Project acronym: **DATAZERO**

Project full title: **DATAcenter with Zero Emission and Robust management using renewable energies**

D2.1 Sources and Material profiling

Author: Stéphane CAUX (Institut National Polytechnique de Toulouse, INPT)

Version: 2.0

Date: 26/09/2016

Deliverable Number:	D2.1 (concatenate previous D2.1 IT profiling, D2.2 material profiling and D2.3 source profiling)
Contractual Date of Delivery:	30/09/2016
Actual Date of Delivery:	
Title of Deliverable:	Source and Material profiling Report
Dissemination Level:	Restricted to other program participants (including the ANR Services)
WP contributing to the Deliverable:	WP 2
Author:	Stéphane Caux
Co-Authors:	G DaCosta, P Stolf, L Grange, J Lecuivre, D. O'Sullivan, T Demissy, S, Kong, D Hissel, R Roche, JM Pierson

History			
Version	Date	Author	Comments
1.0	15/07/2016	S Caux (INPT)	3 parts Draft version
1.1	15/09/2016	S Caux (INPT)	Full version
2.0	25/09/2016	S Caux (INPT)	Full version formated

Abstract
The aim of this deliverable is to provide results and tools obtained during the first year of the project, together with source code repositories. IT profiling with DCWORMS and source code, EATON power electronic distribution and Renewable Source sources profiling also with source code.

Keywords
Profiling Report, IT profiling, Power architecture, Renewable Sources profiling.

Table of Contents

Deliverable D2.1 : T0+12 report

General Introduction

This document intends to propose IT (WP2.1), electrical distribution (WP2.2) and Power and Energy (EnR) source profiling (WP2.3) meeting Datazero project constraints [1]:

"WP2 is responsible for the Elements Profiling. It will profile the different elements of the system, software and hardware. First, applications will run on the infrastructure (WP2.2 profiling) taking advantages of various Renewable Energy sources (WP2.3 profiling). Target applications are either services or batch processing, inside a cloud environment (WP2.1 profiling). There is a need to profile these applications in terms of resources usage (classical CPU, memory, network) but also power consumption. The hardware components of the systems (solar panels, wind turbines, fuel cells, batteries, DC current buses, converters, computer and network infrastructure) will be studied and their profiles produced, in terms of efficiency, nominal operating conditions (in particular in different environmental constraints-temperature, wind, sun …). Real world experiments have started to validate the profiles, in particular using solar panels, batteries stack and fuel cells available in partners' lab (FEMTO-ST/ENERGIE department, INPT-LAPLACE laboratory) and from EATON who provides electrical equipment's (ePDU, UPS)."

Services might be moved from physical hosts to another, or suspended/delayed for a while, depending on information coming from the electrical plane. Conversely, the electrical plane must schedule energy flows with a certain degree of freedom due to several energy sources available, according to the computing demands. These two scheduling decision processes must be understood together in coordination and control loops from both planes must be enforced, in an autonomic way.

To do so, WP2 will not only prepare separately all characterizations of every element included in DataZero project, as well as Renewable Energy Sources, Electrical Network Distribution, DataCentre Topology and IT Computing Service split in different computers, but also merge IT/EnR profiling to be used in others optimization Work Package. WP2 and this report are thus divided in 3 parts:

- **WP2.1** deals with computer tasks characterisation, that means having parameters describing in terms of power demand and computing capacity/availability on different heterogeneous devices (CPU, memory, switch…) and scheduling policy.

- **WP2.2** deals with distribution analysis using ePDU/Power converters, provided by EATON, and preparing structured data files to be read/write in the optimization phase and identifying what can/should be done on power electronics feeding the data centre to reach a certain Quality of Service (QoS).

- **WP2.3** deals with Energy sources characterisation, which means establishing a set of parameters showing current, voltage, efficiency evolution of the different renewable sources (EnR: Fuel Cell, Battery, SuperCap, Solar Panel, Wind turbine…).

To be noticed, a second version D2.2 (T0+27), will provide if necessary a more accurate model taking into account parameters dispersion, ageing, State oh Health…

Optimal sizing is part of other Work Packages (WP3/WP4), the proposed D2.1 thus can be scalable depending on results coming later.

Two experimental databases have been obtained thanks to:

- the financial support of several LAPLACE' projects, France
  Thanks to Christophe TURPIN, Eric BRU

- the financial support of Franche-Comte Region, France
  Thanks to Daniel HISSEL

List of abbreviations

AC : Alternating Current

DC : Direct Current

FC : Fuel Cell

PV : PhotoVoltaïc/Solar Panel

H2 : Hydrogen

Batt : Battery (LiIon type)

ePDU : (connected) Power Distribution Unit

PSU : Power Supply Unit

UPS : Uninterruptible Power Supply

1 - WP2.1 : Datazero IT profiling proposals

This part describes computer hardware and tasks characterisation. It will serve as a reference for high level optimisation but also implementation in the context of DataZero [1].

1.1- IT profiling and scheduling policy

High level characteristics of IT can be summarised in: What to execute, when and where ?

In order to share a common framework, standards have to be used to describe the answers to these questions. The following will be based on the work done in the European CoolEmAll project [2]. In a detailed point of view, the following will be described:

- When and what requests are submitted to the system
- What is the policy of management of these requests

Several contexts are possible depending on the exact goal. HPC (High Performance Computing) and Cloud systems have different characteristics. In cloud systems, requests have changing resource demands while for HPC the resources are most of the time fully loaded. HPC applications can be batch processes which have a deadline while in the cloud applications might be services which will never end. The presented model is able to represent both cases.

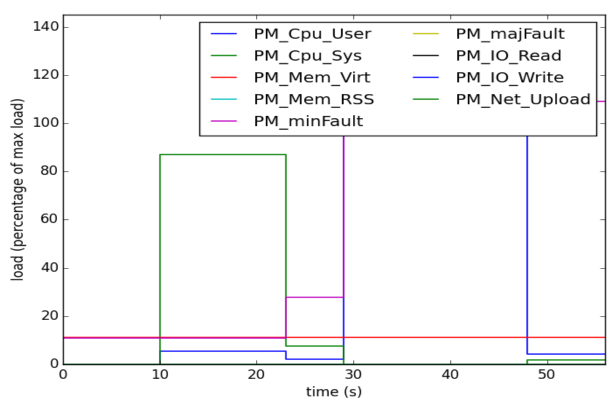


Figure 1.1: Application profile

The policy will have as an effect several reconfiguration of the hardware such as frequency scaling of processors (DVFS) or switching on/off servers which are described in detail in 2.3.

An application is modelled by:

- Time of arrival
- Resource consumption profiles over time
- Processor, memory, IO, network
- Policy related informations
- Priority

An experiment is composed by a SWF file (Standard Workload Format) following the standard described in [3] that describes for each arriving task or service its requirements, its profile and its arrival time. The profile itself as shown on Figure 1.1 is described in [2] and is a XML description of the resources consumed over time. The policy part will be defined in the deliverable D5.1 and will be used as parameter of the simulation tool DCWorms.

1.2 - DCWorms (input/output and parameters)

DCWoRMS is a data center simulation tool [4], which will be used for IT simulation purpose in DataZero. It is highly versatile in terms of simulated model, making it able to simulate both Cloud and HPC oriented systems.

Its main goal is to simulate, with a given description of IT infrastructure, scheduling policy and IT workload, the resulting resources usage over time and their power consumption. The infrastructure is described in an **XML dialect**, representing both the resources characteristics (computing ability, power consumption, heat generation) and their hierarchical and physical organisation inside the data center. The workload is, as described above, a set of SWF and XML files, respectively for the global description and for individual task or application characteristics.

The scheduling policy is given as a Java plugin, which interface directly with DCWoRMS in order to take any bits of information available for decision making and to apply those task placement decisions. It is also the goal of this plugin to take some other decisions, like powering off idle machines if required, or managing power-saving functionalities on computing nodes, like DVFS.

Several kinds of outputs are provided by DCWoRMS. One of the most important in the DataZero context is the **power consumed** at every moment of the simulation, by the whole data center, or by any part of it (i.e. at rack or node level). In addition, other outputs may be used to evaluate the quality of service.

As there are several criteria used to define **QoS**, depending on the kind of workload simulated, there are also several QoS metrics. For HPC-like workloads, information at task level, such as makespan and finished time are directly usable to measure QoS. For services, the simulator do not output directly a QoS measurement, but it may be calculated using other output data. The computing resources usage, for each machine and CPU, coupled with the task placement across time, allow to compute higher level information like service response time or allocated resources for each task. Figure 1.2 plots the input/output data used in DCWoRMS.

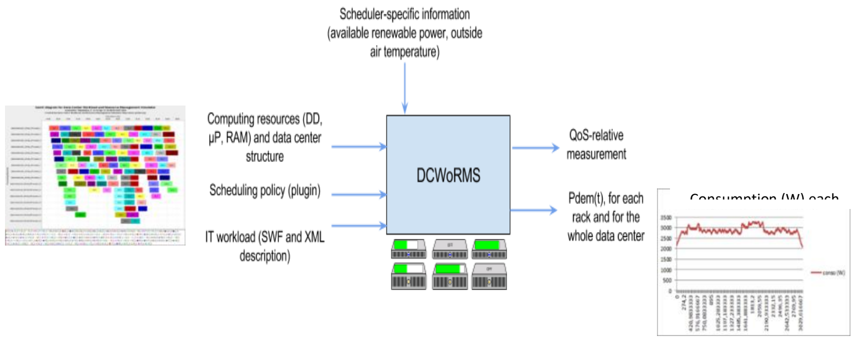


Figure 1.2: DCWORMS

1.3 - Programs for D2.1 : IT profiling

IT Profiling is done using the software suite **application_profiler** available in the project repository. The 3 programs are:

1. **sources/track.c** : monitor system values (memory, processor) associated with a processus
2. **phases.py** : takes the execution traces from the monitoring tool and create the XML profile
3. **xml_to_png.py** : transforms a XML profile into a PNG figure such as Figure 1.1

An example of XML profile is shown below:

```
<resourceConsumptionProfile>
   <resourceConsumption>
      <referenceHardware>Generic Intel</referenceHardware>
      <degradationLevel>none</degradationLevel>
      <duration>PT11S</duration>
      <behaviour name="userLoad"><value>0.000000</value>  </behaviour>
      <behaviour name="systemLoad"><value>0.000000</value>   </behaviour>
      <behaviour name="vSize"><value>11173888.000000</value></behaviour>
      <behaviour name="RSS"><value>242.000000</value>    </behaviour>
      <behaviour name="minFault"><value>97.000000</value></behaviour>
      <behaviour name="majFault"><value>0.000000</value></behaviour>
      <behaviour name="ioRead"><value>0.000000</value></behaviour>
      <behaviour name="ioWrite">    <value>0.000000</value>   </behaviour>
```

These XML elements will be used by the simulation toolkit depending on the exact scenario. Two adaptations will be possible.

- The simulator will be able to adapt the profile depending on the exact state of the IT hardware infrastructure. As an example, using DVFS, a profile might be extended as the lower frequency will lead to a slow-down of the running application.
- The second adaptation will be to have several profiles for each application in order to represent the different levels of downgrading of the quality of service. From a technical point of view, it will be necessary to run the application on each level (no degradation to maximum degradation) which will produce several XML files each tagged with the degradation level.

The complete workflow from the executed application to the final XML and associated image if shown on the figure 1.3 below:

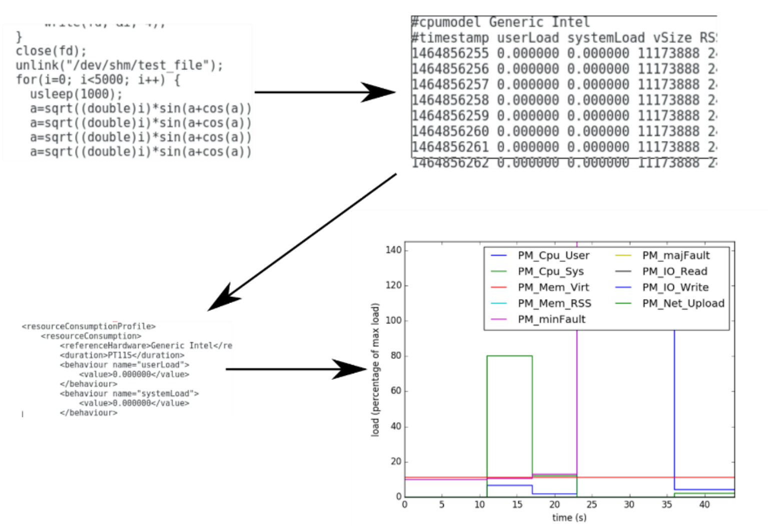


Figure 1.3: program workflow

The present section explained the format used to describe the IT workload defined in relation with the deliverable 5.1 and how it will be used for simulation purpose.

Tools are mainly updated and adapted version of the tools provided by the European CoolEmAll project.

2 - WP2.2 : Datazero Electrical architectures proposals

2.1- Introduction

This document intends to propose electrical Datacentre architectures meeting Datazero project constraints [1]. Several architectures have been discussed and some of them not classified because judge not adapted for DataZero or EATON context. This document intends to extend the new concept that has been prototyped for Greendatanet research project [5]. This concept is illustrated on next figure and it allows connecting 2 kind of renewables to UPS. Here both "PV" and "recycled Li/ION batteries" are connected to UPS DC BUS. We call this device **GDN UPS** in this presentation.

This concept allows by design better efficiency (avoiding unnecessary power conversions).

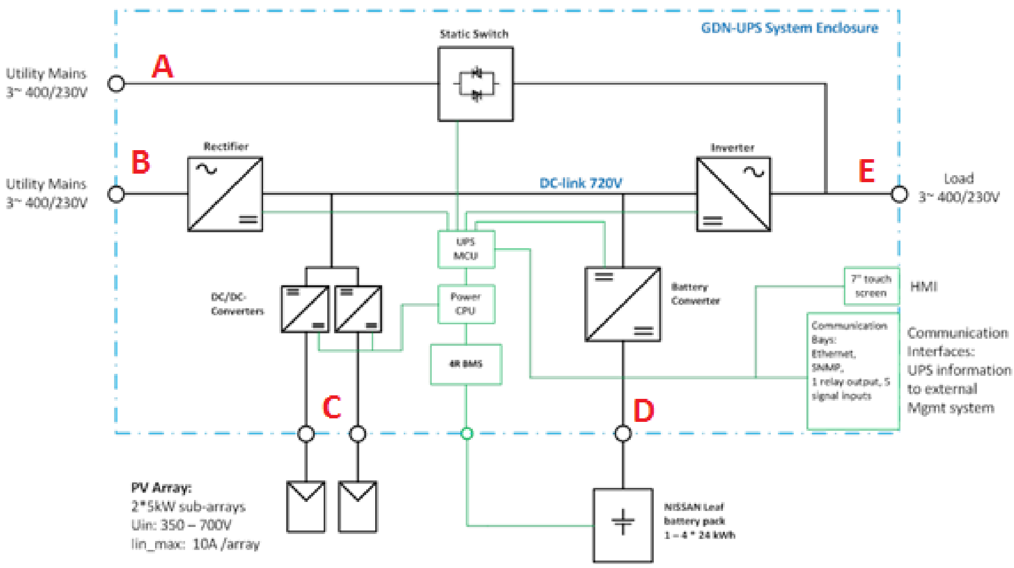


Figure 2.1 : GDN UPS Topology

In this paragraph, we will propose 2 Datacentre electrical architectures integrating renewables production. We name first architecture "**Classical**" and the second one "**Breakthrough**". In the next paragraphs we will detail the hypothesis for each architecture.

2.2 - Hypothesis for "Classical" Datacentre architecture

In this paragraph, the hypothesis are detailed, taken into account to design the "Classical" datacentre architectures that are the following ones [6]:

a) Target datacentre redundancy is **N+1** or **2N**:
   - **2N** redundancy means that DC architecture will comprise two complete systems, each containing N components, and are run in parallel to hot swap between each other.
   - Note: Proposal 1 hereafter can be considered as **N+1** in reality as feed A and feed B are not fully separated.
   - **N+1** redundancy means that the number of components provided is one more than the number (N) of components needed.

b) In normal operation mode:
   - Loads will use only renewable power sources such as PV / Wind / FC / Li-ION batt / …
   - Grid power will not be used in normal mode. Grid connection is here for 2 purposes: first purpose is to provide target redundancy in case of failure and second one is to allow power resell.

c) Datazero target Datacentre size 1 MW / 1000 M^2
   - Open question: 1MW = Critical load or Total load?
   - Note: it will be seen later in this document that architecture is scalable from 50KW to 1.2MW

d) Critical Load is powered by 2 input branches (~50/50%)

e) HVAC (Heat/Cooling ancillaries) is ~40% of IT Load

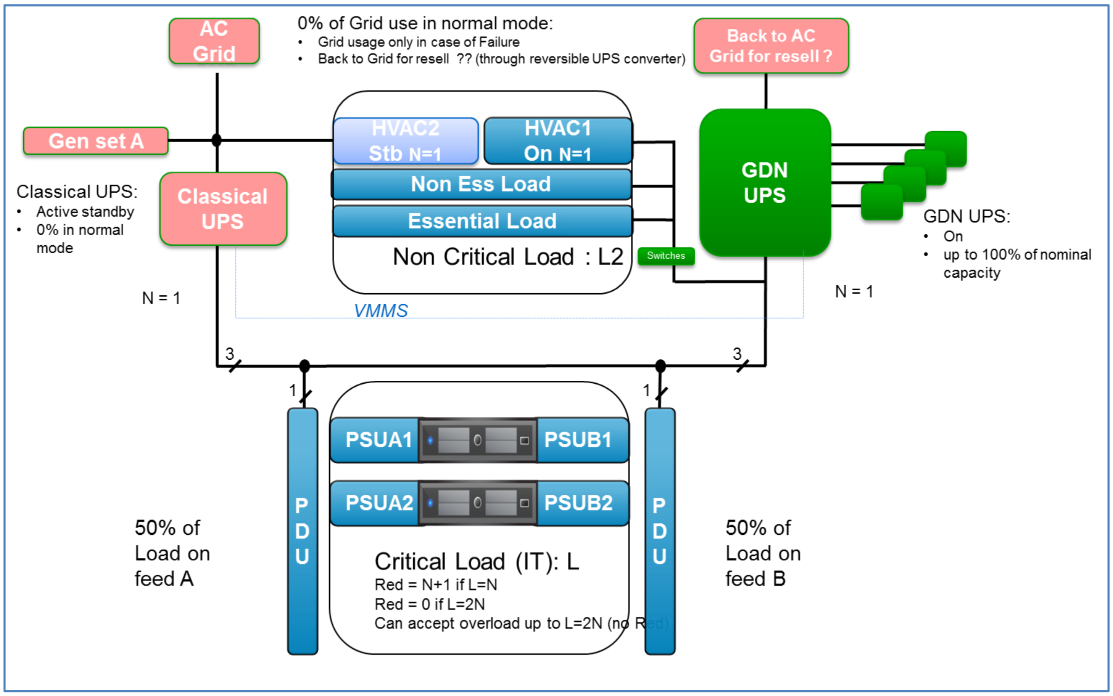


Figure 2.2 : Proposal 1 for Classical architecture « Up to N+1: (Green + Grid)»

2.3 - Hypothesis for Breakthrough Datacentre architecture

In this paragraph, we are more ambitious and we tune a) and b) hypothesis in order to get a "Breakthrough datacentre architecture".

a) **2N** as target redundancy:
   - **2N** redundancy means that DC architecture will comprise two complete systems, each containing N components, and are run in parallel to hot swap between each other.

b) In ALL modes (normal mode or failure mode) the load will only use renewable power sources such as Photovoltaic (PV) / Wind Turbines (Wind) / Fuel –Cell (FC) / Li-ION (Batt) / …
   - Grid power is not used to power the Load (either critical or non critical load)
   - Grid connection might be here just to resell excess power.
     Note: excess power can be also sold through Hydrogen resell process if Grid connection is not available.

c) Idem as for « Classical architecture »
d) Idem as for « Classical architecture »
e) Idem as for « Classical architecture »

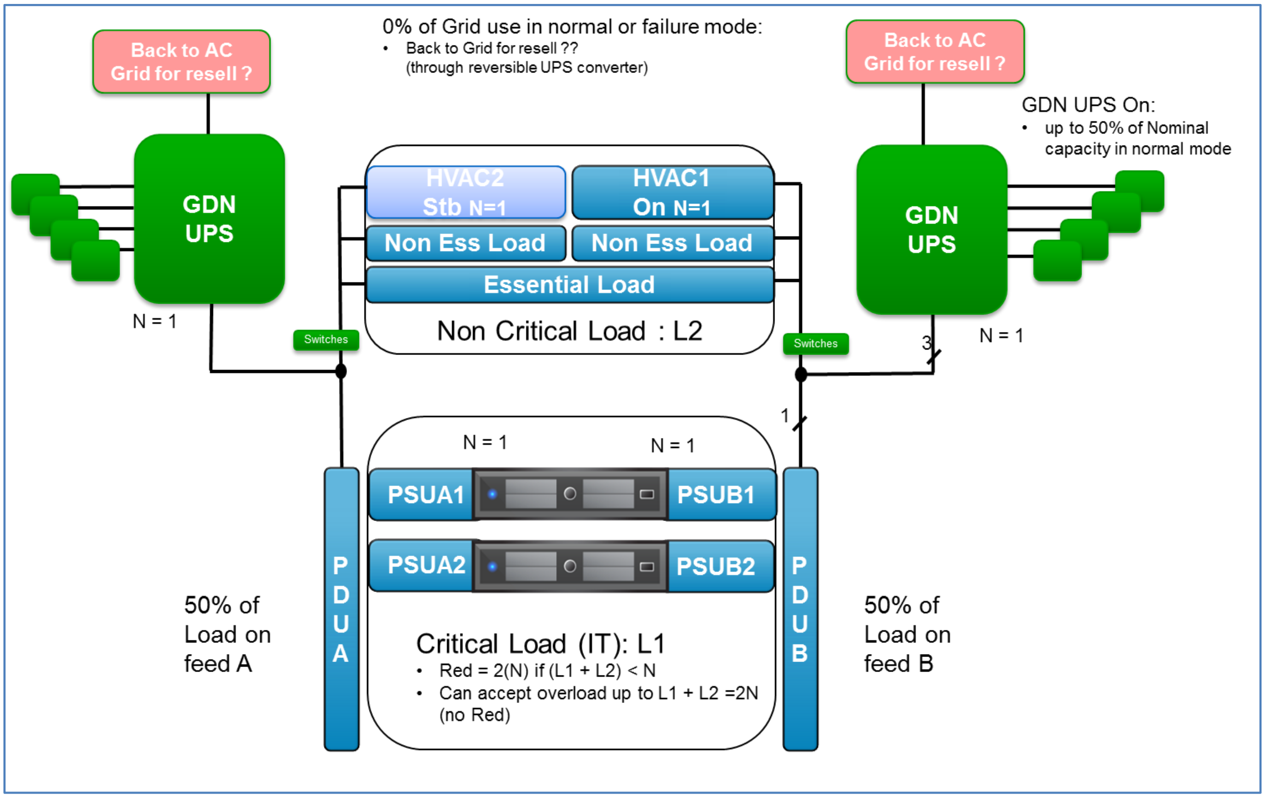


Figure 2.3 : Proposal 2 for Breakthrough architecture « Up to 2N Green»

2.4 - Comparing “Classical” and “Breakthrough” architectures

In Proposal 1 “Classical”:

- On the right hand green power branch:
  - The sizing of green power is just 1N (green power production runs up to 100% of nominal capacity)
  - The right side HVAC (powered by green energy) is powered by GDN UPS as it seems difficult to power it directly by Green DC
- On the Left hand grid power branch:
  - The left side HVAC is normally off
- *Note: Need to check that VMMS works with 2 different UPS technologies*

In Proposal 2 “Breakthrough”:

- The sizing of green power production is 2 times more massive than on Proposal 1: (green power production runs up to 50% of nominal capacity to keep 2N redundancy)

- We introduce two kind of flexibilities to be able to use this excess green power production:
    - Non Critical Loads can be immediately switched off through switches
    - Connection to AC Grid for resell
- The 2 HVACs (powered by green energy) are powered by GDN UPS as it seems difficult to power them directly by Green DC power sources.

2.5 - UPS Details and Connection to Green Power sources

In this schematic, we detail "GDN UPS topology" and how we connect renewable sources to electrical architecture. Here we have 2 UPS modules connected in parallel called "GDN UPS A1" and "GDN UPS A2".

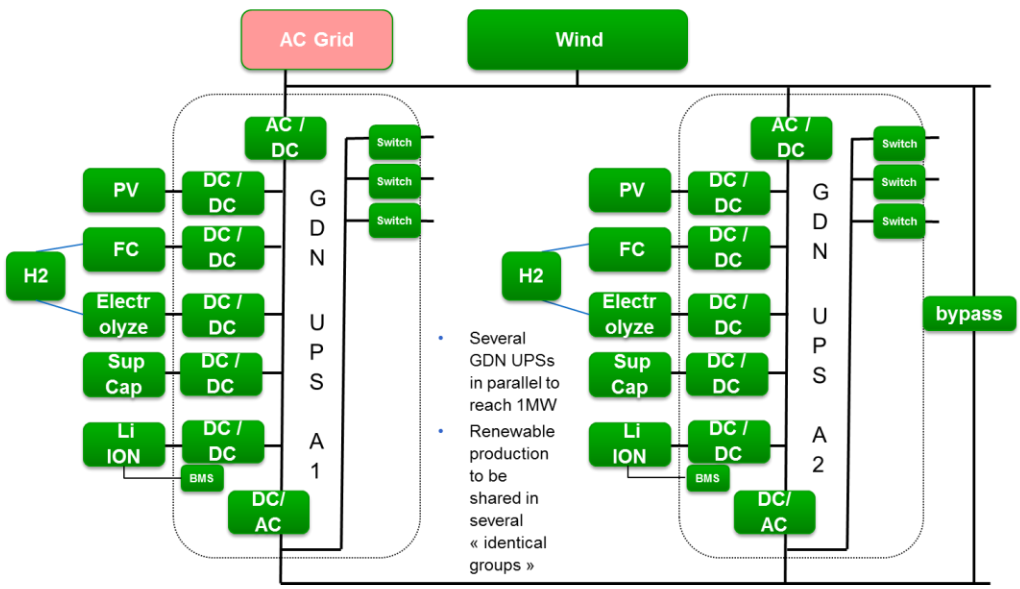


Figure 2.4: UPS Modules connected in parallel

2.6 - UPS Power considerations

- Eaton 93PM GDN UPS [7] has 50 KW inverters that can be paralleled (e.g. with 4 Inverters in parallel we reach 200 KW). Note: 93PM has a 720V DC bus
- Eaton 9395P UPS series UPS [8] has (300 KVA / 275 KW) inverters that can be paralleled (e.g. with 4 Inverters in parallel we reach 1.1 MW) Note: 9395P has a ~700V DC bus

It can be connected renewable power sources in a similar way on 93PM and on 9395P. So we get electrical architecture scalability from 50 KW up to 1.1 MW

2.7- Renewable power sizing

- Renewable production to be shared in several « identical groups » …
    - Maximum renewable Power per group is 50 KW if use of 93P UPS
    - Maximum renewable Power per group is 275 KW if use of 9395 UPS
    - Except for Wind turbines that are connected in AC
        - Wind turbines are considered as more efficient when bigger capacity [9]
        - Needs at least 2 Wind turbines for 2N architecture

- Details linking EATON, FEMTO and LAPLACE

To remember: optimal sizing of power/Energy sources is part of other Work Package (WP3/WP4) as well as optimal power splitting between the different EnR sources.
The proposed D2.1 thus can be scalable depending on results coming later. Whatever the association in series and/or in parallel of energy sources pack, the distribution architecture and power distribution can be characterised.
Power converter (UPS) should be controlled keeping DCbus Voltage quite constant as requested and controlled in current to deliver the power requested (issued from optimization step) to split optimally the different sources solicitation.
Following figures under scalability assumptions, shown a quite constant efficiency of power electronics (97-98%) in the 'typical UPS operating range'.

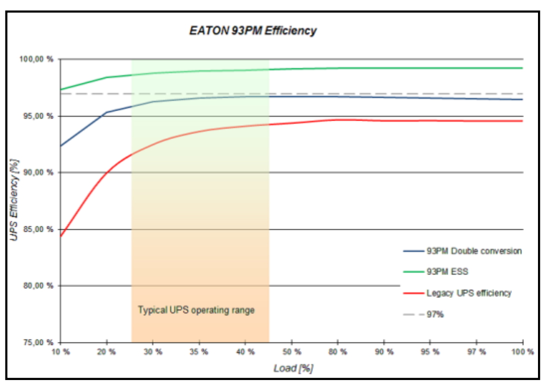


Figure 2.5 : Eaton UPS efficiency map

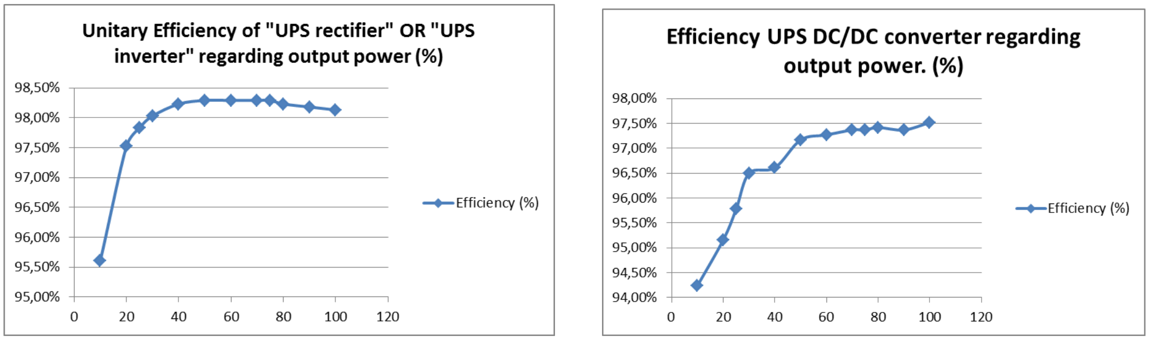


Figure 2.6 : Eaton AC/AC – DC/DC power electronics efficiency

2.8- Comments on cooling

Cooling represents an important percentage of electricity consumption of recent datacenters due to the high computing density of servers. During the European project CoolEmAll, UPS/IRIT has produced several models with diverse granularity [10]. The mostly used model is the proportional model based on the Power Usage Effectiveness (**PUE** = Total Power / IT Power). It considers that non-computing elements consume an energy that is proportional to the one consumed by IT equipment. Most recent datacenter had a PUE of 1.7 meaning that for 1kW consumed by servers, 700W are consumed mainly by the cooling infrastructure. EATON indicates 1.4 is possible (including actual heat/cooling ancillaries) or less due to accurate control and optimal power splitting involved in this project.

The other mostly used model use accurate 3D model of the hardware and cooling infrastructure and uses fine grained airflow models to evaluate heat production and movements inside the datacenter. A simplified model can be obtained after such an airflow simulation to model the impact of heat produced by servers on the power consumption of nearby other servers. This system is based on a matrix representing this head cross-impact called D-Matrix [11][12]. In the context of Datazero we will mainly use the classical approach of PUE to model the cooling impact. Partners of the project already used other types of approaches in dedicated contexts and projects, but it is not in the core of the Datazero project.

3 - WP2.3 : Datazero Renewable sources profiling proposals

3.1- Introduction

This document intends to propose Power and Energy sources profiling meeting Datazero project constraints [1]. This document intends to obtain parameters taken from actual measurements to provide sources behaviour in terms of discrete equations linking, voltage, current, state of charge, efficiency/losses of all elements to be used in the optimization loops.

At this first level (D2.1 T0+12), classical models are provided, coming from literature and with some assumptions (first order models) and with constant behaviour (no ageing, no dispersion). The renewable energy sources treated are:

- Battery (Li-Ion)
- Supercapacitor (SupCap - SC)
- Fuel Cell (FC)
- Solar Panel , Photovoltaic Panel (PV)
- Wind turbine (Wind)

The corresponding electrical distribution (part WP2.2), scalable from 50kW to 1MW is recalled hereafter in Fig 3.1.

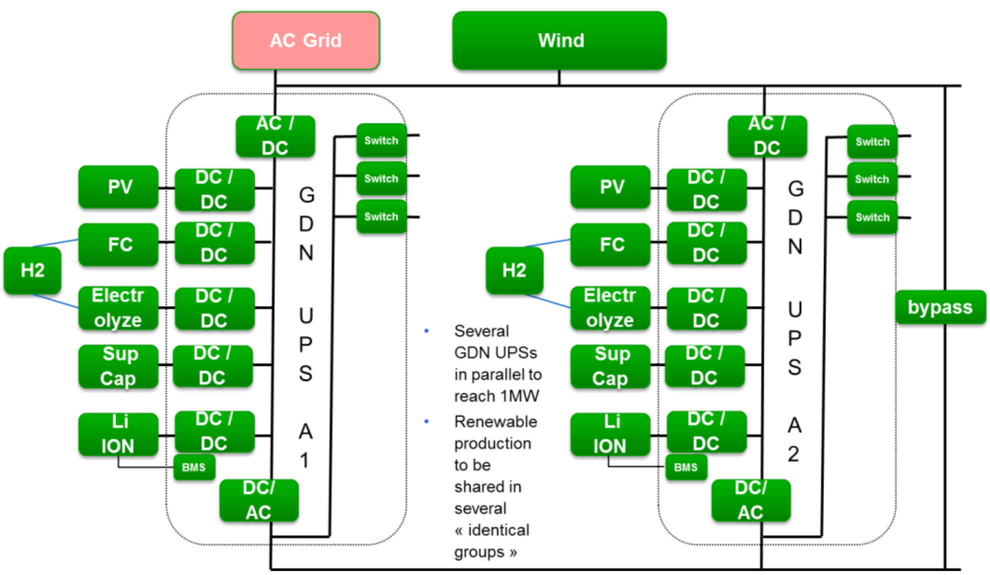
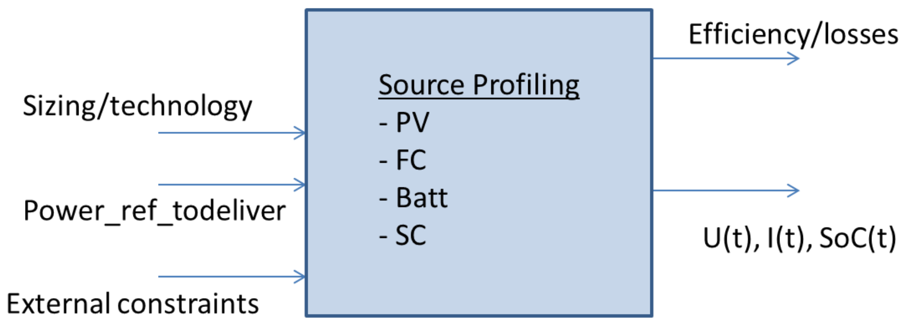


Figure 3.1 : UPS Modules connected in parallel

The programs and methods for Renewable energy sources profiling purposes are in two steps:

- The first step is using data measurements (Data Carac), making polynomial approximation to extract a model and its parameters, scalable on different sizing
- The second step, depending on the sizing and reference power to deliver, furnishes discrete equations giving at each discrete step time *t*, what are the current *I(t)*, voltage *V(t)*, state of charge *SoC(t)* and efficiency/losses of each source.



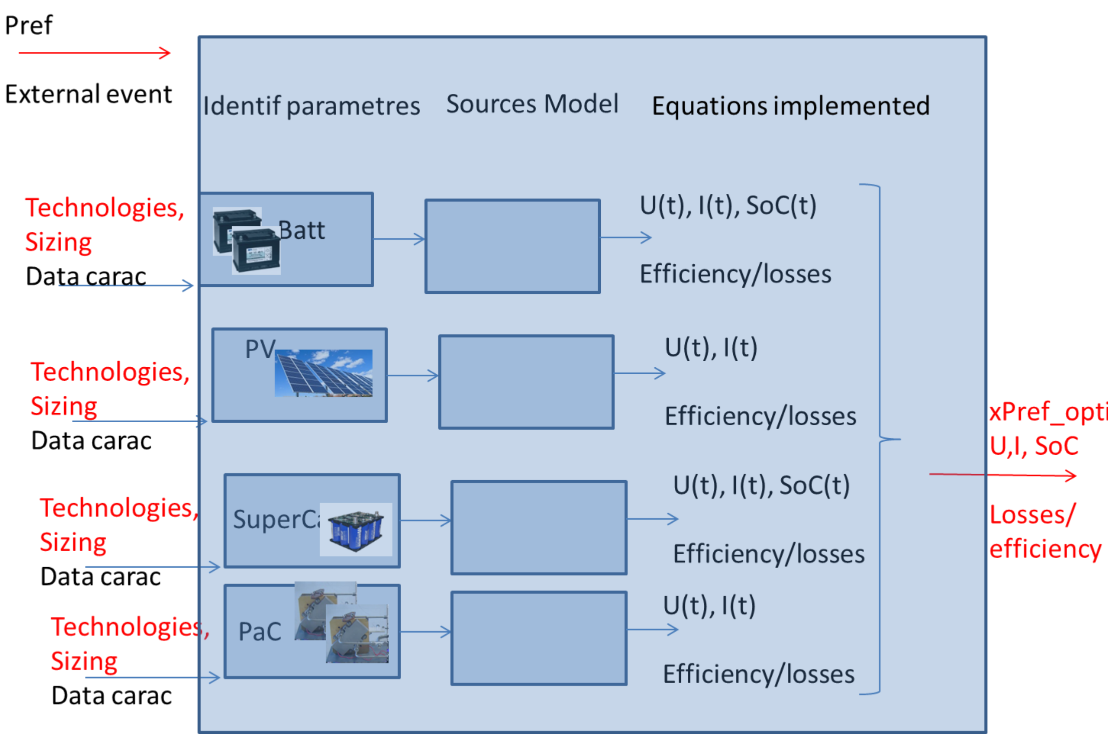


Figure 3.2 : Multisource profiling

3.2 - Fuel Cell System profiling

In this paragraph, we detail the hypothesis taken into account to design the fuel cell system characteristics. The Fuel Cell system is a non reversible sources creating electricity from hydrogen (no electrolyser part to produce hydrogen). The output voltage and current are dependent on some polynomial equations representing FC behaviour extracted from polarization curves and/or impedance spectrometry analysis [13][14].

For this first source profiling, considering no ageing and a **future control of voltage and current** (letting the power delivered in the correct operating zone), a simple model is possible with a set of 3 third order polynoms (ax^3+bx^2+cx+d) corresponding to 3 specific behaviours.

1 –Activation zone P1 (0A-18A) :

2 – Ohmic zone P2 (18A-50A) :

3 – Diffusion Zone P3 (50A -85A) :

Table 3.1: *3 zone coefficients of approximated polynoms ($ax^3+bx2+cx+d$)*

	a	b	c	d
P1 (0A - 18A)	-0,0002882	0,0096553	-0,1247926	4,82588
P2 (18A - 50A)	0	0	-0,0150766	4,3072126
P3 (50A - 85A)	-3,346E-06	0,0005512	-0,0459025	4,8936159

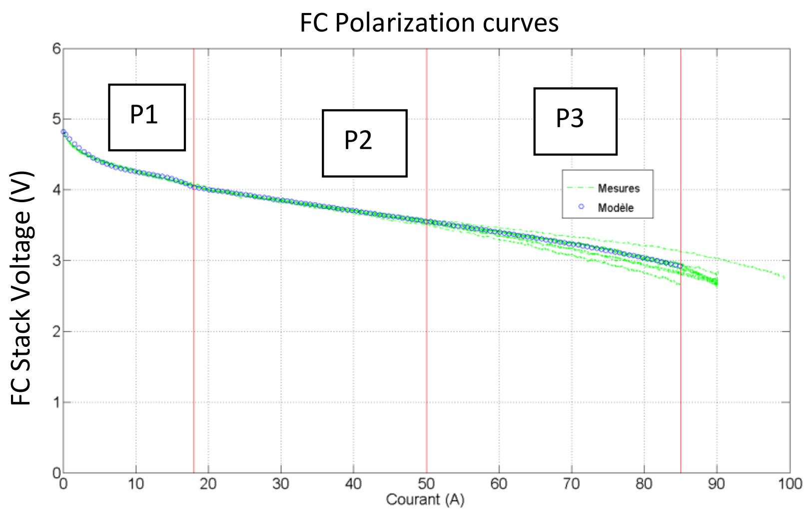


Figure 3.3 : Comparison FC measurements/polynomial model

Actually, some researches are made on a reversible Fuel Cell System. Such systems are also able carrying out the opposite process called *electrolysis*. Using electricity, this reversible Fuel Cell can create hydrogen, for future reuse or resell if in excess. This profiling will be made later due to industrial confidentiality, but roughly the produced hydrogen mass produced is proportional (depending on sizing), to the product *i.dt*, in other words: the H2 mass is proportional to the energy brought in by a current magnitude *I*, during a step time *dt*.

3.3 - Battery system profiling

Different measurements are available: 6 cells Li-Ion (LiFePo4, 3.2V 39Ah), (cf datasheet in ***annexe***):

- 6 cells in series
- 2 cells in series, 3 legs in parallel
- 3 cells in series, 2 legs in parallel
- 5 cells in parallel

Characterisation is possible using different current profile exiting the battery stack. For a simple quasi-static model (similar to the polarisation curve of Fuel Cell system), a constant current charging the battery is used with different magnitude [16].

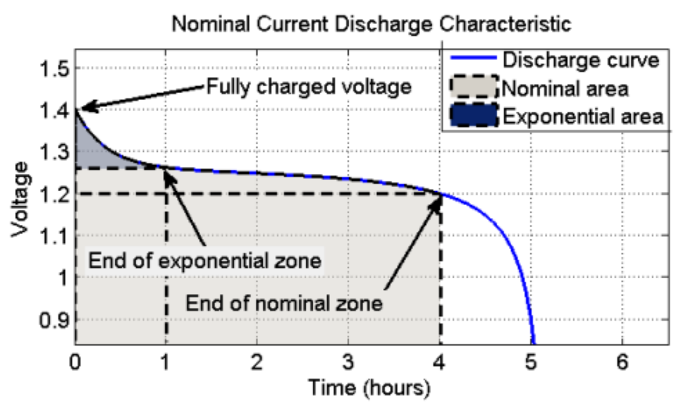


Figure 3.4 : LI-Ion profiling

The charging/discharging symmetry is assumsed and hysteresis effects are negligible for actual Li-Ion technology. Similarly, we do not consider Peukert effect letting constant the parameters whatever are the current and state of charge.

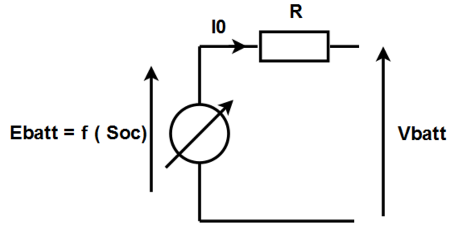


Figure 3.5 : Li-ion equivalent electrical model

Using the measurements, the equivalent capacity Q of the battery is identified integrating the current over time ($Q = 34.28\ A.h$). Identifying the equivalent resistance R of the stack ($R = 6.5\ m\Omega$ and introducing the state of charge (SoC) behaviour depending on the current (charging/discharging) and given between [0 1] (means between 0 100%) all behavior can be computed with equations:

$$\dot{SOC} = \frac{V_{OC} - \sqrt{V_{OC}^2 - 4R_{int}P_{EM}}}{2R_{int}Q_B}$$

$$I = -\dot{SOC}\,Q_B$$

$$P_{ess} = V_{OC}I$$

The different coefficients are identified, and this first simplified model verified to be used in simulation loops in optimization parts of this project:

<u>Table 3.2</u>*: Battery coefficient values*

Q	3,43E+01
R	6,50E-03
E0	3,61E+00
A	1,97E-01
B	8,75E-02
K	5,25E-05

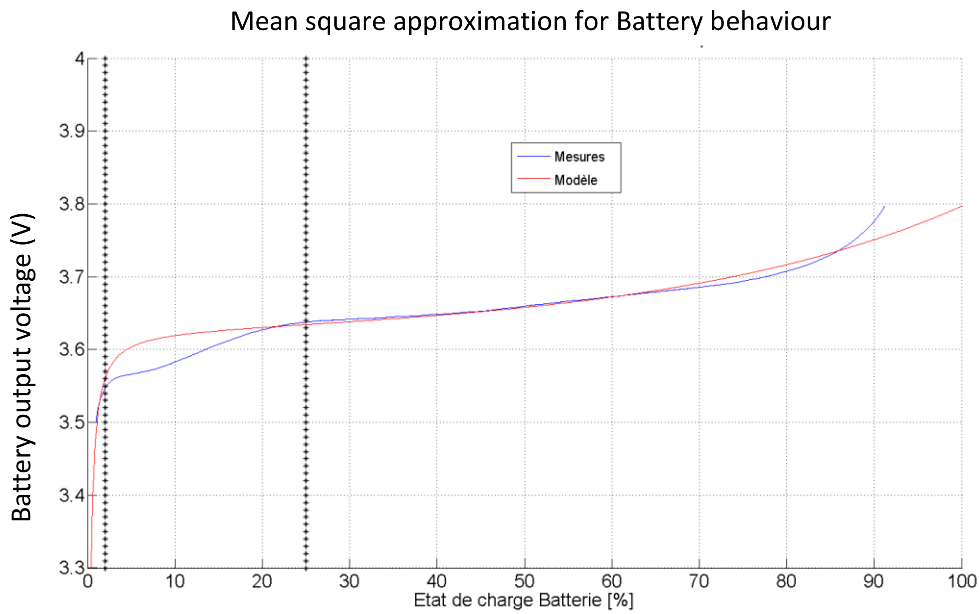


Figure 3.6 : Comparison Modelling/Measurement Ebatt = f(SoC) profiling – Batt profiling

3.4 - SuperCapacitor system profiling

We are using 35 measurements made on 35 supercaps a capacity of 58F from *Maxwell BMOD0058 E016 B02* (datasheet in annexe).

For this first modelling approach a simple RC equivalent circuit is chosen, and its parameters should be identified [15].

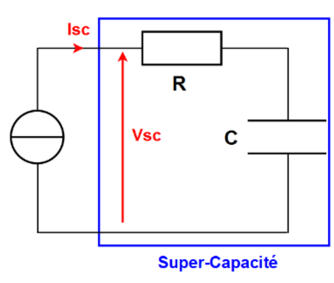


Fig 3.7 : Supercaps electrical equivalent RC circuit

Charge and discharge of such component are symmetrical; charging curves at different current magnitudes allows us to identify these 2 parameters (*R*, *C*) linked to the classical behaviour shown on the following figure.

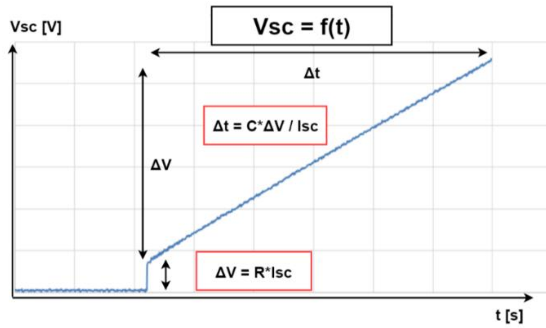


Figure 3.8: RC identification for supercaps element

Table 3.3 *: RC dispersion results*

N° Sc	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
R [mΩ]	31,12	27,47	31,62	29,05	30,4	30,36	35,3	28,91	30,27	32,43	29,07	32,11	31,97	25,83	29,85	29,25	26,38
C [F]	58,44	58,74	58,72	58,8	59,04	59,01	59,24	58,78	59,14	59,8	58,82	59,94	59,75	59,16	58,97	59,04	58,89
ΔR [%]	-8,66	4,082	-10,4	-1,44	-6,18	-6,03	-23,3	-0,96	-5,73	-13,2	-1,5	-12,1	-11,6	9,81	-4,25	-2,14	7,883
ΔC [%]	1,344	0,83	0,862	0,731	0,334	0,373	-0,01	0,763	0,157	-0,96	0,705	-1,2	-0,86	0,119	0,449	0,32	0,587

18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
29,39	28,79	27,59	27,16	29,5	26,58	24,77	28,25	26,9	28,18	26,85	30,74	26,93	25,19	24,76	28,72	25,99	24,57
59,01	59,55	59,35	59,26	59,8	59,01	59,09	59,18	59,88	59,24	59,54	59,45	59,8	58,93	59,56	59,22	59,92	59,11
-2,65	-0,54	3,651	5,157	-3,02	7,185	13,48	1,331	6,075	1,601	6,238	-7,34	5,937	12,03	13,54	-0,3	9,236	14,21
0,372	-0,54	-0,19	-0,05	-0,96	0,37	0,238	0,086	-1,08	-0,01	-0,51	-0,36	-0,95	0,513	-0,54	0,021	-1,16	0,211

In this D2.1 we did not take into account the parameters dispersion (will be delt in D2.2). Nor self-discharge phenomenon on a long time has been included at this level.

So we keep constant :

R = 28.6 mΩ (22 mΩ **+-**25% as indicated in manufacturer datasheet in annex)

C = 59.23 F (+/- 1.34% more accurate than 58 F +-20% provided by manufacturer).

For the computational step requested by optimization loops, the behaviour is translated in equations:

$$\begin{cases} X = q_{sc}(t) \\ Y = V_{sc}(t) \\ U = i_{sc}(t) \end{cases} => \begin{cases} \dot{q_{sc}}(t) = i_{sc}(t) \\ V_{sc}(t) = \frac{1}{C_{sc}} * q_{sc}(t) + R * i_{sc}(t) \end{cases} => \begin{cases} A = 0 \\ B = 1 \\ C = \frac{1}{C_{sc}} \\ D = R \end{cases}$$

We obtain the following figure showing a quite correct model behaviour.

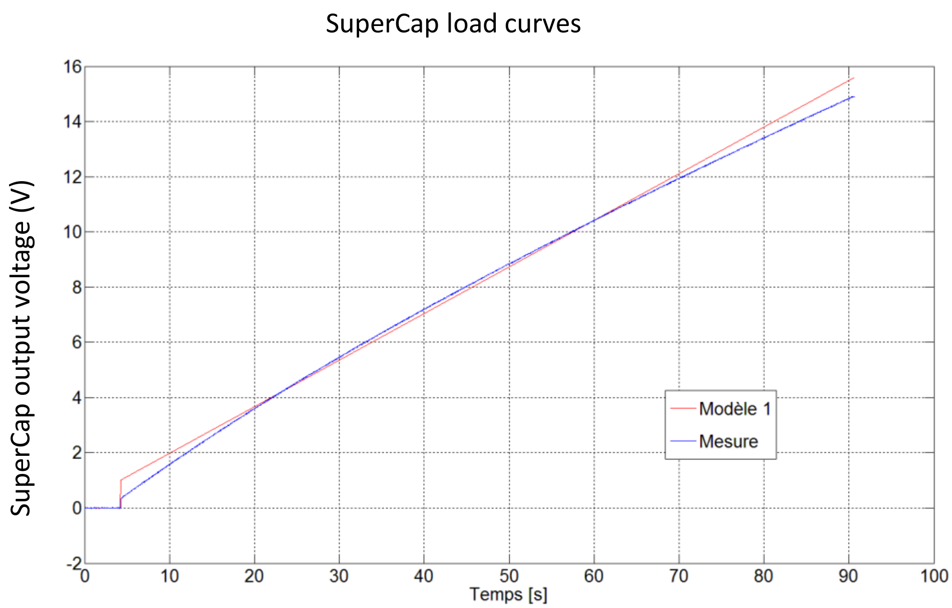


Figure 3.9 : Comparison measurements/modelling supercapacitor – SC profiling

3.5 - PhotoVoltaic panels Profiling.

Solar Panel devices have been installed on the Laplace lab's roof, there is 5 sheds with 4 different technologies (cf ***annexe***):

- 2 sheds from "Sun Power"
- 1 shed from "Panasonic-Sanyo"
- 1 shed from "First solar"
- 1 shed from "Avancis"

Automatic measurements are used; with a datalogger *Fronius IG Plus* data measuring every 5mn : I, U, Power, Radiation, Temperature…(measurement period Toulouse-France: 18/05/2015 - 00:00 end 24/07/2015 - 10:00).

Sun radiation [may 18th 2015 – july 24th 2015] on different panel

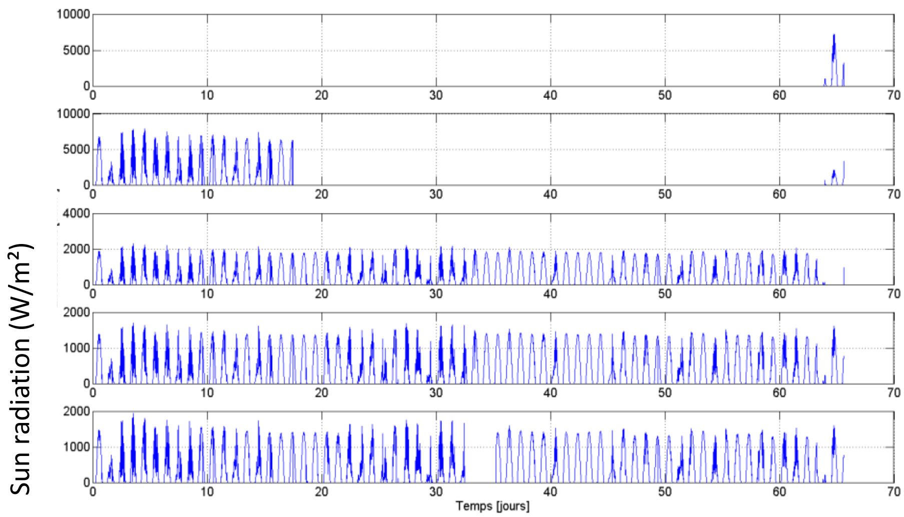


Figure 3.10 : Power measurements on different area of sheds PV

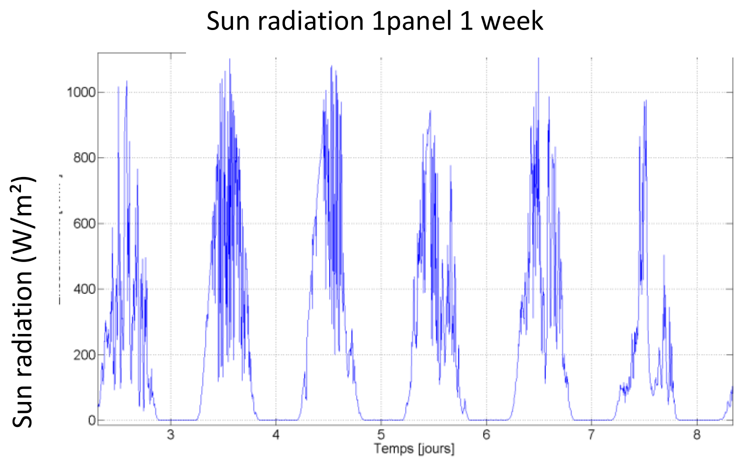


Figure 3.11 : Sun radiation on a week in the test period-Toulouse 2015

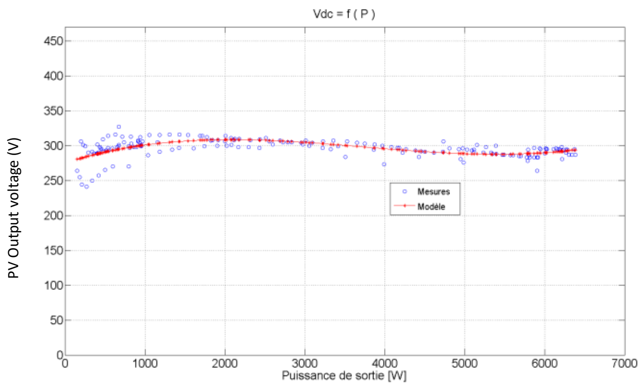
Solar Panel characteristics strongly depend on the sun radiation, but also inclination, temperature and climatic condition.

At this first 'simple' profiling step, we suppose a proportional link between sun radiation and temperature, homogeneity on the PV surface, and we isolate the same temperature and condition to extract an approximation representing the PV behaviour. It can be shown hereafter, that this behaviour strongly depends also on the technology of the PV.

To be noticed, measurements are made at chopper output including a Maximum Power Point Tracking (**MPPT**) allowing controlling the PV output voltage depending on the sun and current it produces.

The model is valid on a given (Sun_Radiation, T°) called '**used climatic condition**'. The objective is to characterize the power (*Pmax*), varying with this 'used climatic condition'

NB: P = f (V) is not suitable to easily extract 'just' one polynomial for each PV. An intermediate step consist in identifying polynomials on V = f (P) means square identification are conducted for a degree 3 polynomials.



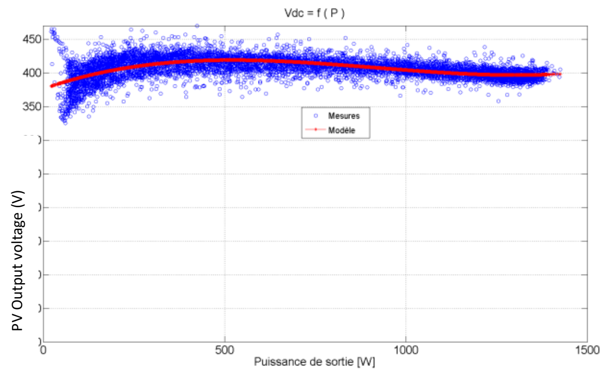


Figure 3.12 : Modelling shed « Sun Power 1 »

Figure 3.13 : Modelling shed « First Solar»

<u>Table 3.4</u> *: coefficients ($ax^3 + bx^2 + cx + d$) for each PV technology*

	a	b	c	d
Sun Power 1	1,116E-09	-1,252E-05	0,0374202	274,91167
Sun Power 2	2,706E-10	-4,217E-06	0,0144671	295,04747
Panasonic-Sanyo	3,627E-08	-0,0001299	0,1306816	333,11586
First solar	9,268E-08	-0,000254	0,1894127	376,0335
Avancis	8,902E-08	-0,0002419	0,1820845	264,93614

3.6 – Wind turbine profiling

In this case, a generator (electrical motor) is set in motion using wind power at a certain velocity. The structure and sizing of the flap and generator are out of the scope of this part. Roughly, a simplified behaviour can be detailed hereafter [17].

Under a low wind-speed value no sufficient torque is produce and no electricity can be extracted and the turbine is considered 'not available'. Using a synchronous machine as generator and modern controlled blade structure (optimal rotor power coefficient *Cp* fixed mechanically with pitch-change angle), when the wind speed is sufficient, the mechanical power (Torque x Speed) is converted and produces an electrical power (current x voltage) quite proportional to this wind power. An additional local control MPPT (Maximum Power Point Tracking) should also be present in converters linking the turbine to the general DCBus (eg: through a Buck-Boost DC/DC converter). Thus the current is quite proportional to this power too and depends on the load resistance value, fixing a controlled constant voltage ie: 48V.

Losses are mainly due to stator resistance *Rs* and produce Joule's losses in terms of $Rs.I^2$.

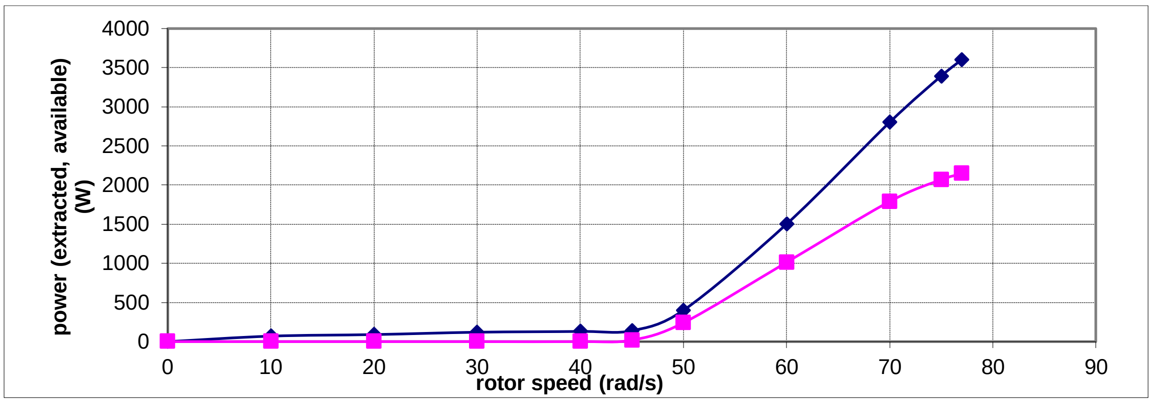
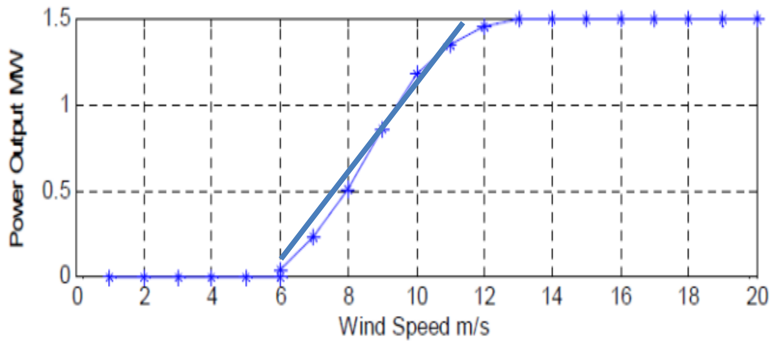


Figure 3.14 : Turbine power extracted depending on turbine velocity.

Table 3.5 *: experimental data wind turbine power converted to electricity*

Vdc=48V					
Vvent (m/s)	Omega (rad/s)	Idc(A)	Vdc(V)	Cem(Nm)	Pem(kW)
6	49,3	0,07	48	1,93	0,11
7	54,9	2,2	48	3,84	0,22
8	57,9	6,2	48	7,8	0,46
10	61,2	16,25	48	18,01	1,23
12	70,6	28,7	48	29,6	2,25
13	78,5	35,5	48	35,2	2,85
14	87,3	42,5	48	40,7	3,5

Choosing the controlled power electronics and mechanical structure adapted nowadays, the simplified behavior cited in [17], allows to validate this simply proportional modeling of a wind source (in Fig 3.15 the conversion coefficient should be K=3.75MW/ms^{-1}).



V_{wind} m/s	*Power Out* MW	*Slip* %
6	0.035	-0.01
7	0.233	-0.32
8	0.501	-0.68
9	0.850	-1.16
10	1.181	-1.76
11	1.344	-2.44
12	1.451	-3.23
13	1.5	-3.96
14	1.5	-4.55
15	1.5	-5.08
16	1.5	-5.56
17	1.5	-5.95
18	1.5	-6.10
19	1.5	-5.97
20	1.5	-5.48

Figure 3.15 : Turbine power depending on wind velocity.

Table 3.6 *: experimental data [17l]*

3.7 - Renewable power sizing / Sources profiling - Programs

For example as a quick tutorial, hereafter are described different functions furnished in this deliverable D2.1, programs available in the project repository, for sources profiling and parameters tuning.

As used in GDN electrical distribution (Part2) actual test bench, Photovoltaic and Battery sources are detailed.

Folder "Alim PV + BATT", via "**Main.m**"

Allowed to write input for optimization package and receive input from one hand sizing part and/or optimal power splitting on the other hand.

- "**Modele.mod**", "**Datas.dat**" & "**Solutions.sol**" : interface Matlab <–> optimization software (glpk)

  * .mod = mathematical model including sources behaviour.

  * .dat & .sol = input/output files changing in optimization iterative procedure.

- Files in format excel :

  Sources profiling and parameters identification: "data analysis", read by "Main.m"

1 – the program load input power profiles.

2 – the program load experimental data for PV, Batt sources.

Input data:

- PV power profile file *Ppv*
- Power demand for the PV *Pdem*

* previous steps should insure the same sampling time and same duration consistency*

- PV and Battery unitary profiling, UPS constant efficiency
- scale factor asking PV *area* (m^2) and element in series *ns*, and in parallel *np* for Battery
- sizing constraints in terms on min/max current, min/max SoC, initial/final SoC etc.

Linked to sizing, sources profiling and coefficient for each polynomial are delivered, allowing computing states evolution

Output data :

- solve first order differential equations furnishing all sources states (current, voltage, SoC, output Power…)

4 - Conclusions D2.1 report

The validation of this work will be done mainly in simulation. We aim at integrating the electrical plane aspects in one cloud scheduling simulation environment.
Real world experiments will be conducted later at small scale to validate the input for the simulations Solar Panels, Batteries stack and Fuel Cell when available in Laplace lab and after adaptation of the FCLAB test bench (Power Hardware in the Loop - PHIL).

Scalable profiling are provided because the overall sizing did not concern WP2 activities, but has to be used **in challenge 2 dealing with this optimal sizing problem:** Given a power demand (coming from IT applications) answering the question: how to optimize the dimensioning of the electrical provisioning and storage (in terms of number of solar panels or wind turbines, batteries, etc.) accordingly so that the datacenter can still operate at a given computing power. Beyond having power lines redundancy (2N) several possible flows of energies usable partly at any time should arise, achieving an operational dynamic redundancy with less hardware equipment.

In WP2.1, the DCWorms simulator, developed in the scope of the COOLEMALL project is extended for this. It now provides power consumption over time on: each CPU, nodes, Racks (group of CPU and Hard Disk...), and for all the DataCenter, and also indicator on QoS, in function of internal elements architecture and policy.

WP2.2 exposed internal (from grid to CPU) and external (from sources to grid) electrical architecture for power distribution and ePDU. UPS are extended from ‘classical’ architecture to a more advanced ‘breakthrough’ GDN UPS structure to obtain an efficient green data net. Power Electronics units behaviors are here simplified and constrained to work in certain operating point linked to policy and security.

In WP2.3, several Renewable Energy sources (Fuel Cell, Solar Panel, Battery, Super-Capacitor, Wind turbine) are dealt for this project. In this T0+12 report and Deliverable D2.1 some simplified ‘input/output’ scalable models depending on structure parameters have been detailed.

This report is thus also the first answers to some challenges exposed in the project:

- **Challenge 3. Optimal command of the electrical converters,** because fixing voltage control, MPPT, and local current control letting devices at an identified working point is a way to command optimally the different converters of the electrical infrastructure provisioning the computer equipments.

- **Challenge 4. Scheduling IT load and IT management,** because the programs established allows to read/write some input/output and it takes into account the availability of energies, the internal environmental conditions of the datacenter, the computing load and characteristics (in terms of applications power profile). Due to power failures or intermittent power, applications may be moved or stopped, taking into account their criticality (for the system resilience) and the SLA (Service Level Agreement).
- **Challenge 5. Develop a simulation toolkit,** because these WP2 programs are the first step for **t**he integration of the developed optimization algorithms and the system profiles, from both electrical and IT planes in a common simulation toolkit that will tighten the links between the IT and electrical aspects of the project. Such an integrated simulation toolkit is nowadays absent from the scientific community.

Characteristics included in both elements developed in these three parts are linked and will be implemented with some communication elements and interfaces adaptation refined in the project in an adapted middleware design, and extended to integrate solutions developed in optimization parts. Off-line optimization and on-line decision are established in in the others DataZero WotkPackage and may use these elements and/or ask to complete them. Some complementary modeling and solving approaches can now be studied. In fact discrete data used in power split and task scheduling can allow using Linear programming with Integer Number, combinatorial modeling and bi-level resolution, particularly suitable to manage such complexity and insure solutions.

For WP2.2 on distribution structure, WP2.3 on parameters representing more events on source profiling but also for WP2.1 on some better indicators, evolutions and new ideas should be added to help the other WorkPackage defined during the project. To do so adaptations are open and the **T0+27** deliverable will conclude these WP2 activities.

References

[1] DATAZERO : Appel à projets générique ANR 2015 DATAcenter with Zero Emission and Robust management using renewable energy: DATAZERO

[2] Micha Vor Dem Berge, Wolfgang Christmann, Eugen Volk, Stefan Wesner, Ariel Oleksiak, Tomasz Piontek, Georges Da Costa, Jean-Marc Pierson. CoolEmAll - Models and Tools for Optimization of Data Center Energy-efficiency. In: IFIP Conference on SustainIT (Sustainable Internet and ICT for Sustainability), Pisa, 2012.

[3] Steve J. Chapin, Walfredo Cirne, Dror G. Feitelson, James Patton Jones, Scott T. Leutenegger, Uwe Schwiegelshohn, Warren Smith, and David Talby, ``Benchmarks and Standards for the Evaluation of Parallel Job Schedulers''. In Job Scheduling Strategies for Parallel Processing, D. G. Feitelson and L. Rudolph (Eds.), Springer-Verlag, 1999, Lect. Notes Comput. Sci. vol. 1659, pp. 66-89.

[4] K. Kurowski, A. Oleksiak, W. Piatek, T. Piontek, A. W. Przybyszewski, and J. Weglarz, "Dcworms - a tool for simulation of energy efficiency in distributed computing infrastructures." Simulation Modelling Practice and Theory, vol. 39, pp. 135–151, 2013

[5] GreenDatanet research project http://www.greendatanet-project.eu/

[6] Data Centre Redundancy Levels,March 2016, Dennis O'Sullivan (Eaton)

[7] Eaton 93PM UPS specifications http://powerquality.**eaton**.com/**93P**M/

[8] Eaton 9395P UPS Specifications www.**eaton**.com/9395

[9] Wind Power Electricity: The Bigger the Turbine, The Greener the Electricity?
http://pubs.acs.org/doi/full/10.1021/es204108n
Marloes Caduff*†‡, Mark A. J. Huijbregts§, Hans-Joerg Althaus†, Annette Koehler†, and Stefanie Hellweg†

[10] Leandro Fontoura Cupertino, Georges Da Costa, Ariel Oleksiak, Wojciech PiąTek, Jean-Marc Pierson, Jaume Salom, Laura Siso, Patricia Stolf, Hongyang Sun, Thomas Zilio. Energy-Efficient, Thermal-Aware Modeling and Simulation of Datacenters: The CoolEmAll Approach and Evaluation Results. In : Ad Hoc Networks Journal, Elsevier, Vol. 25 N. B, p. 535-553, 2015

[11] Wojciech PiąTek, Ariel Oleksiak, Georges Da Costa. Energy and thermal models for simulation of workload and resource management in computing systems. In : Simulation Modelling Practice and Theory, Elsevier Science, 2015.

[12] Hongyang Sun, Patricia Stolf, Jean-Marc Pierson, Georges Da Costa. Energy-efficient and thermal-aware resource management for heterogeneous datacenters. In : Sustainable Computing: Informatics and Systems, Elsevier, Vol. 10.1016/j.suscom.2014.08.005, p. 1-15, 2014.

[13] ECM09 –Energy conversion and Management – Ed Elsevier : S. Caux, W. Hankache, D. Hissel, M. Fadel : "PEM Fuel Cell Model Suitable for Energy Optimization Purposes", DOI 10.1016/j.enconman.2009.09.028

[14] FDFC 2008 – article de la communauté PAC (14 labo représentés dont Hissel - Caux) "A review on existing modelling methodologies for PEM Fuel Cell Systems."- FDFC2008, December 10-12th, 2008 - NANCY – FRANCE

[15] 'Electrical, Frequency and Thermal measurement and modelling of Supercapacitor performance', ESSCAP'O8, symposium on supercapacitors ans applications, rome 6-7novembre 2008,: Y Diab, P Venet, H Gualous, G Rojat.

[16] 'Experimental Validation of o Battery Dynamic Model for EV Applications' : O Tremblay, L-A. Dessaint, World Electric Vehicle Journal v3: ISSN 2032-6653 (2009)

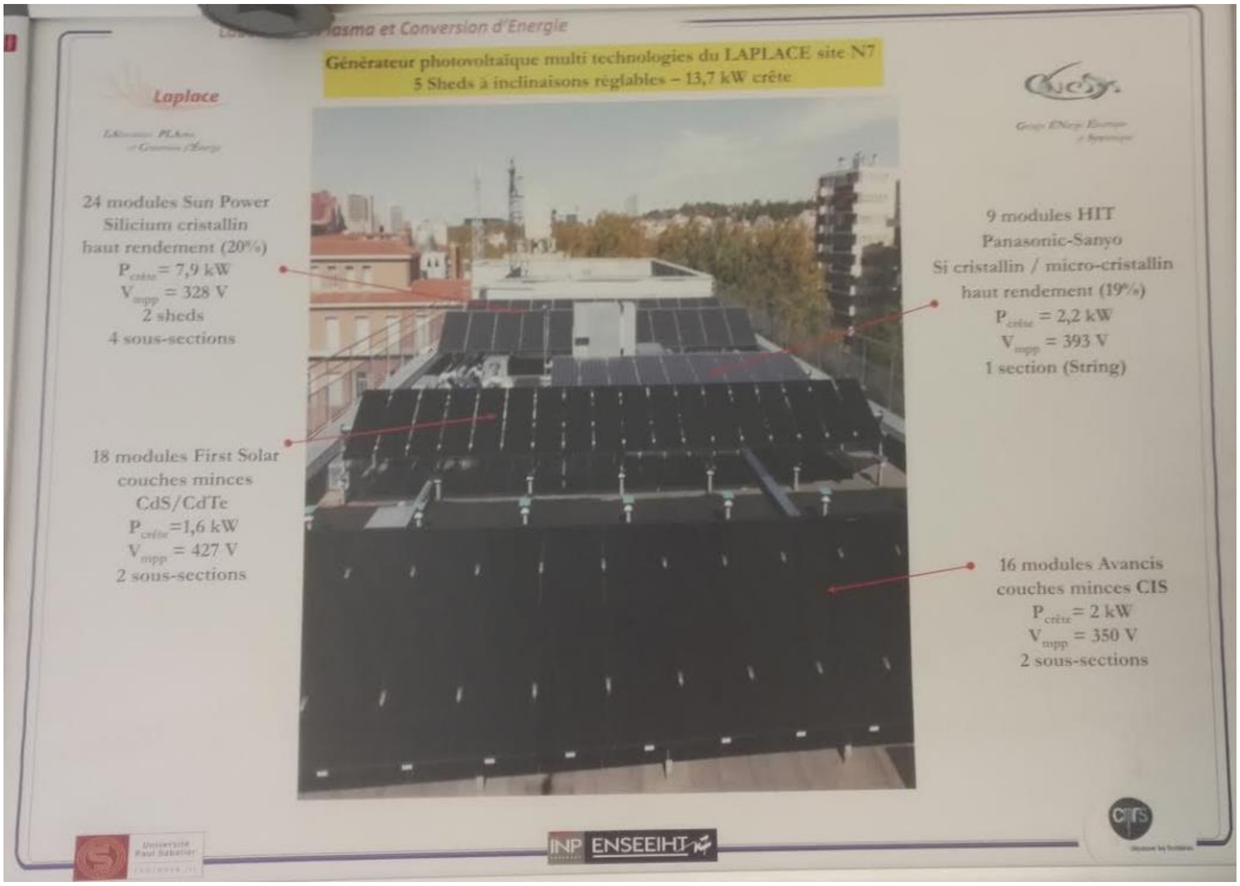
[17] NREL: National Renewable Energy Laboratory report : "Dynamic Models for Wind Turbines and Wind Power Plants", January 11, 2008 – May 31, 2011 : Mohit Singh, Surya Santoso

Annexes

Configuration Parallèle

BATTERIE $LiFePO_4$ 51.2V/78Ah (32 éléments)

CARACTERISTIQUE		VALEUR	REMARQUES
Capacité	Capacité nominal	78Ah	**16 unités en série de 2 éléments 39Ah couplés en parallèle**
	Capacité minimale	76A	
Voltage nominal		51.2V	
Résistance		<40mΩ	
Energie stockée		3993.6Wh≈4kWh	
Charge	Mode de charge	CC/CV	
	Tension maximale de charge	58.4V	56.233V CHARGEUR
	Courant de charge standard	≤30A	Température entre 5°C et 35°C Fin de charge : 0.39 à 3.65V
	Courant de charge rapide	≤1.5C	≤117A **DISJONCTEUR : I_{max}=100A**
	Courant de fin de charge	2A	
Décharge	Tension minimale de décharge	32.0V	44.2V BOOST
	Courant de décharge continu	≤3C	≤234A **DISJONCTEUR : I_{max}=100A**
	Courant maximal pulsé	≤5C	≤390A **DISJONCTEUR : I_{max}=100A**
Courant d'utilisation		≈40A	≈C/2
Masse batterie seule		≈40kg	≈55kg tout compris
Densité énergétique	Batterie	≈100Wh/kg	≈4000Wh/40kg
	Effective (pack complet)	≈72Wh/kg	≈4000Wh/55kg
Utilisation limite	Courant maximal	100A	
	Puissance	≈5000W	


asma et Conversion d'Energie
Générateur photovoltaïque multi technologies du LAPLACE site N7
5 Sheds à inclinaisons réglables – 13,7 kW crête
Laplace
24 modules Sun Power
Silicium cristallin
haut rendement (20%)
P crête = 7,9 kW
V mpp = 328 V
2 sheds
4 sous-sections
18 modules First Solar
couches minces
CdS/CdTe
P crête =1,6 kW
V mpp = 427 V
2 sous-sections
9 modules HIT
Panasonic-Sanyo
Si cristallin / micro-cristallin
haut rendement (19%)
P crête = 2,2 kW
V mpp = 393 V
1 section (String)
16 modules Avancis
couches minces CIS
P crête = 2 kW
V mpp = 350 V
2 sous-sections
INP ENSEEIHT