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Supporting Energy Efficiency in Smart Generation Grids Through ICT

Thematic Network

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TEST FACILITIES REQUIREMENTS

D7-2

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Executive summary

SEESGEN-ICT Work package 7 acknowledges the importance of a rigorous, transparent and independent testing of existing and new ICT-based solutions intended for deploying Energy Efficiency in Smart Grids and focuses on assets and capabilities Test Facilities should have in order to prove the effectiveness of such solutions and remove non-technical barriers to their entry in the market, as well as to support standardization.

As a first step, compiling such a list of requirements is the objective of this deliverable, while a survey of the availability and compliancy of testing capabilities or initiatives suitable for the independent testing of application for smart grids in Europe will be carried out in the next tasks.

As planned, the priority of the work was given to the requirements to be fulfilled in order to test and validate applications and strategies – supporting energy efficiency in smart grids and requiring information and communication technology – which were identified as promising in the other Work Packages of SEESGEN-ICT.

Although a wide range of very different applications have been analysed by the SEESGEN-ICT WPs – and as a consequence a wide range of requirements for the related Test Facilities have been extracted – it has been found that a limited numbers of Test Facilities, ideally equipped, could carry out any verification, validation or assessment of any ICT-based solutions intended for deploying Energy Efficiency in Smart Grids, likely even those at present yet unforeseen.

Those facilities have been identified and described in this document, taking into account the state-of-the-art and the best practises in the related domains, whenever available.

Of course, it is acceptable that not all the capabilities are implemented because of limited resources, and it is reasonable that facilities with complementary capabilities collaborate to offer the complete suite of tests. In fact, the work of WP7 is finally intended to enhance and improve a real cooperation of the EU Test Facilities, exploiting the respective complementarities and, possibly, fostering a mutual accreditation of the laboratories.

With this purpose in mind, requirements have been marked with an ID in order to allow a mapping of test facilities capabilities against this list. Moreover, referenced requirements can be discussed with the stakeholders and modified or detailed, whenever needed, by contacting the authors of this document.

1 Introduction

SEESGEN-ICT Work Package 7 (WP7) – acknowledging the importance of a rigorous, transparent and independent testing of existing and new ICT-based solutions intended for deploying Energy Efficiency in Smart Grids – focuses on assets and capabilities Test Facilities should have in order to prove the effectiveness of such solutions, to assess their impact on the grid and to remove the barriers to their entry in the market.

The main objective of the deliverable is therefore to list the requirements, in terms of assets, capabilities and policies, a Test Facility should comply with in order to play an effective role in ensuring a proper validation of ICT-based solutions or components relevant to SEESGEN-ICT scope.

In the views of this deliverable, ancillary objectives of a Test Facility are enabling new services and products to enter into the market and supporting their standardization.

The work of WP7 is finally intended to enhance and improve a real cooperation of the EU Test Facilities, exploiting the respective complementarities and, possibly, fostering a mutual accreditation of the laboratories.

As identified in the strategic agenda [1], the priority of the work is given to the requirements to be fulfilled in order to test and validate applications and strategies identified as promising in the other Work Packages of SEESGEN-ICT. Of course, the described ideal Test Facilities and their final requirements list are as general and comprehensive as possible in order to make it possible that applications and strategies at present yet unforeseen can be tested as well.

Furthermore, analysis showed that the interoperability and the impact of the integration of a ICT solution into the grid are the most critical aspects and therefore a large share of the required Test Facility capabilities are addressed to the thorough testing of these aspects. This includes also latency measurement, availability and security of data, as well as protection of sensitive information.

Although the primary area of concern is the distribution grid, should it be found that part of the transmission grid is relevant for evaluating the effectiveness of the application under test, it will be considered as well.

On the other side, the test of a single device or a specific algorithm without its interaction with the grid is out of the scope for the considered Test Facility, and it is assumed to be performed and passed well in advance. In other words, we do not consider early HW or SW prototypes or single commercial devices.

Also, requirements not connected to the ICT aspects, e.g. pure electrical issues, are not considered as well.

Besides the integration tests, both functional tests and SW tests have been considered, with the aim of verifying both their compliancy with standard and general requirements and their capability of facing the widest variety of working conditions.

The structure of the document is as follows.

Chapter 2 highlights the general problems and characteristics of the Test Facilities needed within the scope.

Chapters 3-7 essentially describe the requirements about the tests to be performed on the different ICT solutions – as elicited by a deep analysis of the different deliverables issued by the technical WPs of SEESGEN-ICT – as well as drafting the description of the Test Facility suitable to perform those tests.

Chapter 8 aims at merging the different requirements identified by the different WPs – which span a wide range of applications within the scope of Energy Efficiency – in order to identify the minimum set of capabilities suitable for testing of all the shortlisted applications and strategies as well as the unforeseen ones, whenever possible.

And last, chapter 9 summarizes the major conclusions of this first phase of work package 7.

2 Background about Test Facilities

Having in mind, as pointed out in the Introduction, that a Test Facility has mainly to focus on the system characteristics of a DER network instead of the limits of a single device, it's worth highlighting the general problems and characteristics of the Test Facilities in our scope.

The aspects considered as the most relevant are briefly discussed in the following.

2.1 Implementation of the test facilities: real and simulated aspects

A testbed is a platform for experimentation of large development projects. Testbeds allow for rigorous, transparent and replicable testing of scientific theories, computational tools, and other new technologies.

We distinguish between **Field Test** (or field experiment) – defined as an experiment or a trial conducted under actual operating conditions – and Laboratory Tests – which are carried out under controlled conditions in a laboratory.

Also, we distinguish between **Test Range** – which is an installation employing physical equipments normally deployed in the electrical infrastructure (generators, storage devices, loads, etc.), at prototypical or commercial stage, normally including hardware and software – and **Simulation environment** – which is a software capability able to implement physical components models and therefore simulate their (steady-state or dynamic) behaviour.

In some situation, both aspects are present in the same Test Facility (a part is realized with real devices and another part with simulation tools), or, sometimes, in the same device (for example, a RTDS equipment, with hardware interface driven by a software model).

While defining the needs for the test of the requirements described in the different WPs, it is essential to distinguish between the aspects that can be (or have to be) verified using a Test Range, with real interconnections and real devices, and the other elements that can be (or have to be) checked using "simulation models".

In fact, the two approaches are often quite complementary.

As the matter of fact,

- Test Range is the only option when it is required to verify response times, not due interactions, troubles and noises, that is all the phenomena strictly related to real interconnections and not completely predictable;
- Simulation environment is essential to simulate a great number of interconnections and elements, unfeasible in a Test Range, or to explore a large number of different working conditions.

As far as concerns the simulation models, it is important to specify the main characteristics essential for the test; for example, in the case of an electrical network model, it is important to specify if the test requires only load flow simulation, or also fast transients simulation.

2.2 Best Practices and Policies

Besides the implementation, other words of caution are about test execution and test report.

Different layers, in order to separate the problems to be checked.

These different layers have to be well defined, through an accurate description of the related assumptions. For example, if the behaviour of an “aggregator” has to be verified, it is not useful to mix this check with the control of the interface protections; then, it has to be clarified that the protections don’t interfere.

Accurate definition of the limits due to the hardware configuration of the Test Facility.

The accuracy must be related to the sensible aspects and it is necessary to specify, for each test, which are the aspects that have more influence on the results, in order to well describe the values and the related choices. For example, if the computation power of a central controller is the main aspect to be considered, it is essential to give a precise definition of this power, but it is not important to describe the size or the weight of the controller.

Accurate definition of the limits due to the software simulation aspects.

Regarding the software simulator used, it is important to specify the employed models and their limits. In order to clarify the reliability of the model, how the model has been validated, describing the real case used to collect the data for the validation and the limits of this collection, has to be specified.

Environmental conditions

Whenever relevant, environmental conditions (temperature, humidity etc) have to be checked and reported.

Scalability

A critical aspect is connected to the possibility to extend the test results to a situation in which the number of specific elements is larger and larger. It is important to identify the elements having influence on the scalability and the related limits.

For example, if the information exchange is an important aspect, the bandwidth of the communication channel is a relevant element, but if the test condition assures an enormous value of the bandwidth in respect to the expected possible number of points, it is possible to extend the test results without any limitations.

Repeatability and Reproducibility

Test procedures must grant that:

- results are repeatable i.e. remain unchanged when repeating a test in the same conditions in the same Test Facility, within specified uncertainties.
- tests are reproducible, i.e. they give the same results, within specified uncertainties, when performed in the same conditions in different Test Facilities

Archiving and Logging

Test results must be logged with a suitable reading/reporting rate, and stored in a proper repository for further analysis and checks.

Quality assurance

The principles of the quality assurance, essential to guarantee the quality of the activities performed and including aspects of organization, management, personnel competence and training, maintenance, use of equipment, calibration of instruments, measurements uncertainties, etc. are implicitly deemed as strengthened in the context of this deliverable and won't be treated further.

Having in mind this background, in the following sections specific requirements from the different WPs will be elicited.

3 Test Facilities and WP2 functionalities (Smart Grid Management)

3.1 WP2 scope

SEESGEN-ICT Work Package 2 (WP2) considers how Information and Communication Technology (ICT) can be used for a better *management of smart grids* in which many distributed energy resources (DER) are integrated.

The focus is on the technical management of smart distribution grids that require information and communication technology, and which allow having a better, more efficient usage of electrical energy. In this scope the main focus for the management of smart grids lies within the domain of 'operation and control', with the following specific functionalities:

- Voltage Control: Voltage control in the smart distribution grid will not only be based on the local measurement of electrical quantities, but also on the exchange of values concerning these quantities among the different control points in the distribution grid. Using such information, the controller at the distribution system operator or elsewhere can use DER to contribute to the reactive power management in the grid, and as such improve the energy efficiency.
- Adaptive Protection: In distribution grids with bidirectional power flows, adaptive protection is required in order to deal with the direction of short circuit currents and to ensure selectivity. Communication among protection devices can ensure reaching these goals but puts stringent requirements to the involved ICT.
- Reconfiguration: Smart grid management may imply the reconfiguration of the topology of the distribution grid – if sufficient hardware (switches, breakers,…) is available – in order to better handle the load and generation in the grid due to a large amount of unpredictable DER and faults. Such reconfiguration can be applied pro-actively before emergency conditions occur, or reactively after an alarm triggers. This latter reactive approach also relates to "self-healing" distribution grids. Proactive and reactive actions are commanded by controllers, based on information provided via different sensors in the grid, and communicated to the former.

3.2 Requirements to be checked

The key issue pointed out by all the above functionalities is communication.

General requirements of the communication are:

- data throughput
- response time
- traffic/application priority[1]
- reliability

[1] Congestion may occur from time to time. The infrastructure must be capable of implementing traffic prioritization (as for example defined in the IEEE 802.1p field within the Ethernet frame header when using tagged frames on an 802.1 network). This includes the policies for deciding the priority, effective marking of traffic and effective traffic queuing

- availability
- security and privacy

The quantitative classification of the communication parameters required for SG management functionality is shown in Table 1, whereas in Table 2 the summary of the function of the different services requested to DER units can be found.

Communication parameter	**Low**	**Average**	**High**
Transfer rate	1-5 kbit/s	5-100 kbit/s	>100 kbit/s
Latency	5-60 secs	0.5-5 secs	<500 ms
Availability	80-90 %	90-99.9 %	>99.9 %
Reliability (Bit Error Rate)	0.1-5 %	0.01-0.1 %	< 0.01 %

Table 1: Quantitative requirements of the communication parameters

	Transfer rate	Latency	Availability	Reliability	Priority
Inject energy surplus into the grid	×	×	×	×	×
Produce maximum power	×	×	×	×	×
Peak shaving (generation curtailment)	✓	✓✓	✓	✓	✓
Anti-islanding	×	✓✓	✓✓	✓✓	✓✓
Voltage and reactive power regulation	✓	✓	✓	✓	✓✓
Support island operation	✓	✓✓	✓✓	✓✓	✓✓
Ensure correct operation of power system	✓	✓✓	✓✓	✓✓	✓✓

Table 2: ICT Requirements based on the function assigned to units DG (✓✓High, ✓Medium, ×Low)

Please note that the Priority parameter is not present in Table 1 as it is an integer (for example in the IEEE 802.1p field within the Ethernet frame header it can have a value between 0 and 7 included) where the higher the number, the higher the priority.

Besides communication adequacy for the different functionalities and, vice versa, the impact of different functionalities on communication, some specific functional aspects need a thorough test.

<u>Requirements for voltage control</u>

The *functionality* of each involved component (controller, measurement, communication infrastructure and tap changer) and the proper *behaviour* of the intended voltage control target must be assured: the components which are involved in the voltage control must be coordinated and react according to the control's set-points. System stability must be guaranteed under any circumstances.

Requirements for adaptive protection applications

Rapid switching actions of adaptive protection systems over a wide area set very high requirements on the communication and control system: safety of persons and assets must be guaranteed under any circumstances.

This is why the ideal Test Facility should allow to

- Test and validate the algorithm for the automatic operation of the protection system for maintaining optimal performance.
- Supervise the adaptive behaviour during the alternation of network system conditions.
- Check the improvement of the reliability and power quality, as well as reduction of the fault and interruption of supply.

Requirements for reconfiguration features

System stability must be guaranteed by operating pro-actively and reactively. This is why

- the optimisation algorithms to find suitable topologies for minimising losses,
- the ability to provide automatic supply restoration,
- the remote control of circuit breakers and other equipment,

must be carefully validated.

3.3 Test Facilities features

In terms of ICT, the test infrastructure must be able to create an environment (partly simulated and partly with real devices) to test the system on following issues:

1. Influence of the command and control infrastructure on system stability under different conditions: normal conditions, fault conditions, fluctuations or losses of generation or loads
2. Dynamics of the command and control system in conjunction with the response time on e.g. changing active / reactive power set-points, tripping switches, getting breaker states, …
3. A variety of communication technologies like PLC, Fibre optics, wireless communication etc should be deployed together and their compatibility should be checked. The various protocols available for communication should also be deployed and checked for correct behaviour if some of their specific properties are exploited, although the main focus is on the functional aspects
4. Loss of communication to generators and measurements nodes
5. Interaction between (a high share of) active network components like inverters, e.g. control stability and oscillating effects due to (active/reactive) power feed-in while keeping voltage limits.

Capabilities useful for the simulation environment are

1. Real Time or offline simulation of the electric network at distribution network level up to 2kHz transients[2]
2. Assess the influence of the superior network (HV transmission-network, MV distribution network) on the underlying (distribution) network under test (fluctuations, voltage dips, frequency variations)
3. Provide a power interface to test the component in a power-hardware-in-the-loop setup
4. Providing an interface to a SCADA or incorporating a SCADA/ICT infrastructure which is interoperable with the components under test. The SCADA deployed should be able to support both central as well as distributed control.
5. Co-simulation of the communication system and electrical power system for testing the dependability and stability
6. Validate the functionality of implemented controller algorithms in a controller-hardware-in-the-loop setup, that is, the optimization algorithms for reconfiguration should be tested.

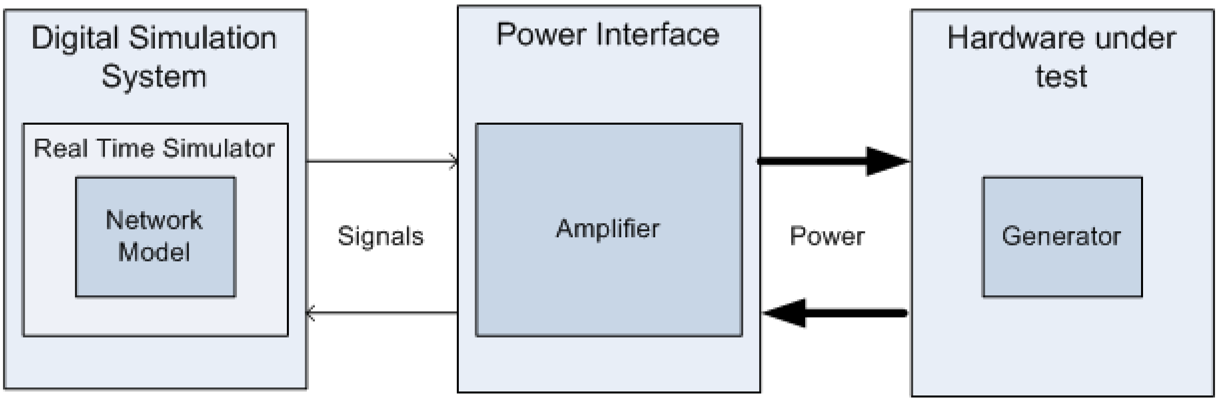


Fig. 1. Simplified representation for conducting Hardware-in-the-loop tests

[2] Standard for power quality (IEC/EN50160) is specified up to the 40th harmonics which is equal to 2kHz

4 Test Facilities and WP3 functionalities (Monitoring)

4.1 WP3 scope

ICT solutions supporting Monitoring in future Smart Grids with high amounts of Distributed Energy Resources (DER) and Renewable Energy Sources (RES), are going to enable increased Energy Efficiency and support user empowerments.

Monitoring of electric and energy efficiency parameters (as, for instance, set-points at the nodes and environment parameters) is an essential task, transversal to all functionalities taken into account within the different SEESGEN-ICT WPs.

Through WP3, the monitoring task is addressed to the Service Level Agreements (SLAs) which rule the commercial relationships between the stakeholders in the service oriented market.

More specifically WP3 focuses on SLAs that can allow flexible grouping of stakeholders and empowerment of users. SLA introduces the need for monitoring of specific quantities, and thus, determines the requirements of ICT technologies, which are necessary for fulfilling the needs.

In order to outline the necessary requirements for Monitoring, in WP3 different Business Cases are selected, related to the scopes of the other WPs of SEESGEN-ICT. These BCs are focused on three regions:

- Network Management (for example, SmartGrid reconfiguration, Energy management and Adaptive protection)
- Demand Side Integration (for example, Support for active user profiling and selling or buying DER)
- CO2 emissions (for example, Supporting incentives for increasing Energy Efficiency)

In the above cases, the concept of **Service Level Management** (SLM) provides the examples for the implementation of the ICT information based monitoring systems. The SLM comprises two essential components:

- **Service Level Agreements** (SLAs), which define the expected service, as agreed upon among the relevant stakeholders, and the conditions for the assessment of the service itself.
- **Sub-contractors agreements,** which are commitments made by external vendors and suppliers that provide components or support services that are relied upon in meeting SLAs, for example guaranteeing uptime for frame relay connections**.**

Based on the above, it is essential for the future grid to be equipped with ICT infrastructures which will support the monitoring of services, to check and validate the quality and quantity of the service agreed in the SLA..

4.2 Requirements to be checked

While emphasizing that the test facilities will not be used to evaluate the performance of SLAs but, rather, attributes of ICT infrastructures which are going to be used in order to support SLAs monitoring, from the technical point of view, we can state that current SCADA or similar Process

Control Systems (PCS) are inefficient for serving monitoring due to their communication restrictions. It's worth reminding, in fact, that communication networks of today's SCADA systems are mostly closed while the advance to SmartGrids (for example SmartGrid architectures like Virtual Power Plants) requires their opening which will provide the system with flexibility..

In details, the implementation of SLAs and the monitoring of them requires a three level infrastructure, which is:

- SCADA or PCS to acquire and control signals from the grid;
- improved network communication (internet);
- use of Business Management Systems to evaluate the service.

It is evident that the transition to this new perspective and especially to the part referring to communication poses a number of challenges and risks which should be checked.

The most critical aspects that the tests should cover through selected test facilities are listed herein after:

- equipment performance
- data handling
- security
- reliability
- interoperability
- scalability of the new integrated ICT systems.

As, of course, SLAs need to be taken into account into the test environment (either as software simulators or as test scenarios), the following attributes

- Service Level Objectives: defined as ranges or functions (allow flexibility and changes)
- Guarantee Terms: defined as ranges or as functions (non-conformities to the Service Level Objective)
- Key Performance Indicators (KPIs). Metrics for quality and/or quantity
- Certificates for Providers and Consumers (conditions for issuing)
- Privacy criteria implementation

should be tested.

Monitoring can be organized into three different categories related to the time of events. Thus we have:

- Predictive monitoring which is based on current measurements and time series of historical data of monitored quantities. Through this type of monitoring, the operator is able to anticipate critical situations and take actions before they happen.
- Live monitoring which acts in real time based on live measurements and direct information of the operator.
- Post monitoring which is also named as audit/trial which refers to non critical situations. In this case daily/weekly/monthly logs are checked for faults/quality metrics and recalculating of the quality factors.

The monitoring of an SLA can be done either by using one of the above methods or by combining them. Anyhow, the three methods should be subject of testing and evaluation.

For instance, concerning the attributes associated to the KPI, a crucial quantity which is proposed for assessing SLAs within the frame of WP3 is the Quality of Compliance (QoC). This value is an index of the Quality of Service and can be measured as follows: each specific SLA can be considered as a vector of quantities (metrics): SLA={m1, ...,mk}. Since in the frame of an SLA these metrics should be satisfied, monitoring of the specific metric and comparison with the agreed value allows the evaluation of QoC.

The nature of metrics is related to the selected SLA: this means that specific SLA define specific requirements for monitoring. As an example, in the business model of power re-profiling when called upon, main attributes are the demand reduction in MW as well as time intervals like maximum duration of a single demand reduction, maximum total duration of reductions within a year or a day etc. In this case the QoC can be evaluated by measuring the electric power as a time function through the consumers kWh meters or by monitoring the total grid power. In a second example of business model which regards selling indoor climate, comfort and functionality to the consumer/customer, the aggregator or ESCo should verify the service by monitoring indoor climate conditions of the customers.

And last, it should be pointed out that the evaluation of SCADA or Process Control Systems per se should be considered out the scope of the test facilities requirements and the focus will be only on the network and business management systems.

4.3 Test Facilities features

Verification and evaluation of the SLA requirements needs a test facility able to cover a large number of monitoring attributes.

It should be noted that testing of a monitoring process could be carried out either by evaluating the monitoring system with all its components or evaluating each component separately by using assumptions.

In the first case it is obvious that the ideal test facility would use parts of the Distribution Network (Test Range) including participation of different stakeholders like DSOs, Aggregators, Retailers, active users etc. This configuration would support the verification of SLA monitoring in an optimum way, however in general it is not feasible, especially if the technology is not well consolidated.

This is why there is the need of test facilities which will provide test convenience and, at the same time, approach as well as possible the different stakeholders of the distribution network. On the other hand, the use of simulators make it possible to work with different SLA scenarios.

For example, the scenario of an SLA between provider and consumers for re-profiling requires the production of different consumption profiles which will cover wide range of actions within the SLA.

Similarly, the role and the behaviour of stakeholders can be simulated either based on data bases or on models.

In addition to this, a number of measurements related to the specific test should be taken into account. Hence, electrical and non-electrical quantities at different points of the test facility should be measured, such as:

- Instantaneous active power
- Reactive power

- Voltage
- Frequency
- Thermal loads

In the following diagram a general overview of the test facilities requirements for SLA monitoring is illustrated.

As it is shown in this diagram, a test facility should include the electrical power domain (which consists of different electricity network actors/player), being able to include or simulate DSOs, Customers (including consumers and producers), intermediate companies like Aggregators or ESCos, and a model for Metering Service Company.

This would allow a large number of possible combinations, without excluding however the possibility of test facilities with less components suitable for tests under limited SLA scenarios. The different components of this domain can be either real parts of the distribution grid or simulated ones. Also, combination of them could be used (i.e. real consumers or DSO with simulation of aggregator). The roles and the interaction between the players are defined through SLAs.

For each test needs, different SLA scenarios could be implemented so as to reveal the performance of the used ICT infrastructure. The latter is included in the second domain of fig. 2 and is the main target of tests. Again in this case simulators could be used for some components while others as i.e. internet communication could be real ones. The selection of the proper combination should be done according the needs of each test and attributes that are evaluated each time.

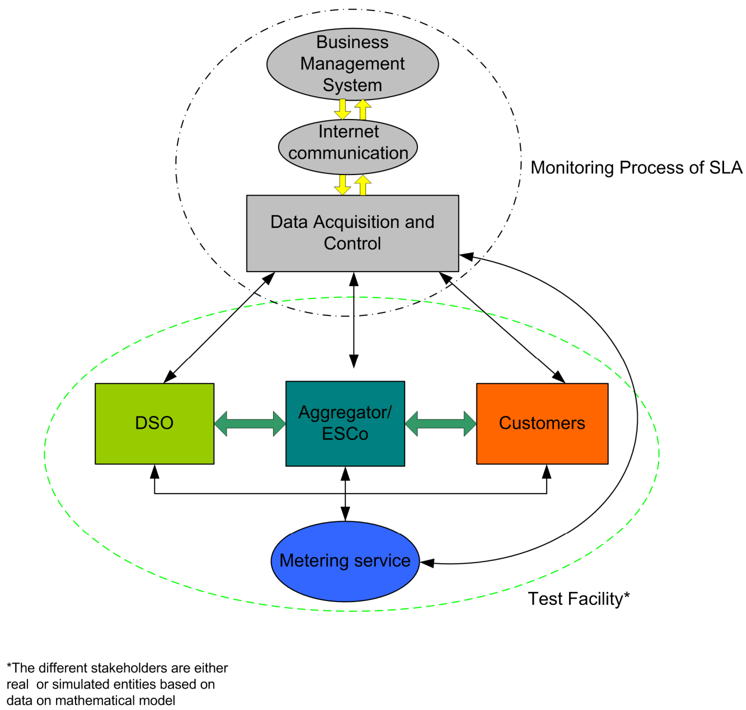


Fig. 2 Simplified representation of test facilities configuration for verifying monitoring processes of SLAs

It is important to mention that each part of the monitoring process could be evaluated separately, so that the facility hardware requirements can be minimized. This option presumes the emulation of the parts that are not included in the test procedure.

5 Test Facilities and WP4 functionalities (Demand Side Integration)

5.1 WP4 scope

Demand Side Integration integrates demand flexibility and controllability of active users into the power system.

It may act on the users by modifying their consumption behaviour (loads) and/or by managing their generation and storage capacity, e.g. to provide ancillary services to the network or to address local demand issues.

To this extent, ICT must ensure the effective interconnection of the DSI management to the end-user from one side and to the network from the other side, taken into account the technical and non-technical requirements of both the stakeholders.

DSI can be managed by aggregators that act in the market or directly by the network operator (DSO).

DSI is actuated through a bi-directional flux of information (price, load schedule, specific requests) or directly by a direct control by the DSI manager on the user actor (e.g. load curtailment).

The user may, in some cases, activate autonomously a DSI action, based on preventive agreements with the DSI manager or on local measurements of the network states.

5.2 Requirements to be checked

Considering the possible ways of implementation of DSI, the following ICT-related aspects have to be mainly considered:

- Interconnection of the stakeholders, i.e. the bi-directional flux of information connecting network operator, aggregator (when existing) and end-users. This includes activation signals, information on the electrical status of the network, planning of loads and generation.
- Interaction of the DSI management with active user energy resources: generators, storage devices and loads
- Direct load control by the network operator (or by the aggregator)

Normally the activation of the DSI is actuated as a reaction of the users to signals from the network operator (or the aggregator) on the dynamic variation of the tariffs, or to specific requests of load shaping, generation of electric power (active or reactive) as for ancillary services.

In special cases, DSI can be autonomously activated by the user, when specific conditions (e.g. local oscillations of voltage and frequency) occur. Normally this kind of activation is automatically managed based on local monitoring of electric parameters.

Implementation of DSI must take into due consideration the boundary constraints tied to the connection to the network (this aspects of voltage and frequency control have been considered into WP2)

A further ICT-related aspect to be managed with the DSI implementation is the exchange of administrative data (e.g. as necessary for billing purposes), due to the privacy and security implications.

5.3 Test Facilities features

Test Facilities features should comply with the testing and validation needs associate with the ICT related functionalities associated with the DSI implementation and listed in the previous section. When the DSI activation comes from external signals, the inputs received by the DSI management can be:

- Electrical state inputs: they can be representative of a variation of the grid electrical state (e.g. exceeding tolerance on voltage) or can come from load control devices. In a facility they may be produced by hardware devices or simulated by a software application. The electrical situation must take into account the grid, the generators, the storage systems, but also the loads. These electrical inputs can be punctual, but also a trend in a defined time slot.
- Other inputs: these may be messages related to tariffs or formal requests, using specific protocols and different media relevant to load shaping or other ancillary services. The most delicate aspect is the possibility of the Test Facility to provide the requested protocols and media, although the focus is on the flow of information, with defined contents and throughput.

The information flux related to a Demand Side Management algorithm is schematically depicted in the following figure.

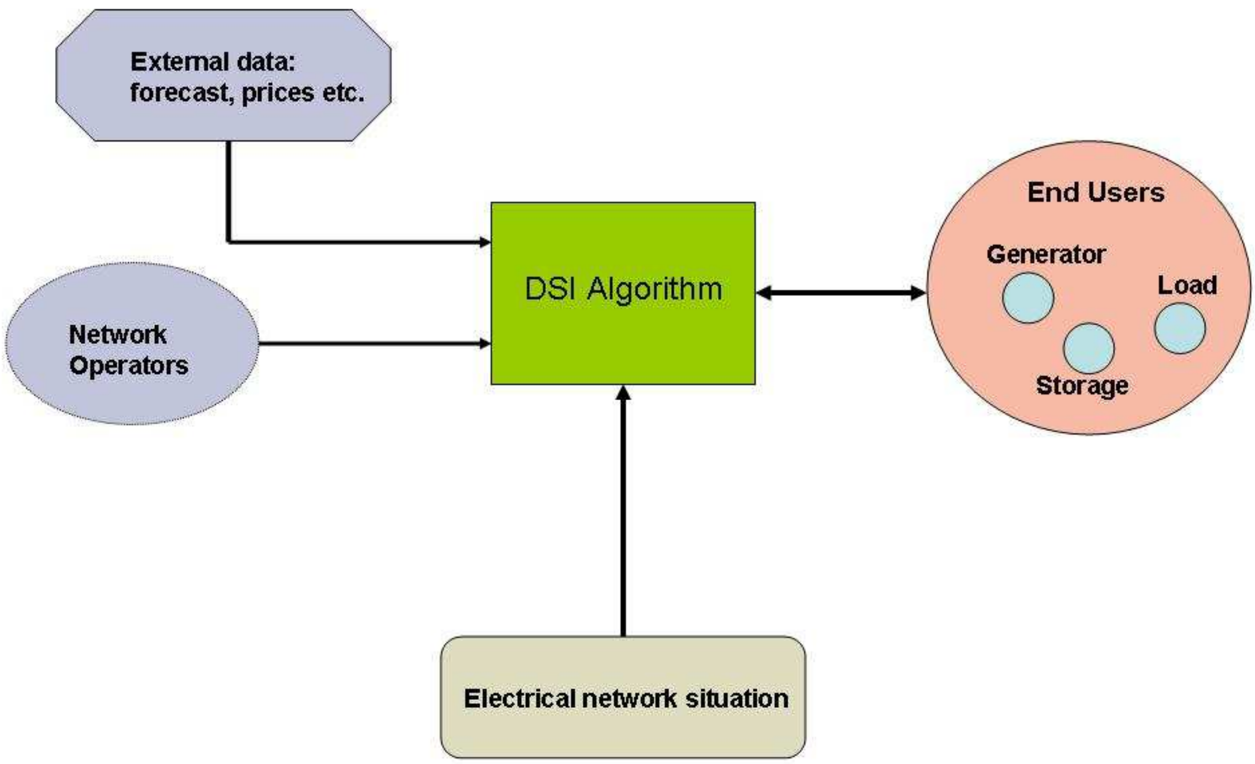


Fig. 3 Interactions with Generators, Storage devices and Loads

The Demand Side Integration Algorithm has to take into account the interface with the other aspects related to the Grid management (see chapter 3) and receive measures and signals from the active user resources (Generator, Storage device, Load) and send commands and set points to these elements.

It is in general necessary also to take into account the “boundary” general conditions, as for example:

- the weather evolution, that influences generation (photovoltaic and wind electrical generation; electrical and thermal generation of co-generators) and loads (electrical and thermal);
- the energy price evolution, for example the trend of an energy market.

These boundary conditions may come from simulations based on historical baselines, or defined by special algorithms, or both. When implementing these simulators, particular problems may arise in consideration of the possible response of the end user:

- if the response to be simulated is automatically produced (for example, following system signal indicating no more power available), it is only necessary to supply the related signals;
- if the response is a choice of the user (for example, when the energy tariff rises), it is difficult to identify a model of this response, because of its arbitrariness and not deterministic aspects; in this case, statistic approaches have to be used, based on analysis of survey results and of historical situation, or based on probabilistic algorithms.

Also for the verification of the interconnection problems, some aspects can be simulated (e.g. the behaviour of the end users distinct from one under test) In some cases tests should be referred to real situations (e.g. when evaluating the effect of latency of the response of some devices).

Aspects related to constraints of generators, storage devices and loads control have to be considered. These constraints can be intrinsic to the energy source (e.g. time necessary for accumulation of energy in storage devices) or imposed by DSI strategies (e.g. a fixed shut down procedure of a generator, or a curtailment of a load smoothed by a local UPS).

The facility should be equipped with ICT cabling and network instruments enabling the use of different protocols (e.g. at high speed). It could be more important to focus on a variety of digital cabling rather than to install all possible communication devices (which is obviously unpractical).

When considering the possibility of autonomous activation of the DSI (see previous session), the action is dependent on the interaction between individual devices and the status of the entire power system. The ability to receive a power system status from local measurements of from signals and to act correctly according to this will be important for new equipment. This feature must be tested in a laboratory. A real time simulator can be necessary for such a validation (e.g. special waveform generators, such as three phase amplifiers, real time digital power system simulator, to create realistic transient state voltage signals).

Appropriate simulators of security conditions and privacy preservation related to the administrative data exchange should be available.

6 Test Facilities and WP5 functionalities (Business Model)

6.1 WP5 scope

SEESGEN-ICT Work Package 5 (WP5) aims at exploring requirements and barriers to the deployment of business models needed to support implementation of energy efficiency services and DER in a competitive market, as well as analysing what kind of ICT solutions and methods are already available to support these business models and what kind of research/developments are still required.

Business model is generically intended as a framework for the management of the commercial relationships among market entities for creating value to the whole chain of the electricity market. In SEESGEN-ICT it is intended as a logic of creating value (such as profits to the company, tax income, benefits to consumers, power quality and improved environment), including description of the stakeholders and of their roles and the most important transactions.

The business models targeted by SEESGEN activities are those which concern the *aggregator* of demand response (DR), distributed generation (DG) and distributed energy storages (DS), which go under the name of distributed energy resources (DER).

The aggregator is considered the best support for the implementation of energy efficiency and the proliferation of DER. An aggregator is a company who acts as intermediary between electricity end-users, who provide distributed energy resources, and those power system participants who wish to exploit these services. In other words, an aggregator is a deregulated power system participant, with the main role of bringing DER on markets for the use of the other players, while providing market access to DER and added value to the electrical system.

The WP5 activity includes a focused survey of business models from a few selected research projects. Existing examples of these business models, if available, have been considered as well as the applicability of these business models in different national situations.

6.2 Requirements to be checked

The two aspects of the requirements to be verified are:

- Overall results performances
- Interconnection and communication

The main focus of the test is related to the overall results that the aggregator can obtain, in different situations.

Starting from a series of defined scenarios in term of energy requested, electric market situation, grid and user configuration, the test facility must allow to assess the performances of an aggregator in terms of absorbed energy and from the economic point of view (having in mind the objectives of the Energy Efficiency and the added value to the electric system that the aggregator has to demonstrate).

It is important to check different hypothesis about User responses (propensity to consume and tariff influence) and User situation (a “traditional” user, a user with local generation, e.g. photovoltaic or micro CHP, a user with o without detachable loads etc.).

Results should be evaluated on grids with different configurations and extension; presetting a

situation with particular elements (for example, storage devices) directly controlled by the Network Operator can be useful in some tests.
The time horizon has to defined for each test: the results have to be analysed in different horizons, according to the aggregator functionality to be tested.

The other item is mainly related to the interaction capability of the aggregator in order to communicate with the End User. This aspect can be critical, because of the particular components, hardware and software, that the Aggregator has to use, for example, to pilot some of the user loads. In order to verify the overall functionality of the aggregator, it is important to check that communication has the right contents and is compliant to the time constraints, in all the predictable situations.

The other possible communication interfaces (see the figure in section 6.3) are less critical, using more common connections and protocols (in most cases, LAN o WAN connections), with time constraints less pressing.

The aspects related to the interconnections and communication are typical also for Demand Side Management, the topics to be focused and tested are the same; then, for the details regarding these elements it is possible to refer to chapter 5.

6.3 Test Facilities features

The Aggregator has two main interfaces:

- with the users providing the services
- with the network operators using the services supplied.

Furthermore, the Aggregator has to take into account the forecasted trend about energy requests, atmospheric weather (for example, temperature can influence the needs of heating or cooling and the electrical production of Combined Heat and Power (CHP) generators; the incoming solar radiation or the wind speed and direction are the inputs for photovoltaic and wind generators) and the prices coming from the energy market (see the following figure).
The Network Operator can exchange information directly with the End User, for example to signal failure situations and sudden power reductions, or to communicate tariff modifications.
The situation of the electrical grid (measures and signals) is acquired by the Network Operator, who is able to send commands and set points to the electrical grid; some pieces of information can go also to the End User. A direct channel from the Network Operator to the End User is also possible.
The Test Facility has to provide all these interfaces, via physical equipments or data and signals provided by simulators.

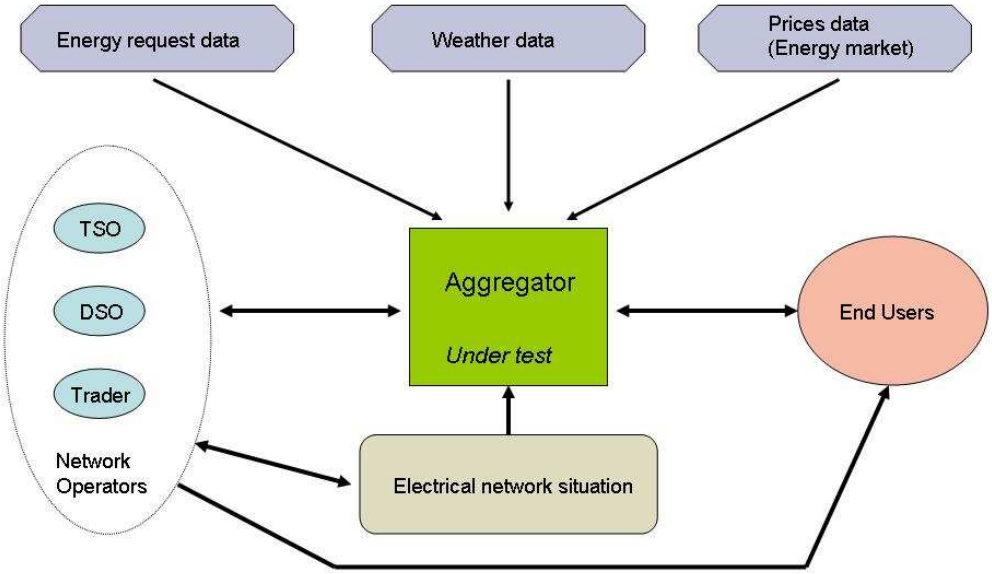


Fig. 4 Simplified representation of test facilities configuration for assessing Aggregator performances

Obviously, not all these interfaces are necessary for all kind of aggregators and for all functionalities that have to be tested; several tests can use only a subset of this overall situation.

For the detail about the interface with the End User, see chapter 5.

The specific test needed for the aggregator are mainly related to the verification of the algorithm. The Test Facility must be provide an appropriate set of sequence of input data, referring to a time interval adequate to represent a significant situation. The best solution is to use real data recorded in the past; it is necessary to have registration of the electrical data, of the prices, of the loads absorption, but also of the related forecasts.
The choice of the appropriate set of input data is tied to the objective of the algorithm under test: for example, if the aggregator aims at shaving the peak, it is necessary to refer to a situation critical to the absorption peak.
Some of the input data sequences are not affected by the decisions taken by the algorithm under test, for example the weather forecast and the weather real trend, but other elements are influenced by these decisions, for example the electrical situation; in this case, the Test Facility must provide the right responses to the requests coming from the Aggregator, using a real or a simulated environment.

7 Test Facilities and WP6 functionalities (Environment Protection)

7.1 WP6 scope

Work Package 6 considers how ICT can be used for Environment protection, focusing on two topics:

- on one hand, the ICT sector itself accounts at present for 2% of global emissions and, being this figure rapidly growing, ICT is therefore urged to reduce the amount of energy used and the related carbon footprint;
- on the other hand, ICT can play an important role in raising awareness by making energy consumptions and GHG emissions visible, as well as being an important component both of the GHG emission monitoring and computation systems, and of the platform for the GHG emission certificate trading.

About carbon footprint of the ICT sector, the working group recognizes that the trend is to deliver more and more computing capacity at lower and lower equipment cost, and we are now at the point where the cost of electricity to run and cool computer systems exceeds the cost of the initial purchase. On the other hand, during the past years increasing demand for computer resources has led to significant growth in the number of data centre servers, along with an estimated doubling in the energy used by these servers and the power and cooling infrastructure that supports them. Besides, data centres operate continuously, which means their electricity demand contributes to peak utility-system demand. Therefore the working group decided to focus on energy efficiency of data centres while analysing how ICT could reduce its own carbon footprint.

About the ICT role in contributing to the EU energy–climate changes package, as the main instruments recommended by the European Union until now are taxes and fees, targeted subsidies, tradable emission certificates, etc, it is critical to ensure that proper CO2 meters exist, and therefore the working group focused on it.

7.2 Requirements to be checked

Data centres use a significant amount of energy to supply three key components: IT equipment, cooling, and power delivery (such as UPS, switch gear, generators, PDUs, batteries, and distribution losses external to the IT equipment).

Therefore, the essential requirements are:

- checking power efficiency of the IT equipment in the most common or specific configuration
- checking cooling efficiency in the most common or specific configuration

More in details, about the IT equipment efficiency, there have been a shift in philosophy in the last years and today is more and more accepted that it is not a good business to not use excess power at times when maximum compute power is not required while it can be satisfactory to not have the maximum compute power be instantly available, as long as the quality of service delivered meets a predetermined standard.

The new motto is then “satisfactory performance at lower energy cost” instead of “always the best performance possible".

Of course, the above assumption implies being able to identify the satisfactory performance, which could be an additional task for the testing team.

In spite of the difficulty of establishing comprehensive metrics for data centres efficiency, today the more accepted are *Power Usage Effectiveness (PUE)* and its reciprocal, *Data centres infrastructure efficiency (DCiE)* metrics,

The PUE is defined as

PUE = Total Facility Power/IT Equipment Power (1)

and its reciprocal, the DCiE is defined as

DCiE = 1/PUE = (IT Equipment Power/Total Facility Power) x 100% (2)

For equations (1) and (2), the Total Facility Power is defined as the power measured at the utility meter — the power dedicated solely to the data centres.

Energy efficiency of <u>cooling systems</u> has caught the attention of many groups and is now included in most of the best practices. A test facility could validate existing results and contribute to find new and more efficient solutions. However, the final assessment has to be done in loco as the real performance is strongly dependent on a number of geographical parameters such as altitude and latitude (which influence pressure, temperature, wind etc). This is why a test facility could try to replicate different situations, but the final acceptance and assessment relies on the single data center and therefore requirements are not included in this report.

Different configurations have to be assessed in order to provide general purpose guidelines or checking/contributing to best practises for specific applications, while specific data centres applications, which are worth being considered for a more detailed analysis, are not in the scope of SEESGEN-ICT general overview.

About the **GHG emission monitoring**, the issue of provision of environmental information is not an easy aspect to manage as certain concerns in different levels such as:

- how to measure the CO2 emissions
- how to communicate the info
- whether there is a capability of one way or two way communication
- the need to assess the different stages that affect the environmental impact, that is to say whether to take into account grid losses or not
- how to update the info provided according to the changes in the energy production mix for more accurate estimations
- whether the emissions factors should be included in the metering systems or sent to them from the TSO
- should the device for CO2 emission calculation be used by a company participating in the Emissions Trading or not
- security in data transmission

- the urge to safeguard the Internal Market and international trade

must be taken into account.

The estimations on the carbon footprint, for converting the electrical consumption to its carbon dioxide equivalent is based most of times on a grid average (mean factor of kg CO_2/kwh) and this is a common practice for the majority of metering systems. However, when using a factor to estimate emissions in line with Climate Change Agreements (CCAs), then the marginal, lower figure should be used based on marginal emissions (which are usually those from high efficiency Combined Cycle Gas Turbines - CCGT). This figure may also be the more appropriate factor when estimating peak energy savings. All figures exclude the incremental emissions due to other GHGs such as CH_4 and N_2O.
The more upgraded calculations within the metering systems use the electricity generation mix of coal, nuclear, gas turbines etc. In this case the factor that is included is calculated as follows:

[kWh*∑(%power_production_of_unit*factor_of_type_of_power_unit(CO2kg/kWh)]

More accurate calculations have to take also into account grid losses in the transmission system.

Since several mathematical models have been developed and used for the estimation of CO_2 emissions in the power sector, it is essential a benchmark to be assigned so as the estimations provided by the different commercial meters to be fairly comparable.
On this subject, it is worth reminding that – regarding the CO_2 measuring in the residential and commercial sector – a number of applications are currently available in the market, and more specifically metering equipment for electricity consumption that also indicates CO_2 emissions because of the consumption (i.e. ecometer, kW series Power Meter, EMON D-MON Green meter etc). Companies in Europe and worldwide include CO_2 data in their metering systems realizing that DSM strategies can become more effective by informing end-users about environmental impact. Most of these meters are certified against a wireless standard (e.g ZigBee) so as to be able to connect and exchange data with different devices no matter where these devices are used (e.g electricity meter, gas meter etc).

Besides the communication with the energy carrier meters, the CO_2 devices could either update the emission factors info provided (most probably by the TSO) according to the per hour changes in the energy production mix or retain some fix average values and use them for the CO_2 estimation.

Should the device be used by a company participating in the Emissions Trading Scheme, the calculations have to be accurate, depicting if possible the hour change of the total system emissions factor, because of the change in the generation mix.

In the event of using CO_2 emissions information in metering systems to mobilize end users for DR techniques, the accuracy wouldn't affect the end user to the same extent.

In any case common and standard ways of depicting the CO_2 emissions should be followed since many differences are observed in the metering equipment available.

It is clear from all the above that what is required concerning the GHG emission monitoring and computation systems is a benchmark able to:

- check and validate CO_2 emission estimations

- check the interoperability of the meter, that is to say its capability to communicate successfully with different devices like other meters or servers
- check emission factor info provided and the correctness of the data
- test security and safety in data transmission.

In all cases, it is important the security in data transmission to be ensured. All the stakeholders participating in the energy market and CO2 emissions trade (TSO, Measurements Operator, ESCO´s, DSO, Retailers, e.t.c) should own a robust infrastructure and high qualified employees so as to manage successfully and in a secure way a vast amount of data. That is to say state-of-the-art hardware, huge storage capacities and enhanced antivirus, anti-spam software that could assure reliability and security in data transmission.

7.3 Test Facilities features

Having in mind equations (1) and (2) The following figure shows a basic schema of a benchmark for assessing IT equipment performances, in which we can distinguish:

- the System Under Test (SUT), which could be a PC but also any programmable hardware
- a Controller, to change and monitor the workload of the system
- a power measurement device
- environmental sensors, to monitor the working conditions.

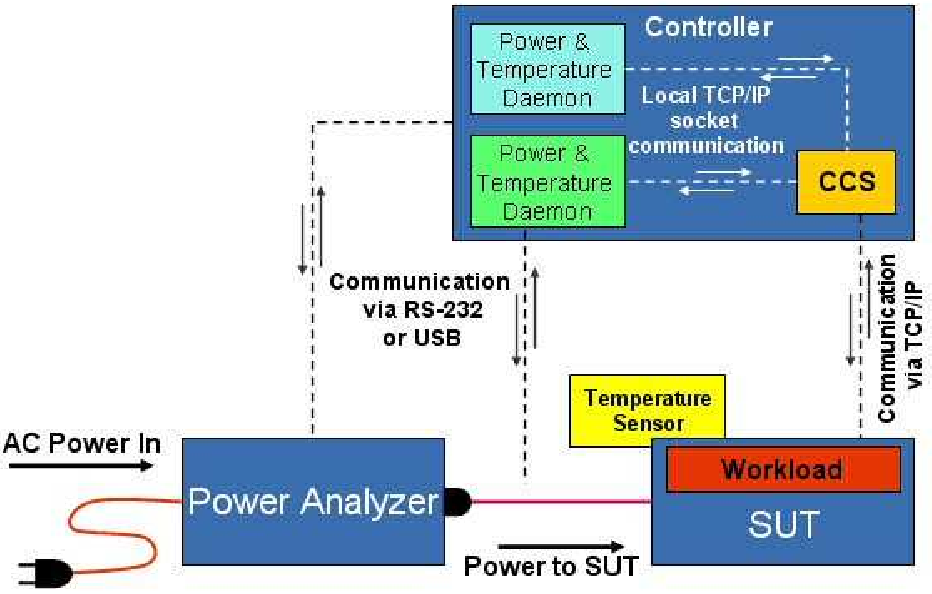


Fig. 5 Simplified representation of test facilities configuration for assessing power efficiency of IT equipment

In order to identify the “satisfactory performance at lower energy cost”, relevant information to the customer will be provided if the controller will be able to vary the load level as power consumption will likely vary at differing load levels. Simulation of real users, dump of real traffic or use of a pilot site would be a plus.

About a Test Facility able to provide a reliable control of a CO2 emission meter, requirements are

- a robust PC System and
- software for the CO2 emissions estimation.

The most critical aspect is of course the software, which should be based on a reliable and widely accepted mathematical model as it is well known that the current meters use different approaches for the CO2 emission estimations. Which approach is used by each meter is mainly depended on the final user of the meter.

It is also vital the software to include and use an extended database of the emission factors of the different power production units. In this way, it will be possible to obtain trustworthy estimation of the CO2 emissions for any energy production mix. The more accurate and complete the database the more reliable results will be achieved.

Just like all the other smart metering devices, CO2 emission meters must bear interoperability. A CO2 emission meter should be capable to communicate with several other devices such as electricity consumption meters or servers located for instance on the TSO premises. The capability of a CO2 emission meter to communicate with different devices could be tested by using specific software tools for each of the communication protocols. In that case, a Test Facility should possess the “testing” software tool for each of the communication protocols that a CO2 emission meter is required to support.

8 Test Facilities Classification

Although the different WPs handled with very different aspects in the Smart Grid domain, the analysis highlighted that there are 3 type of facilities which, ideally equipped, could carry out any verification, validation or assessment of any existing and new ICT-based solutions intended for deploying Energy Efficiency in Smart Grids. They are

- Simulation Environment
- Test Range
- Performance Benchmark

and will be described in the following sections. Requirements are marked with an ID in order to allow a mapping of test facilities capabilities against this list.

Referenced requirements can be discussed with the stakeholders and modified or detailed, whenever needed, by contacting the authors of this document.

These Test Facilities could serve for

- verifying that the solution and its associated data is acceptable for use for a specific purpose;
- determining the degree to which the solution provides an accurate representation of the real world from the perspective of its intended uses;
- verifying that the implemented solution accurately represents the conceptual description and specifications;

although the last item is not in the scope of the SEESGEN-ICT analysis.

Please note that the different Test Facilities descriptions took into account the state-of-the-art and the best practises in the related domains, whenever available.

Differences in their details are a direct consequence of the maturity of the state-of-the-art.

8.1 Simulation environment

The simulation environment is claimed as needed in most of the analysis done on the applications highlighted by the different WPs, as it is the first step of the concept validation and solution robustness.

It’s worth noting that, as different applications focus on different layers of the (quite complex) electrical system, the ideal Test Facility includes the simulation/emulation of all of them. The added value of this approach is that it is possible to assess the impact of the solution also on the other layers which may not have been taken into account during their design, implementation or test.

The figure below represents a basic simulation environment capable of fulfilling the validation requirements of the typical application in all the analysed themes.

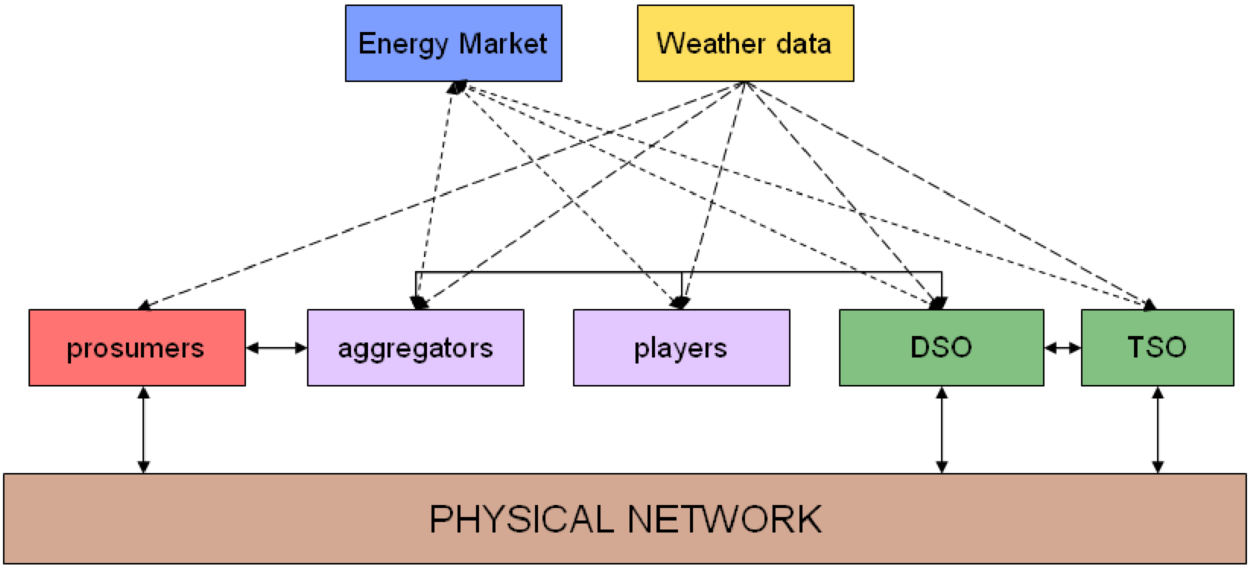


Fig. 5 Simplified representation of a simulation environment for assessing ICT solutions for Energy Efficiency in smart grids

The layers are

- the physical network, which of course is simulated or emulated
- the players: prosumers, aggregators, retailers, DSO and TSO
- the external world: energy market and weather data

About the physical network, it should be at minimum simulated *(SE_1)*, and could include some emulated part with real time power system simulators *(SE_2)*, which is mandatory whenever the application requires electromagnetic transient in real time, closed-loop testing of control equipment or for any hardware-in-the-loop application.

The simulation environment must allow the topology of the physical network *(SE_3)*, in order to be able to represent different European grids, grids on different areas and different topologies.

In order to provide trustworthy results, the simulation environment must interface commercial power simulators or proprietary simulators properly validated by comparison with the output of the most widely employed commercial power simulators *(SE_4)*. The employed simulator must be disclosed.

Interface with the simulated physical layer must include the possibility of changing the load and the status of the generators *(SE_5)*.

About the prosumers, they have a direct impact on the physical layer, in particular the load and the generation (for the DER part). They can be simulated either as single entities *(SE_6)* or as aggregated entities *(SE_7)*, depending on the granularity required by the application.

The simulated behaviour must be disclosed in order to allow the interpretation of the results. We suggest to distinguish normal behaviour from “business target and strategy” like bill reduction and to clearly state the statistical distribution of the different behaviours.

The metering service must be deployed *(SE_8)* whenever relevant.

Aggregators and different retailers in general are agents, whose business logic will likely be under test. The simulation environment must support their communication and deploy the different actors letting to easily plug and play the different algorithms supporting the business logic (examples could be profile clustering, optimisation algorithms, game algorithms, SLAs etc) *(SE_9)* .

DSO and TSO parts of the simulation environment will be equipped with the normal tools available in the control centres (SCADA for data acquisition and control *(SE_10)*, Energy Management Systems *(SE_11)* and State Estimator *(SE_12)* as Decision Support Systems, Business Management Systems *(SE_13)*) and shall provide a Human Machine Interface *(SE_14)* in order to allow real operators to assess the application on their own (User Acceptance Test) or to participate to training/exercise sessions.

Tools may be commercial ones or proprietary ones. In this first case it is recommended that the environment support same type of tools from different providers, while proprietary tools will be needed especially whenever the application under test requires modifications of the existing tools (for example if it is needed to migrate from the centralized to the decentralized control).

The communication infrastructure with the same characteristics (including supported protocols) of the planned/implemented one must be deployed *(SE_15).* Administrative data as for billing are mandatory too *(SE_16)*.

About the energy market module *(SE_17)*, it is mandatory for validating all the applications aimed at enabling the participation to the market of existing or new players. Data for the simulation should be realistic but also repeatable, so it is recommended to dump real data from the energy market in order to be able to compare performance of different solutions in the same situation and also to be able send those data with the same frequency as in the real world *(SE_18)*.

Please note that this aspect is quite challenging because in principle the energy market could be influenced by the activities of the different players. Therefore, the possibility to simulate the market starting from acceptable influence assumption could be investigated.

As the weather influences generation and loads, a weather module is needed too for a proper representation of the environment *(SE_19)*. As for the energy market module, data for the simulation should be realistic but also repeatable, so it is recommended to dump real data in order to be able to compare performance of different solutions in the same situation *(SE_20)*.

Although not included in the fig. 5 to make it more readable, a logging feature *(SE_21)* is mandatory to debug and assess performances/results. It should interface all the components, both at physical and at market layer *(SE_22)*. Apart from messages to be logged for checking proper behaviour *(SE_23)*, all the numerical values of the simulation should be stored in a suitable database for further metrics extraction *(SE_24)*.

8.2 Test Range

The Test Range is needed whenever it is required to verify all the phenomena, such as not due interactions, strictly related to real interconnections and not completely predictable or modelled.

Furthermore, after its validation in the simulation environment, it is wise to deploy a new solution on a real – but isolated! – environment before deploying it in the fully connected grid.

Besides this main role, the Test Range can be used to calibrate the Simulation Environment, by validating its performance and behaviour, and to refine the employed models.

On the other hand, as a Test Range – however large – is intrinsically limited, its use is likely to be complementary to the Simulation Environment and not exclusive.

The figure below represents the schema of a Test Range capable of fulfilling the validation requirements of the typical application in all the analysed themes.

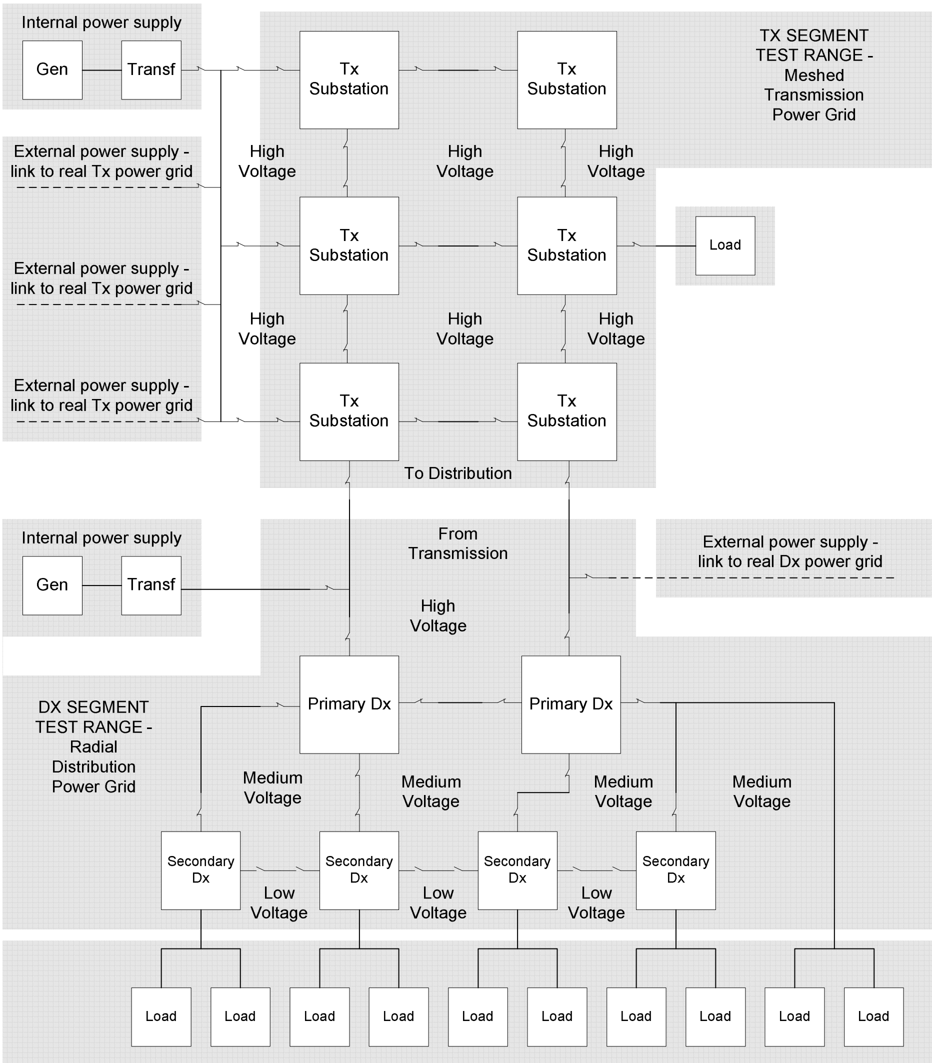


Fig. 6 Diagram of Electricity Transmission and Distribution Test Range

The Test Range is made by a real power grid *(TR_1)*.

A set of generators reproduces the power feed arriving from power plants *(TR_2)*. It would be useful if different types of generators (spanning from Photovoltaic to Wind to Diesel Generator, to rotating synchronous generators as three phase variable frequency AC voltage sources etc) and storage systems were deployed *(TR_3)* and could be connected depending on the wanted configuration *(TR_4)*. Generators' specifications should be fully disclosed.

One or more transmission substations, connected with a meshed grid, perform voltage transformation (both step up and step down) and regulation, providing electrical measurements and safe switchgear *(TR_5)*.

Beside a power load, which is connected to the grid in order to reproduce the energy consumers and is controllable, transmission network also feeds the distribution network *(TR_6)*. Transmission lines operate at high voltage *(TR_7)*, connecting substations with the generators, the load, and the distribution network or the other substations. They are provided with double switches *(TR_8)* that are normally closed. Thus, by using them, each substation, generator and load can be isolated from the remainder of the grid, as well as the distribution network itself can be isolated from the feed of transmission power grid.

As a result, the topology of power grid has the possibility of being fully configurable, according to the testing requirements. Electricity distribution is reproduced by the means of a radial power grid *(TR_9)*. Transmission lines provide power feed arriving from the transmission network *(TR_10)*, while external generators provide independent high voltage power supply *(TR_11)*.

One or more primary distribution substations receive the high voltage power supply and provide step down to medium voltage *(TR_12)*. Secondary distribution substations provide the step down to low voltage *(TR_13)*; each secondary substation feeds a number of controllable power loads *(TR_14)*. In addition, some power loads may be directly connected to a primary substation.

Like transmission network, each distribution line is provided with a double switch, connecting the elements in the grid. In the same way, each substation can be isolated from the remainder of the grid: under normal conditions, only primary substations are connected with each other, while connections between secondary substations are open (because the grid is radial). However, also in this case the presence of the switches allows the full configurability of the grid topology. As for the electrical lines, medium voltage lines operate at 20 kV *(TR_15)*, while low voltage lines operate at 400 V *(TR_16)*.

Referring to the typical values of the European networks, transmission substations should be located at a distance in the range between 10 km and 200 km from each other; primary distribution substations at a distance in the range between 5 km and 10 km from each other, and secondary distribution substations at a distance in the range between 5 km and 10 km from each other. Distribution loads are typically 1 km far from the secondary distribution substations.

However, it's worth noting that an electrical line with a given length preserves unchanged its electric propagation properties if it is replaced by a shorter line equipped with concentrated resistance and impedance, properly designed. Applying this solution leads to avoid, the high costs deriving from the installation and the maintenance of long haul transmission and distribution lines.

The Test Range must be provided with proper electrical measurement equipments and a SCADA, set up to collect and analyze the experimental data coming from the field *(TR_17)*. Data should be archived *(TR_18)*.

The communication system must include different technologies *(TR_19)*: LAN Ethernet, Wireless and Power Line.

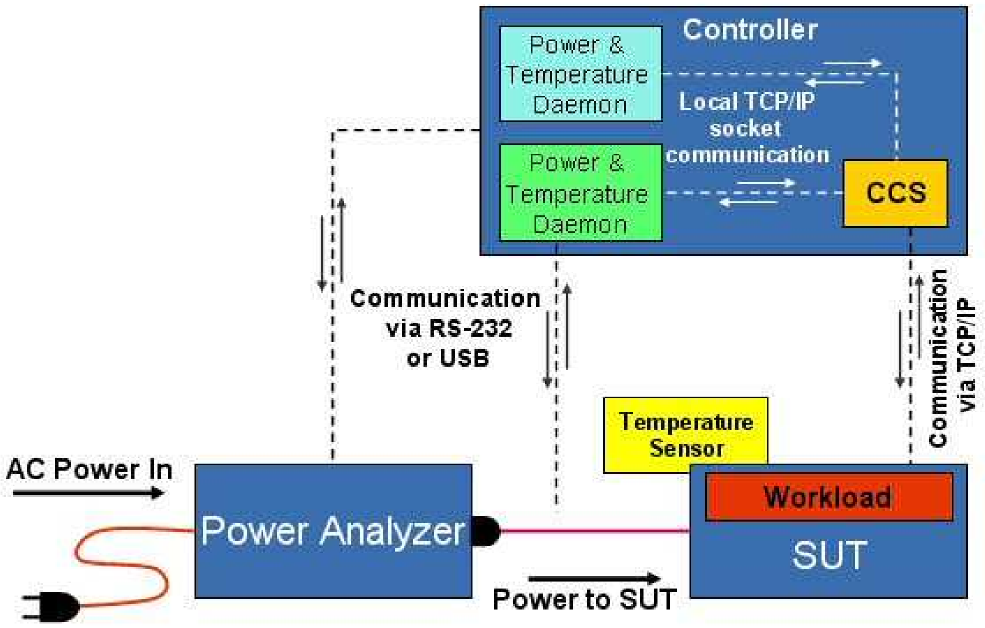
The Test Range must be under the control of a qualified staff and, if unsafe and unforeseen scenarios arise, appropriate safety procedures will be in place to minimize risks.

Operators of the electricity transmission and distribution infrastructure could attend to and interacts with Test Range experiments, too.

Last, it worth noting that a Test Range can be considered as an investment, as it can be used for experiments in different topics. In fact, the Test Range as described above is adapted from [8].

8.3 Performance Benchmark

The figure below represents a generic benchmark environment that is capable of driving and monitoring both performance and power components of the workload, as described in [7]:



We can distinguish:

- the System Under Test (SUT), which could be a PC but also any programmable hardware
- a Controller, to change and monitor the workload of the system
- a power measurement device
- environmental sensors, to monitor the working conditions

About the controller, performance benchmarks can be driven by a driver that is either internal to the system under test or external to it *(PB_1)*. Typically, unless the driver comprises such a small fraction of the workload that it doesn't affect the result, the best performance is achieved with an external driver. This allows the driver to regulate and monitor workload requests to the system under test.

The functions of the measurement server are:

1. Start and stop each segment (phase) of the performance benchmark *(PB_2)*
2. Control the workload demands for the performance benchmark *(PB_3)*
3. Start and stop collection of power data from the power meter so that power data and performance data from each phase can be correlated *(PB_4)*
4. Store log files containing benchmark performance information and benchmark power information *(PB_5)*
5. Include logic to convert the raw data to the format needed for reporting, submission and validation of the benchmark *(PB_6)*.
6. Collect and store environmental data, if automated for the benchmark. Optionally, there may also be some logging functions required within the SUT, such as resource utilization and potentially some throughput performance information *(PB_7)*.

It will often be possible to integrate these functions into the driver that is specifically designed for the performance benchmark. However, as environments become more complex, it may be desirable to split these functions, where the overall measurement control is maintained in a separate, flexible application. In this case, the performance measurement of each defined performance step is controlled via the defined driver, while the overall coordination between the various components is managed by the CCS (Control and Collect System).

The key item is the ability to drive the workload in a controlled manner at a rate that is less than the maximum (PB_8) as this will provide a benchmark that can deliver more relevant information to the customer and that will have greater flexibility for academic exercises, as well.

Since power consumption will likely vary at differing load levels, benchmarks should be enhanced to allow the drivers to request work at intermediate points between zero and the maximum throughput value (PB_9).

For a benchmark that has a measure based on throughput, the sequence of events is:

1. System is made ready for measurement.
2. Harness starts environmental measurements
3. If required, initiate calibration process to determine maximum throughput
4. Compute intermediate measurement targets
5. Iterate:
    a. Harness starts benchmark segment run at throughput interval X, where X begins at the highest target throughput and reduces each iteration until a zero-throughput point can be measured, to obtain an Active-Idle measurement
    b. Delay 30 seconds (or as needed for benchmark synchronization and steady state)
    c. Harness starts power measurements
    d. Harness or benchmark collects power and performance metrics.
    e. Harness ends collection of performance and power measurements
    f. Delay 30 seconds (or as needed for benchmark synchronization)
    g. Benchmark segment completes
    h. Harness delays at least 10 seconds (or as needed for synchronization)

6. Harness ends environmental measurements

7. Harness post-processes performance and power data

It is important to note that the intermediate points should be based on the maximum throughput value for the system under test, and not on any measured utilization. For example, if a 20% point is desired from a benchmark that can achieve 55,555 transactions per hour at 100% of system capacity, the benchmark should be run at 11,111 transactions per hour, even if the processor utilization shows 15%, or 35%. Not all hardware and software architectures quantify processor utilization in a way that is comparable at low utilization levels. This is particularly true when a power management feature is employed that actually slows the processor in lightly loaded situations. The only measure that can be viewed with confidence is the percent of maximum throughput.

While the selection of intermediate points can be an arbitrary decision made by the benchmark owners, the decision should include measurement levels that are representative of systems in the environment represented by the business model of the benchmark.

Idle and 100% capacity points should also be included *(PB_10)* – *100%* because it measures the limit of the system and usually the best performance/power ratio available; *idle* because many systems are left sitting idle on occasion (and often more frequently) or drop to a idle state in between periods of operation.

If a benchmark workload is driven by an external driver that simulates real users (that is to say, the benchmark harness not only controls the benchmark execution rules, but also simulates the individual workload transaction requests), chances are there are “key-think” delays that are already in the driver.

In this case, the intermediate points of the measurement curve can be driven in a two step process:

1. Compute the approximate key-think delay needed to run at the reduced transaction rate and measure the result.

2. If the result shows the throughput to be outside of a predefined tolerance level, adjust the key-think further and run again.

We should point out that this is inherently approximate.

A given “user” will request work from the system and receive a result after some response time. The “user” will then delay some period of time before requesting another transaction. In many benchmarks, the delay time between transaction requests is zero, in order to drive more throughput through the system under test. The response time is not constant, however, because it is comprised of the combination of execution time and queuing time. Queuing time can be very long when the system is heavily used and it can be very short if the system is lightly used.

The result is that a simple calculation of a delay between transaction requests will likely generate more throughput at the lower utilization levels than expected, because the response time component of the “transaction life cycle” will be much shorter.

A more accurate control is to work with total “transaction life cycle” for the work submitted in the benchmark, by controlling the timing of the beginning of each transaction request, rather than the delay time between transactions. This will automatically account for any variation in the response times due to queuing changes.

Including variability in performance workloads *(PB_11)* is important for two reasons.

First, a set of regular iterations of delay for all tasks in the system can lead to a harmonic "drum-beat" situation where the work is all-on, then all-off.

Second, extremely regular transaction flow is not representative of customer reality. When a system is operated at 10% of its compute capacity, it is almost certain that the workload demand will not be a steady 10%, but will be a highly variable sequence of load requests that happen to average 10%. This is important from an energy consumption perspective, because power management routines need to be designed to react to the variable workload requests on systems that are operating at low average fractions of capacity. To the extent possible, while maintaining measurement comparability, a variable load should be included in the driver mechanism – particularly for measurement segments that are targeted for less than 50% of capacity.

To avoid harmonic amplification and to provide a more realistic/random arrival rate for work requests, the cycle times for each task should vary in some way, such as using a negative exponential distribution. A negative exponential distribution is generally accepted by queuing theorists as being representative of the inter-arrival time of work requests. Values for the distribution can be computed "on the fly", but will be more controlled if a deck of specific values that match the distribution is shuffled randomly prior to the measurement run and then each transaction cycle is determined by pulling a single card from the deck.

For power measurements an external measurement device will be required *(PB_12)*, even if a SUT may have the capability to monitor power characteristics internally. In fact, a benchmark requires measurement methods that are certifiably consistent, which would likely exclude internal measures.

Moreover, any benchmark that requires measurement of power usage during the benchmark must specify the requirements of the power analyser used to collect the power-related information, as well *(PB_13)*.

The measurement control that starts and stops the performance measurement should also start and stop recording for the power meter *(PB_14)*. The power analyzer should have an interface to automatically upload the results *(PB_15)*.

Performance benchmarks are inherently variable, with run-to-run variations often being on the order of several percent. In that regard, it is not necessary for the power instrumentation to be extraordinarily precise. However, power analyzers that are used to provide benchmark information should satisfy a minimal set of criteria that will instill confidence in the measurement and provide for a level playing field for comparison of information.

Characteristics of the power analyzer should include *(PB_16)*:

- Measurements: True Power (W), volts, amps and power factor must be reported by the analyzer.
- Logging: the meter must store measurements to an external device, with a reading/reporting rate >= 1/sec and an averaging rate that is 1-2 times the reading interval.
- Control: Either the start and stop recording/logging functions of the meter must be able to be controlled from an outside program or the logging function must include sufficient timestamp information that data points which are outside of a measurement interval can be ignored
- Accuracy: measurements must be reported by the analyzer with an overall accuracy of 1% or better for the ranges measured during the benchmark run. Overall accuracy means the sum of all specified analyzer uncertainties. Note that the analyzer accuracy is dependent on range settings and on measured load
- Calibration: Must be able to calibrate the meter by a standard traceable to national

metrology institute in EU or USA. The meter must have been calibrated within the past year.

- Crest Factor: the meter must be capable of measuring an amperage spike of at least 3 times the maximum amperage measured during any 1-second-average sample of the benchmark test.

For each distinct measurement point, the following information should be reported:

- Average Voltage
- Average Current
- Average Power
- Average Power Factor
- Minimum Ambient Temperature
- Performance metric or sub-metric

In addition, the benchmark should require reporting of

- Power Line Frequency (50Hz or 60Hz or DC)
- Power Line Voltage (100V, 110V, 120V, 208V, 220V, other)
- Power Line Phase characteristics (single phase, two-phase, three-phase)
- Power Line source (wall, UPS, Regulator, etc.)
- Altitude of measurement laboratory and a statement if artificial air pressure was employed
- Power Analyzer(s) used, including model number(s) and date(s) of calibration
- Voltage and Amperage range-settings of the power analyzer(s)
- Temperature sensor used
- Any other data required to be reported for the performance measurements

About the Power Measurement/Reporting Requirements, for every distinct segment where power and/or performance is measured in a benchmark, the average power characteristics should be collected at least once per second *(PB_17)*. The average for all measurement points during the benchmark segment should be reported. In order to show variation of power characteristics during the benchmark segment, the individual measurements may also be reported.

Some environmental conditions can affect the power characteristics of computer equipment. These conditions may need to be controlled, and should be required to be reported as a part of the benchmark disclosure.

Temperature has a very substantial affect on power characteristics. In general, the lower the temperature of the air cooling the equipment, the lower the power needed to operate the equipment.

Benchmarks should be defined to restrict the minimum acceptable temperature to an appropriate level.

A minimum of 20 degrees Celsius (68 degrees Fahrenheit) is a good starting point, as ASHRAE recommendations for data center equipment are for 20-25 degrees Celsius. A higher minimum could be specified, such as 25 degrees Celsius (77 degrees Fahrenheit), although this could be problematic, as many data centers are maintained in the 22-23 degrees Celsius range.

It is typically not necessary to specify a maximum temperature threshold, as allowing the temperature to raise will only hurt the power measurement of a computer system.

Note that this discussion assumes “traditional” air-cooled equipment. For larger configurations, alternative cooling methods, such as liquid-cooled, liquid-assist and sealed air-flow systems can be much more power-efficient than cooling with ambient air. If the business model of the benchmark supports configurations of systems that use these cooling methods, some consideration to encourage them is advisable. For example, the minimum intake temperature requirement could be removed if advanced cooling methods are employed.

Care should be taken when comparing power ratings for air-cooled and water-cooled equipment, because the power characteristics of the air-conditioning equipment and the water cooling equipment are not included in this methodology and are quite probably different. At a minimum, full disclosure of the cooling methods should be required.

Temperature should be measured no more than 50mm (approximately 2 inches) upwind of the main inlet for airflow to the equipment being benchmarked. If there are multiple inlet locations, a survey of temperatures should be taken, and the inlet with the lowest ambient temperature should be used to monitor temperature.

To ensure comparability and repeatability of temperature measurements, the following attributes for the temperature measurement device should be required in the benchmark *(PB_18)*:

- Logging: The sensor should have an interface that allows its measurements to be read and recorded by the benchmark harness. The reading rate supported by the sensor should be at least 4 samples per minute.
- Accuracy: Measurements should be reported by the sensor with an overall accuracy of +/- 0.5 degrees Celsius or better for the ranges measured during the benchmark run.

Temperature should be measured on a regular basis throughout the measurement. The low temperature measured should be reported with the benchmark disclosure. The test sponsor should be required to include a statement that they did not do anything to intentionally alter the temperature for any equipment inlet during the run of the measurement and that they measured the temperature at the air inlet expected to have the lowest ambient temperature.

Measurements of performance and power will be most easily accomplished if the controlling application or tool used to initiate, control and record results for the performance benchmark can also exercise control and record results for the power monitoring and thermal monitoring devices. Many monitoring devices have command interfaces where actions can be controlled via the call of APIs. If devices that do not support API control interfaces are allowed to be used in the benchmark, then sufficient run requirements must be in place to ensure that the power metrics can be properly aligned with the performance metrics.

There can be significant differences between configurations for the SUT. For example, a discrete server may be designed to include up to 2 disk drives or up to 8; it may have room for 1 integrated ethernet port or it may have space for multiple I/O adapters; it may be designed to fit in a rack on a machine room floor or it may be designed to sit desk-side in a quiet office area. It will not be possible to create categories that delineate all of these areas, but sufficient information should be required to be disclosed so that readers of benchmark data can draw their own conclusions.

For SUT components that have an integrated battery, the battery should be fully charged at the end of each of the measurement intervals in the benchmark. It may be appropriate to limit the inclusion of systems that are designed to run on battery power for extended periods of time, as the technology in these systems relies heavily on battery power management and this could affect the validity of the result.

Since the power benchmark is designed to measure actual power required during the benchmark, a valid result should require that the system be measured while connected to an external power source and that proof is available that it is not relying on stored battery power while the measurement is in progress. Systems that have an option to drain the battery periodically and recharge it at a later time (a typical means of preserving battery life) should be required to have this feature disabled. If a system is configured with a battery that is intended to sustain it when AC power is not available, data should be required to demonstrate that the battery is fully charged at the end of each measurement period (e.g. screen shots or tabular battery charge data that includes time stamps).

Note that integrated batteries that are intended to maintain such things as durable cache in a storage controller can be assumed to remain fully charged. The above paragraphs are intended to address “system” batteries that can provide primary power for the SUT.

9 Conclusions

Although a wide range of very different applications have been analysed by the SEESGEN-ICT WPs – and as a consequence a wide range of requirements for the related Test Facilities have been extracted in Task 7.1 – it has been found that instead of setting up one or more Test Facilities or Laboratories for each domain (smart grid management, demand side integration, business models etc.) and sub-domain (voltage control, adaptive protection, reconfiguration, billing etc.), it is more efficient to have a more comprehensive vision with a limited numbers of Test Facilities which, ideally equipped, could carry out any verification, validation or assessment of any existing and new ICT-based solutions intended for deploying Energy Efficiency in Smart Grids.

Those facilities have been identified and described in this document, taking into account the state-of-the-art and the best practises in the related domains, whenever available.

The fact that just three types of test facilities fulfil all the identified requirements makes the authors quite confident that they are general purpose enough to be able to test applications and strategies at present yet unforeseen.

Furthermore, it is very likely that the very same facilities could serve for validation of other applications in other domains (for example security) of the Power Grid, which were outside the SEESGEN-ICT scope. Therefore, implementing those facilities can be seen as a good investment.

Of course, it is acceptable that not all the capabilities are implemented because of limited resources, and it is reasonable that facilities with complementary capabilities collaborate to offer the complete suite of tests, and SEESGEN-ICT WP7 aims at fostering this approach at EU level.

As identified requirements have been marked with an ID, a mapping of test facilities capabilities against this list is an easy task and highlights complementarities and opportunities for mutual accreditation.

Last but not least, in order to achieve the larger consensus on the identified list, stakeholders and audience of this document in general are strongly encouraged to review the identified requirements and, should modification or details be needed, contact the authors of this document for further discussion or amendments

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