCAD® 2008 - 2007 - 2006 - 2005 - 2004 - 2002.

Version for AutoCAD LT® releases available.

### **7.3.9. Support and Training**

[http://www.aceri.com/cont/usuarios/ingreso\\_eng.php](http://www.aceri.com/cont/usuarios/ingreso_eng.php)

### **7.3.10. Where to Buy**

This product may be purchased online.

It is also available directly from the developer -- call +34 934531206 or visit <http://www.aceri.com>.

## MoreMicroGrids

STREP project funded by the EC under 6FP, SES6-019864

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Or visit <http://www.aceri.com> for a list of dealers through whom this product may be purchased.