



Intérêt de la prévision photovoltaïque pour minimiser les impacts sur les réseaux : activités en cours au SIRTA

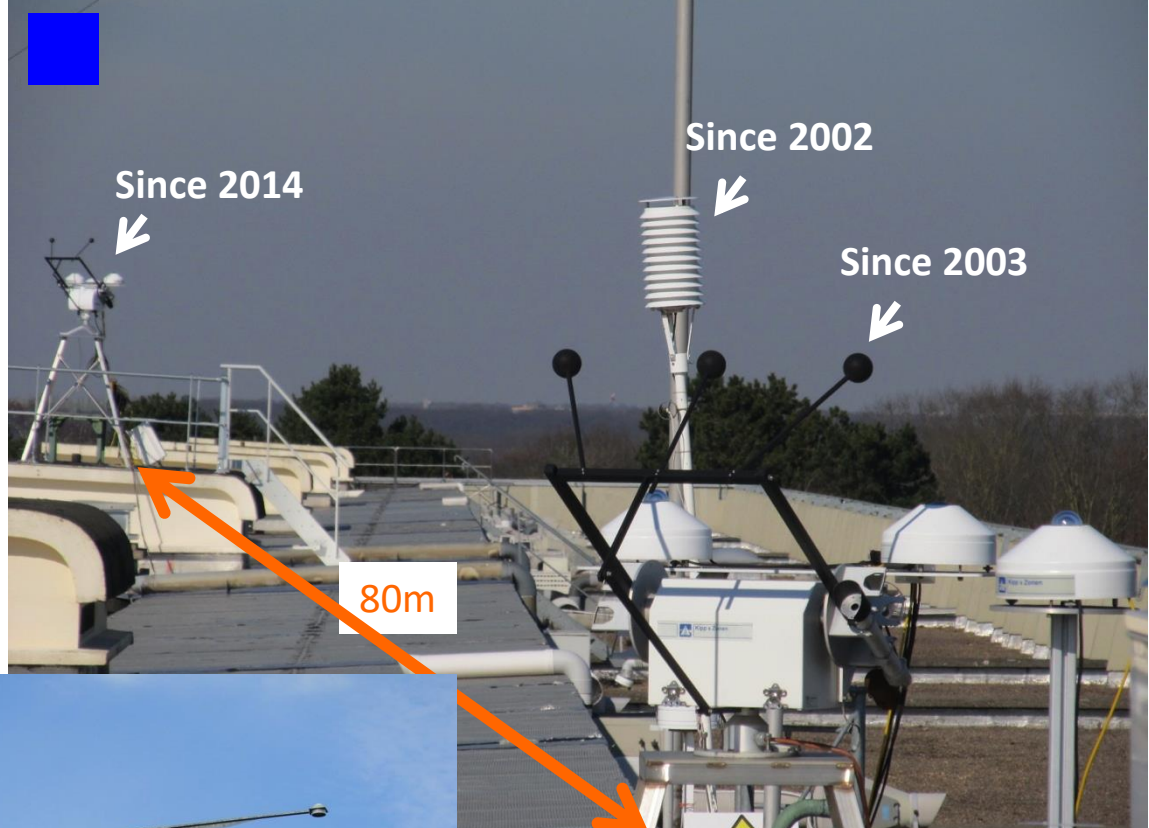
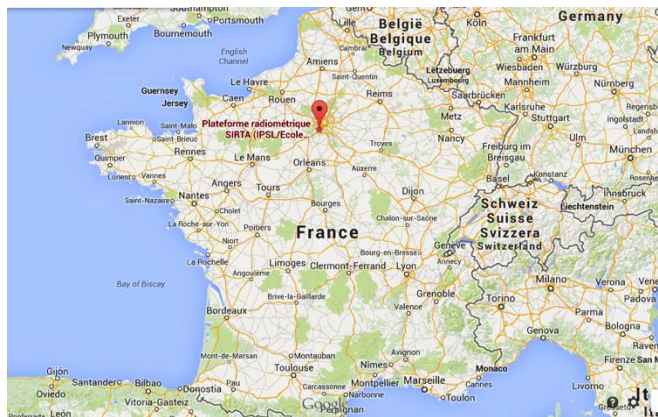
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Station PAL, Paris region, France

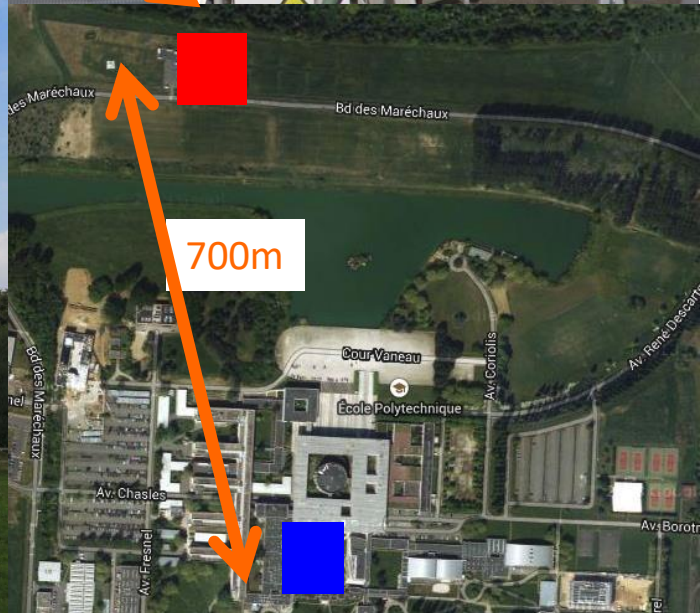


Contribution to BSRN since 2003.

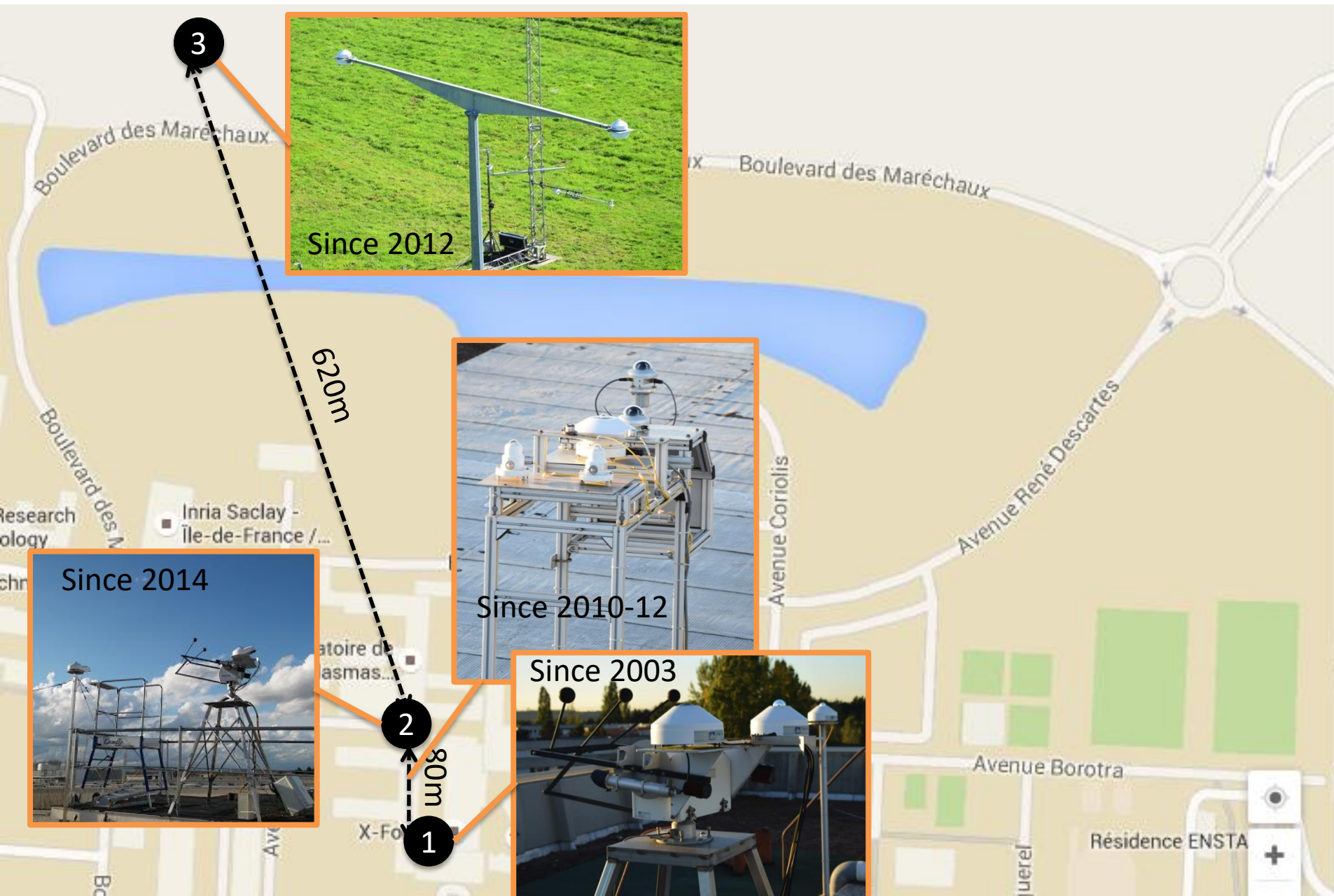
Current available parameters in BSRN archive :

- SWDn (DIF, DIR, GLO), LWDn
- Air temperature, RH, pressure

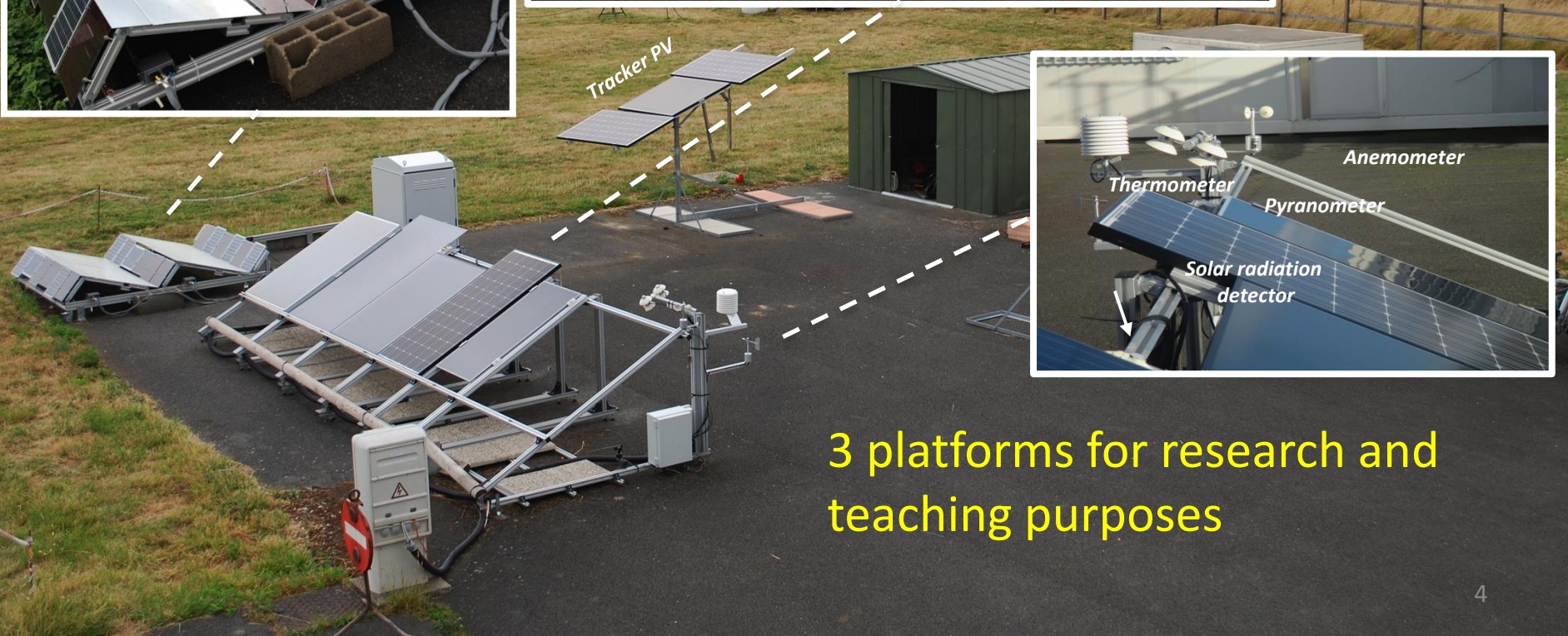
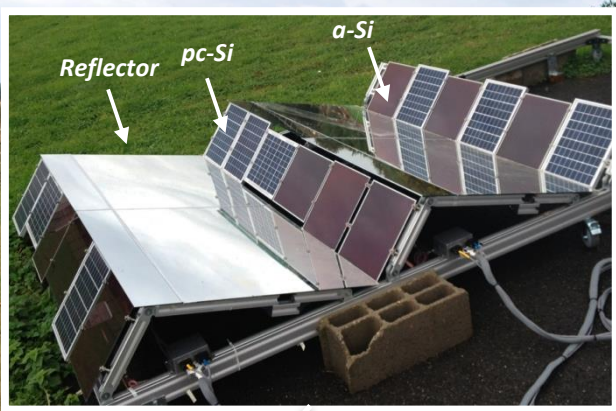
The new installation in 2014 will become reference for the site.



Radiative measurement locations at SIRTA



Photovoltaic characterization under real life conditions



3 platforms for research and teaching purposes

PHOTOVOLTAIC CHARACTERIZATION

Outdoor PV characterisation test bench

$\mu\text{-Si/a-Si}$ tandem

$P_{\text{mpp}} = 128 \text{ W}$

$\eta = 9,5\%$ **SHARP**

Thin film technology

CIS

$P_{\text{mpp}} = 150 \text{ W}$

$\eta = 12,2\%$

Thin film technology



CdTe

$P_{\text{mpp}} = 82,5 \text{ W}$

$\eta = 11,4\%$

Thin film technology



C-Si

$P_{\text{mpp}} = 250 \text{ W}$

$\eta = 15\%$

1st generation



a-Si triple junction



$P_{\text{mpp}} = 144 \text{ W}$

$\eta = 6,7\%$

Thin film technology



HIT

$P_{\text{max}} = 240 \text{ W}$

$\eta = 19\%$ **Panasonic**

Best PV efficiency

Intérêt de la prévision de la production et de la demande

Opérateurs Réseau & Grandes centrales



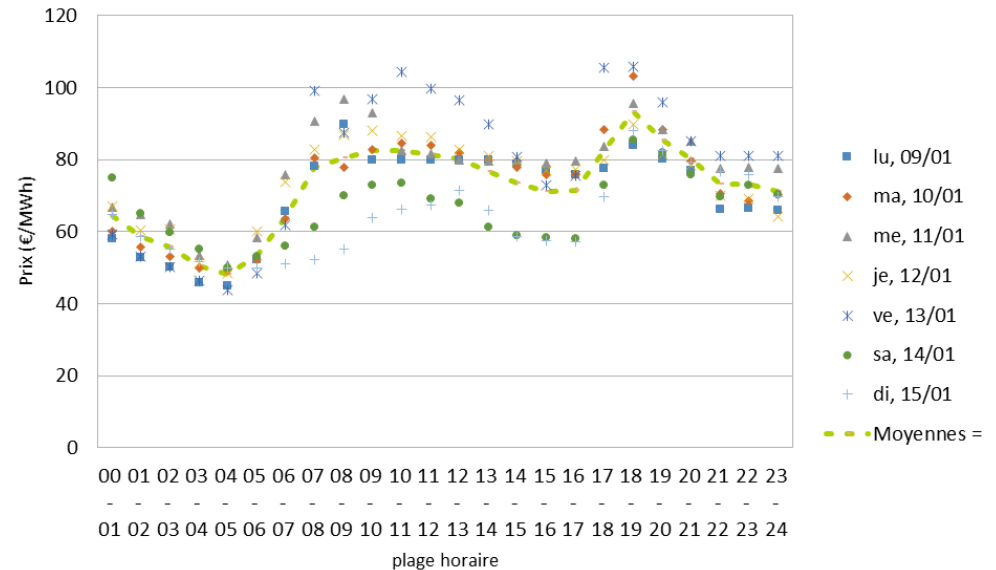
Equilibrage réseau :

- Production
- Effacement

Trading :

- Injection
- effacement

Prix Spot



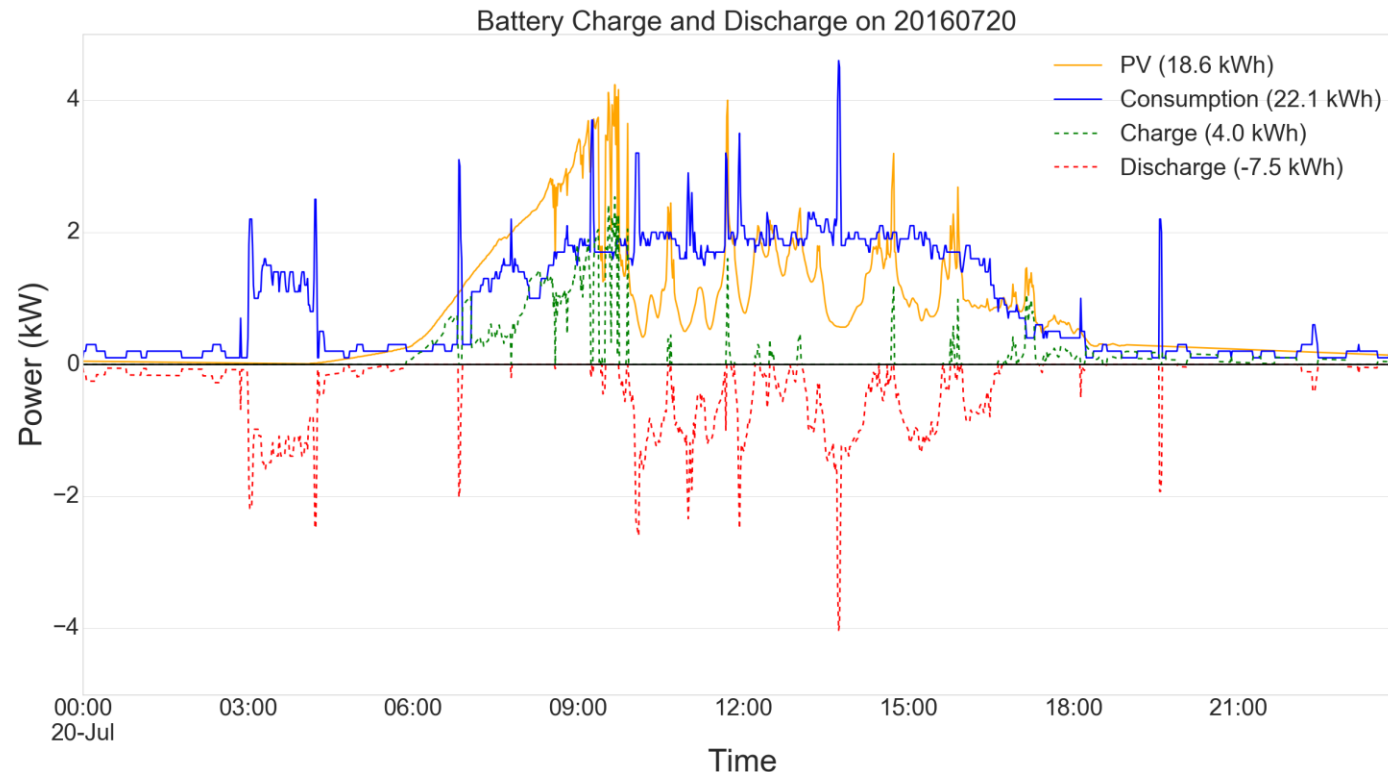
Intérêt de la prévision de la production et de la demande

Micro réseaux ilotés ou raccordés

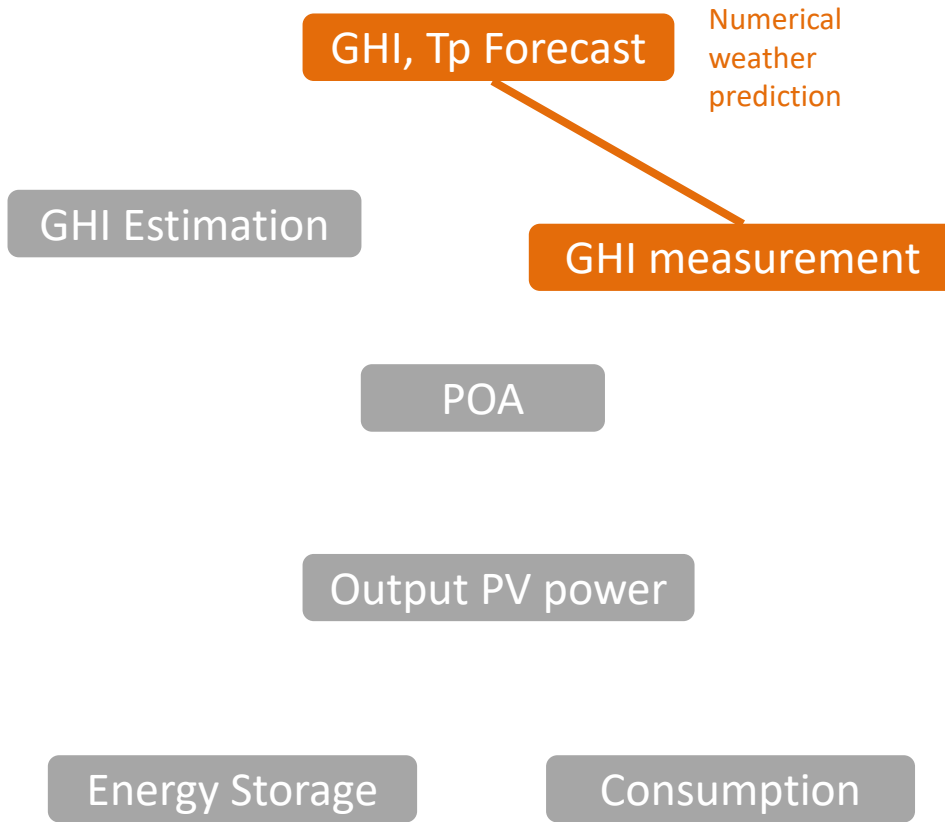
Zone éloignée du réseau 100% autoconsommation et autoproduction
Equilibrage réseau :

- Minimiser l'impact pour une injection massive d'ENR
- Contribuer à la stabilisation

Trading ?



Etudes en cours



GHI: Global horizontal irradiance
 POA: Plane of array irradiance
 Tp : Panel temperature

Numerical weather prediction



Evaluation of Day-ahead Solar Irradiance Forecasts

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INTRODUCTION AND OBJECTIVES

- Global Horizontal Irradiance (GHI) is the amount of solar radiation that reaches the surface of the Earth.
- The forecast of solar irradiance has an importance in predicting the amount of energy potentially generated in solar photovoltaic (PV) installations.
- The purposes of this research are to:
 - compare different forecast model performances,
 - understand the seasonal difference with regards to the forecast accuracy, and
 - acquire prerequisite knowledges to improve forecast models by observing the uncertainty quantities based on different types of days.

METHODOLOGY

- The ground-based GHI measurement is from SIRTA. (48.713°N and 2.208°E)
- Arome and Arpege of Météo France are the forecasts.
 - Models named with 'D+1' are calculated at 12 UTC on the previous day, while the 'D's are computed at 0 UTC of the target forecast day.
- One-hour resolution data are acquired over the period of one year, from December 1st, 2015 to November 30th, 2016.
- Persistence model with one-day lagged values is used to fairly compare different methods of day-ahead forecasts. Regarding comparison, root mean square error (RMSE) and mean bias error (MBE) are considered in relative manner as following:

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (F(i) - I(i))^2} \quad MBE = \frac{1}{N} \sum_{i=1}^N (F(i) - I(i)) \quad \begin{matrix} F = GHI \text{ Forecast} \\ I = GHI \text{ Measurement} \end{matrix}$$

$$Relative\ RMSE = \frac{RMSE_{Forecast}}{RMSE_{Persistence}} \quad Relative\ MBE = \frac{MBE_{Forecast}}{\sum_{i=1}^N I(i)}$$

- For different types of days, days with clear sky index ($= \sum I / \sum I_{clear}$) of more than 0.7 are defined as clear days, more than 0.4 are variable and the others are cloudy. Examples of each type of the days are as following :

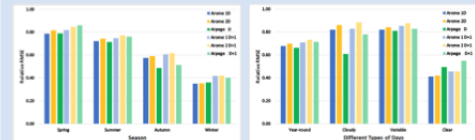


ACKNOWLEDGEMENT

This work was conducted in the frame of the TREND-X research program of Ecole Polytechnique, supported by Fondation de l'Ecole Polytechnique.



RESULTS



- Relative RMSE graphs (above) show that the forecasts of 'D have tendency to have less error than that of 'D+1's, meaning that the day-ahead forecasts perform better with the up-to-date data. 'D+1's and 'D's differ by 12 hours.
- Seasonal graphs show that the relative errors are the highest in the spring. Considering the solar irradiance is the highest in the summer, it is inferable that the primary reason of errors is not the position of the sun.
- Arpege model shows better performance than Arome in general, except in the Winter and Clear days. The two day-ahead forecast models show that the ensemble model of them might result in the improvement of forecasts.



CONCLUSION

- Matching with the objectives of the research,
 - In day-ahead forecasts, up-to-date data are one of the core competencies in predicting with higher accuracy.
 - Arpege performs better than Arome not always, but in general. Especially in the winter and the clear days, Arome showed better performance.
 - The forecast uncertainty does not primarily rely on the position of the sun. It would rely on what is in between the Sun and the GHI instrument.

RESEARCH TRAJECTORY

- The evaluation metrics of RMSE and MBE do not convey a measure of the variability of the time-series for the solar irradiance data. Thus, the studies will further focus on:
 - First, evaluation of day-ahead time-series solar irradiance uncertainty.
 - Second, improvements of day-ahead forecast models using Statistics.

Etudes en cours

GHI, Tp Forecast

GHI Estimation

GHI measurement

Variability study
Day types

POA

Output PV power

Energy Storage

Consumption

GHI: Global horizontal irradiance
POA: Plane of array irradiance
Tp : Panel temperature



LES MICRO-CLIMATS SUR L'ÎLE DE LA RÉUNION - QUELS ENJEUX POUR LA PRODUCTION PHOTOVOLTAÏQUE ?

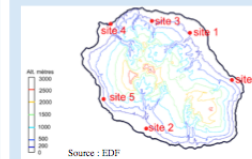
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OBJECTIFS – ENJEUX

Quatre ans de mesures d'irradiance au sol (2013-2016), acquises sur six sites de mesure LE2P/EDF dispersés sur l'île de la Réunion, ont été exploitées pour étudier la climatologie de l'île. Trois micro-climats clés ont été identifiés grâce aux critères d'énergie, de variabilité du rayonnement, et de différence AM/PM de l'indice de ciel clair. Cet exposé présente la situation climatologique de l'île et son impact sur la production photovoltaïque (PV).

DISPOSITIF INSTRUMENTAL



Six sites de mesure sur l'île de la Réunion



WXT520

SPN1

4 ans de données minutaires :

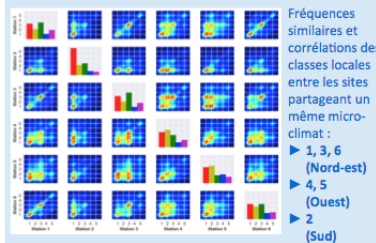
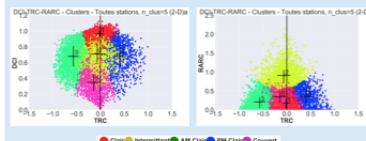
- ▶ De l'irradiance (GHI, DHI)
- ▶ Du vent à 10 m (vitesse, direction)
- ▶ De la température extérieure à 10 m
- ▶ De la pression atmosphérique
- ▶ De l'humidité relative

RESULTATS

| Indicateur journalier | Equation | Sens physique |
|-----------------------|----------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| DCI | $\frac{\sum_{i=1}^n (10^{-0.18} \frac{GHI_{MEAS}(i)}{GHI_{MET}(i)})}{n}$ | Quantité de rayonnement normalisée |
| DVI | $\frac{\sum_{i=1}^n (10^{-0.18} \frac{GHI_{MEAS}(i)}{GHI_{MET}(i)} - 1)}{n}$ | Variabilité cumulée du GHI (normalisée) |
| TARC | $\frac{\sum_{i=1}^n (10^{-0.18} \frac{GHI_{MEAS}(i+1) - GHI_{MEAS}(i)}{GHI_{MET}(i)})}{n}$ | Variabilité cumulée du ΔI (I) |
| TRC | $\frac{\sum_{i=1}^n (10^{-0.18} \frac{GHI_{MEAS}(i+1) - GHI_{MEAS}(i)}{GHI_{MET}(i)} - \Delta I_{MET}(i))}{n}$ | Différence matin / après-midi de ΔI (I) |
| RARC | $\frac{\sum_{i=1}^n (10^{-0.18} \frac{GHI_{MEAS}(i)}{GHI_{MET}(i)})}{n}$ | Variabilité instantanée cumulée du ΔI (I) |

Définition des indicateurs journaliers en s'appuyant sur les critères d'énergie, de variabilité, et de différence AM/PM ($k_c = GHI_{MEAS}/GHI_{MET}$)

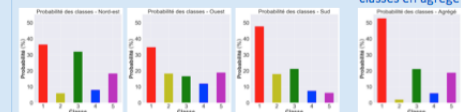
Les journées, caractérisées par DCI, TRC, et RARC, ont été groupées en 5 classes locales



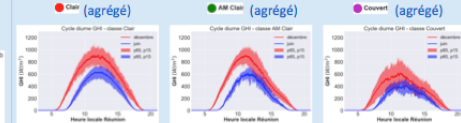
Fréquences similaires et corrélations des classes locales entre les sites partageant un même micro-climat :

- ▶ 1, 3, 6 (Nord-est)
- ▶ 4, 5 (Ouest)
- ▶ 2 (Sud)

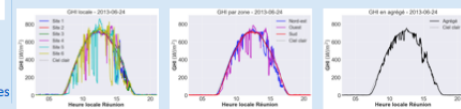
Histogrammes des classes par zone



Trois classes de conditions météorologiques ressortent en agrégé :



Effet de lissage sur le rayonnement



CONCLUSIONS

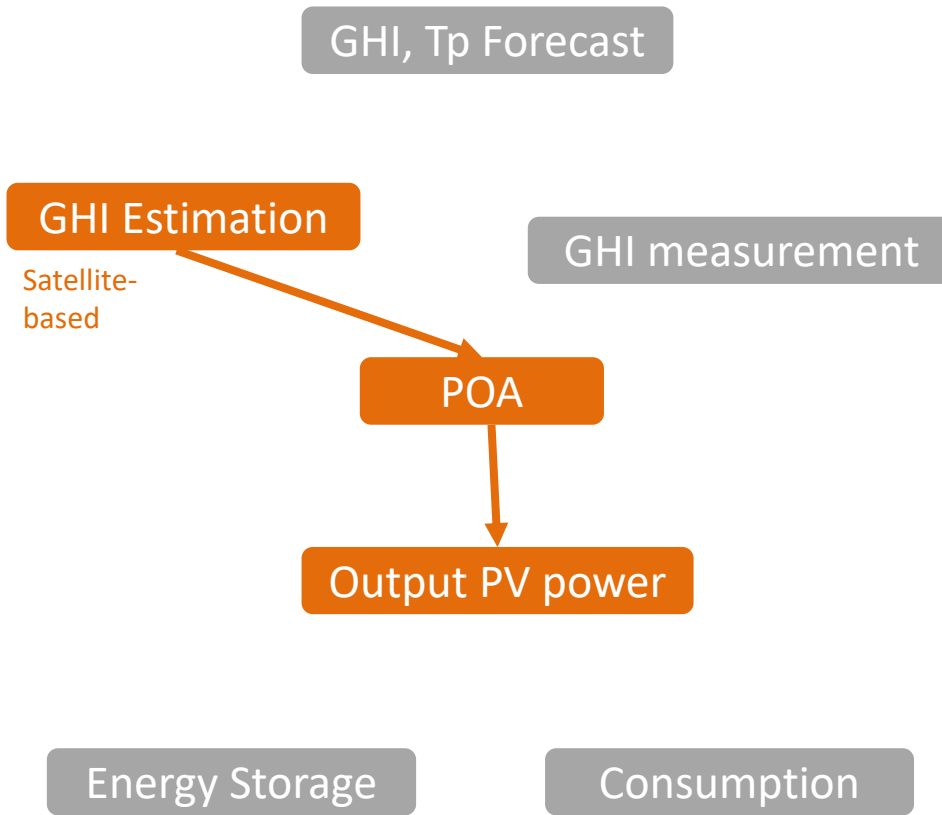
- ▶ Nous présentons une méthode pour classifier les types de jours sur l'île de la Réunion. Nous retrouvons cinq journées type (classes).
- ▶ À partir des fréquences et des corrélations de classes, nous trouvons 3 micro-climats clés dans 3 zones distinctes (Nord-est, Ouest et Sud)
- ▶ La variabilité est diminuée en agrégeant les sites par zone ou sur l'île
- ▶ En agrégé, 3 journées type peu variables ressortent, simplifiant la prévision de la production photovoltaïque et la gestion du réseau

REMERCIEMENTS

Cette étude a été conduite dans le cadre du programme de recherche TREND-X de l'École Polytechnique, soutenu par la Fondation de l'École Polytechnique



Etudes en cours



SIRTA **VERS UN MODÈLE END-TO-END DE LA PRODUCTION DES CENTRALES PHOTOVOLTAÏQUES** **QUANTOIM** **LMD**

Auteurs : Thibaut Lecallier, Marko Pavlov, Jordi Badosa, Harold Darras, Vincent Bourdin, Anne Migan-Dubois
 Contributeurs – Quantum, LMD, GEEPS, LIMSI

CONTEXTE
 Un modèle end-to-end de la production des centrales photovoltaïques permet :
 - De comprendre le comportement d'un site donné.
 - De faire une prospective de la production d'une centrale à construire.
 - D'essayer d'améliorer la production d'un parc photovoltaïque avec des miroirs par exemple.

OBJECTIFS ET MÉTHODES
 L'objectif est de modéliser la production d'un onduleur à partir des données d'irradiance d'un satellite géostationnaire, et du modèle CAMS^[1]
 Site étudié : centrale dans le sud-est de la France, d'une puissance installée de 1,3 MW, qui possède 3 onduleurs centraux. Les panneaux sont inclinés à 19° et orientés à 23° ouest.

DESCRIPTION DU MODÈLE

Données CAMS
 Angles : inclinaison et orientation des panneaux, angles solaires

Conversion GPOA → Modèle PString → Efficacité onduleur Pdc → Modèle de Sandia^[2] → Efficacité conversion DC-AC Pac

Mesures onduleurs → Cycles diurnes d'efficacité par string.

Effacité moniteur de string

Ciel clair **Journée intermittente** **Ciel couvert**

Tous les jours

$rMBE = \frac{modèle - mesure}{mesure} \times 100$
 $RMSE = \sqrt{\text{mean}(modèle - mesure)^2}$

$RMSE = \sqrt{\frac{\text{mean}(modèle - mesure)^2}{\text{mean}(mesure)^2}}$

CONCLUSION
 Il est possible de simuler les performances d'une centrale photovoltaïque, à partir de sa géométrie et des données d'irradiance satellite.
 L'objectif est maintenant d'en améliorer les performances en ajoutant des miroirs face aux panneaux.

Glossaire
 AC = Alternative Current
 BPOA = Direct irradiance on the plane of incidence.
 DPOA = Diffuse irradiance on the plane of incidence.
 DC = Direct Current.
 GPOA = Global irradiance on the plane of incidence.
 Pac = puissance à la sortie de l'onduleur (courant alternatif).
 Pdc = puissance, du courant continu, avant la conversion en courant alternatif.
 PString = Puissance électrique à la sortie d'un string.
 rMBE = Relative mean bias error
 RMSE = Root mean square error

Ratio de performance

| Année | Modélisation | Mesure |
|-------|--------------|--------|
| 2013 | 79.18% | 84.02% |
| 2014 | 80.11% | 83.19% |
| 2015 | 82.18% | 86.23% |

Ratio = $\frac{\text{Energie par satellite}}{\text{Energie nominale}} \times 1000 \text{ Wh/m}^2$ / $\frac{\text{GPOA}}{\text{GPOA}}$

Références :
 [1] : M. Schroedter-Homscheidt. *The Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service in a nutshell*. ECMWF Copernicus Report, 2016
 [2] - David L. King, Sigifredo Gonzalez, Gary M. Galbraith, and William E. Boyson, *Performance Model for Grid-Connected Photovoltaic Inverters*, Sandia Report, 2007

GHI: Global horizontal irradiance
 POA: Plane of array irradiance
 Tp : Panel temperature

Etudes en cours

GHI, Tp Forecast

GHI Estimation

GHI measurement

POA

Small emulated scale

Output PV power

Energy Storage

Consumption

GHI: Global horizontal irradiance
 POA: Plane of array irradiance
 Tp : Panel temperature



PV-powered Nanogrid hardware & software development for academic experimentation

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 Victorien Hamon – IUT Cachan (victorhamon@yahoo.fr)



OBJECTIVES

- To study small-scale low-voltage DC power systems
- Develop a hardware that allows to test basic energy management algorithms in a PV powered nanogrid
- To have a system for teaching experimentation in smart grids, small scale DC power systems and renewable energies
- To record real time data of the electrical behavior of this type of systems that can serve for further research

The system is intended to be a starting point for further developments of the hardware & software to include other renewable sources, alternative storage means as well as meteorological information to support the energy management of the system

INSTRUMENTAL SETUP

- 240 W HIT Solar panel
- 50 W Solar simulator
- 2kW electronic variable load
- 100 Ah lead-acid deep-cycle Battery
- RaspberryPI + Arduino microcontrollers



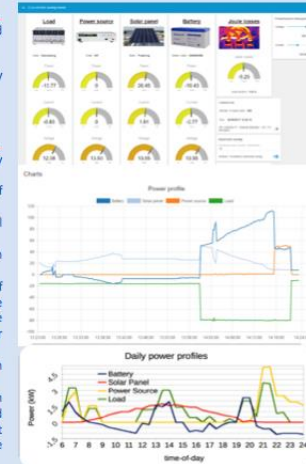
SYSTEM OUTCOMES

Measurements

- Current, voltage, power and cumulated energy of each element
- Joule losses of the system
- Irradiance & panel temperature in PV simulator mode
- Date & time and recorded data counter

Functionalities

- Real-time power & cumulated energy graphs for all the elements
- Visual indications regarding the sense of the power flow for each element
- Remote voltage and current limit control of the power source
- Manual connection/disconnection of each element of the system
- Automatic disconnection of the elements if voltage/power limits are surpassed. The system warns the user before disconnection (limit values can be user defined).
- Manual and Remote selection between external PV panel or PV simulator
- Two modes for irradiance input in simulation mode: manual and pre-loaded daily irradiance profile. Four different "type of days" can be chosen, which can be defined by the user



- Creation of excel file in simulation mode with the recorded data (V,I,P,E), power & energy graphs and performance parameters. The file is send by mail automatically to the user at the end of the simulation cycle
- User-defined simulated battery size and initial state of charge. View of the current state of charge.
- Possibility of user-defined power scale factor to simulate bigger PV arrays in simulation mode

Small scale DC power systems

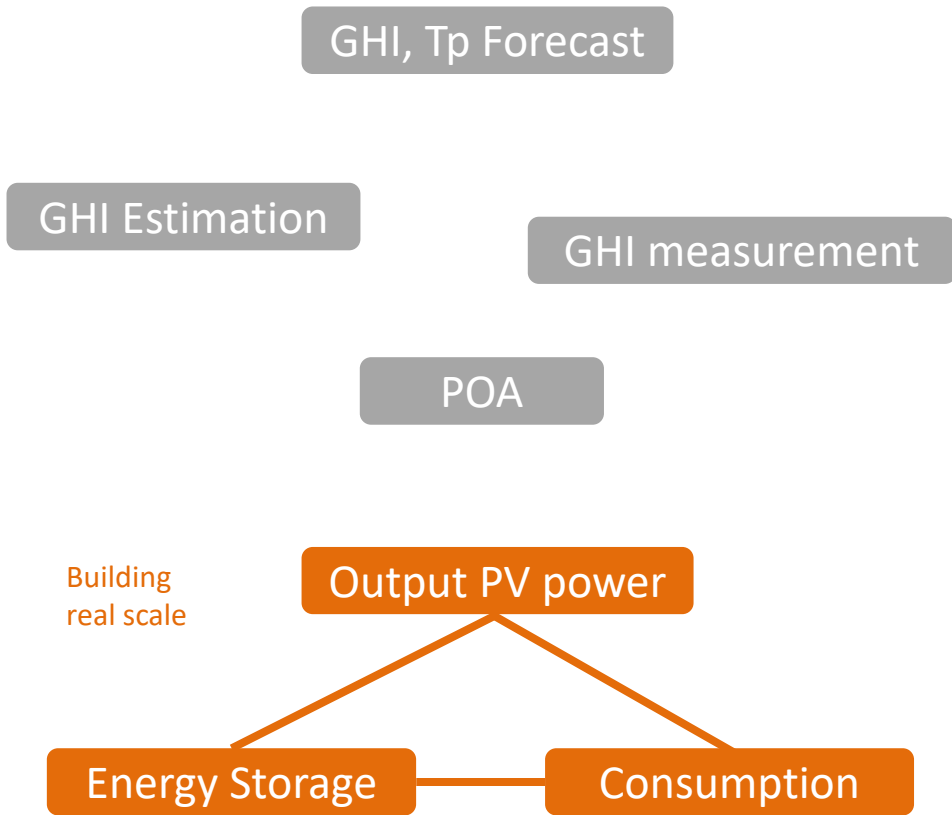
- The equilibrium point between demand and consumption is always passively assured by the system as long as there is enough production to satisfy the demand
- If the system cannot supply the demand required, the voltage of the system drops until finding the balance point. If this point is not found, the system will 'collapse'
- Voltage is the agent that controls the flow of power between the elements. Voltage control of the elements is mandatory if manipulation of the flow of power in the system is required

REMERCIEMENTS

Universidad de Costa Rica, Siebel Energy Institute and TREND-X program of École Polytechnique for the partial funding of this project, with the support of Fondation de l'École Polytechnique



Etudes en cours



GHI: Global horizontal irradiance
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 Tp : Panel temperature



MICROGRID FLEXIBILITY STUDY: ACHIEVING HIGHER SELF-CONSUMPTION

Stuart Jackson, Jordi Badosa, Elodie Gigout, Philippe Drobinski, Vincent Bourdin
 LMD, Trend-X R&D, contact : Stuart.jackson@polytechnique.fr



Objectives - Challenges

The Drahi-X building at Ecole Polytechnique will be equipped with photovoltaic roof-top installation and a battery storage system. Analysing consumption data from the building and production data from the solar panels, we aim to understand load demand variability and potential flexibility in the building. Through qualitative analysis we also aim to identify human behaviour that can be changed to improve consumption flexibility in order to better match production and increase self-consumption.

Data available for the Drahi-X Optimization

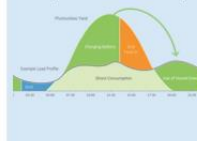
The 7 Zones at the Drahi-X Innovation Building

1 year of minute data:

- ▶ Building consumption data from all zones (kWh)
- ▶ Photovoltaic production (kWh)
- ▶ Air temperature (°C)

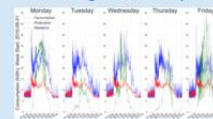
Flexible Consumption

Flexible production and consumption



Flexible consumption is the amount of PV production or load demand that can be shifted by storing surplus PV production in batteries and releasing at a later time, or by changing the time of demand.

Establishing flexible consumption



The goal is to optimise for self-consumption by minimising electricity taken from the grid. It is then necessary to identify the amount of production and load that can be shifted to synchronize with PV production.

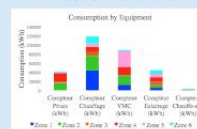
- ▶ Identification of flexible electricity consumption
- ▶ Determine the incentives to achieve load shifting
- ▶ Determine the amount of consumption that can be shifted by a change in behaviour
- ▶ Determine the amount of consumption that can be shifted by technical means

Battery Modelling



When loads are considered critical there is no room for optimisation. Therefore optimisation requires the identification of loads that can be curtailed or rescheduled.

Disaggregated consumption

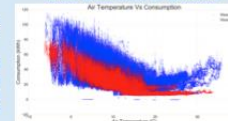


Understanding building equipment:

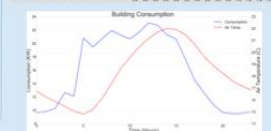
- ▶ Identify critical loads – essential to buildings operation
- ▶ Curtailable loads – loads that can be temporarily reduced
- ▶ Reschedulable loads – loads which can be rescheduled

- ▶ The biggest consumer of electricity at the Drahi-X building is the heating and cooling system
- ▶ To reduce load from heating and cooling systems it is necessary understand the relationship between outside temperature and consumption

Consumption Vs Air Temperature



Monthly temperature commands



- ▶ Data from the heating and cooling systems reveal human interaction and behavioural patterns with temperature
- ▶ It shows when the system is switched on/off and when a temperature change is demanded
- ▶ Reduced consumption is possible by optimising the heating and cooling system using behavioural knowledge
- ▶ Real time alerts informing users of consumption peaks and curtable/rescheduling possibilities can improve self-sufficiency

Acknowledgements:

This work was conducted in the frame of Trend-X research program at Ecole Polytechnique, supported by Fondation de l'Ecole Polytechnique. We would like to thank Amisi Francis for the operational specification of the heating and ventilation system, and to the entire SIRTA team.



Thanks for
your attention

