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TECHNICAL DESIGN AND CHARACTERIZATION OF A GROUND BASED SOLAR METROLOGY NETWORK ON REUNION ISLAND

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ABSTRACT

The roadmap of Reunion Island regarding energy is to reach autonomy by 2030. Obviously, renewable energies will play a key role in this ambitious project. However, a couple of years ago, a limit set by the French government relatively to the amount of lethal power injected on the electrical grid stopped the thrust: at any time, intermittent sources should not exceed 30 % of the whole production. This is due to the fragility of the grid: rugged topography, no interconnection.

The University of La Reunion through the LE²P lab (Energy, Electronic and Process) decided to search a solution by predicting the solar resource in order to erase part of the intermittency of the production coming from the solar plants. Along this track, the first step is to evaluate precisely the resource and study its spatio-temporal variability. To do so, the LE²P gets engaged in deploying, at ground level, a network of monitoring stations. These units should be capable to produce field data responding to specific requirements in terms of acquisition frequency and quality, compatible with the clustering tools and mapping programs developed beside.

Today, LE²P team manages a fleet of more than 15 stations, with various configurations, all over Reunion Island and plans to extend its network to neighboring territories.

This article proposes to present in details the different components of a typical station, how they have been selected and how they are maintained.

We will also see how the lab gets organized in order to propose top quality data to the solar scientific community.

Keywords - Solar irradiance, Metrology, Insular Grid, Pyranometer, Spatio-Temporal Variability

Nomenclature:

k_b	[-]	Direct fraction, experimental index giving an image of the atmosphere transmission
f_{diff}	[W/m²]	Diffuse radiation
f_{glo}	[W/m²]	Global radiation
f_{dir}	[W/m²]	Direct radiation

Subscripts

H	Hour
D	Day

INTRODUCTION

In the context of sustainable energy development policies, socio-economic impact of alternative energy resources due to global depletion of fossil fuels and the reduction of anthropogenic pollution, the situation of Reunion Island - as most of tropical islands - appears to be particularly singular:

- ⇨ total energy consummated on the territory increases by 2.5 % every year (2 970 MW in 2014)
- ⇨ Reunion Regional Council ambitious scope is to bring the island to the energy autonomy by 2030
- ⇨ today, still 64 % of the energy come from imported fossil energy
- ⇨ when looking at the renewable - current and potential - resources, the island is located in an particularly interested region: from 1 100 to 2 100 kWh/m²/year of solar radiation [5], steady trade winds, ideal tropical conditions for biomass...
- ⇨ however, today, no more than 30 % of the energy injected on the grid, at any time of the day, may come from lethal sources: this is mainly due to the topography of the territory which allows only one peripheral distribution line on the island, and its isolation which prohibits any inter-connexion off the island.

Facing this challenging goal, LE²P team decided, a few years back, to search ways to erase as much as possible the lethal character of renewable resources following the prediction path: if you know your resource, you can predict it, you can then predict how much electrical power you can get from solar plants. This way, you remove part of the production uncertainty.

Reunion Island is a young volcanic island with altitudes going up to 1 600 m in inhabited areas (top summit is at 3 069 m), with steep slopes and deep ravines excavated by torrential rains, with windward and leeward coasts, with onshore and offshore breezes, with distinct seasons, diversified local weather regimes and significant orographic forcing. Moreover, the superimposition of seasonal wind patterns on both sea and land breezes modulate the diurnal variability throughout the year.

The spatio-temporal profiles of the solar resource are consequently pretty complex.

One way to give oneself the chance to characterize the resource as finely as necessary for the prediction tasks is to monitor it at ground level where the production plants are located. Meteorological parameters are to be followed as well.

In 2011, LE²P team started to deployed solar measurement stations. Today, we manage a fleet of 15 stations or so.

This paper presents the work that is being conducted on Reunion Island in order to get as much knowledge as possible on the solar resource at ground level. There are three main goals to this work: the development of mapping tools that deal with finer spatial scales, the management and the monitoring of the quality of observed data, the short term forecasting for intelligent handling of intermittent resources.

The first section will present the observation instruments and the structure of the observational network. A brief overview of the organization of the website will be then presented.

A GROUND LEVEL RADIOMETERS NETWORK

Started in 2011, the RCI_GS project funded by EU, the Regional Council and the French government permitted to spread across Reunion Island around 12 stations (with a reference unit dating back to 2008). All the stations provide global horizontal irradiance, diffuse horizontal irradiance at 1-minute averaged time using SPN1, a 2-in-1 pyranometer from Delta-T Devices [23, 24], and meteorological data using the 6-in-1 sensor WXT520 from VAISALA [17, 18].

As shown in Figure 1, the past and current campaigns cover more than twelve sites, mainly located along the coast. The heights of the island have been investigated only in one place in the circus of Cilaos (1 720 m).

The network is composed of three different types of stations:

- ⇨ the reference station located in Saint-Denis on the university campus: it is equipped with referenced sensors.
- ⇨ the fixed stations hosted within EDF's dispatching sites (EDF is the national grid operator): for these five stations, a specific arrangement has been developed as the sensors are located on top of a 10-meter high folding mast.
- ⇨ mobile stations: compact, easily portable and deployable, these stations have been forecast for 1-year campaign in one place then moved to another.

For the next couple of years, LE²P team foresees to extend RCI_GS network, using the same equipment, to neighboring countries: Comoros, Madagascar, Mauritius, Seychelles and as far as South Africa.

The installation of a station on Mauritius should be finalized within a couple of months.

Concerning South Africa, it is to be mentioned that the universities have been developing their own ground level network based on the suntracker technology. It is the SAURAN network (SA Universities Radiometric Network, www.sauran.net). The scientific cooperation between Reunion Island and South Africa, started two years ago, should soon allow to share stations of both technologies on both networks.

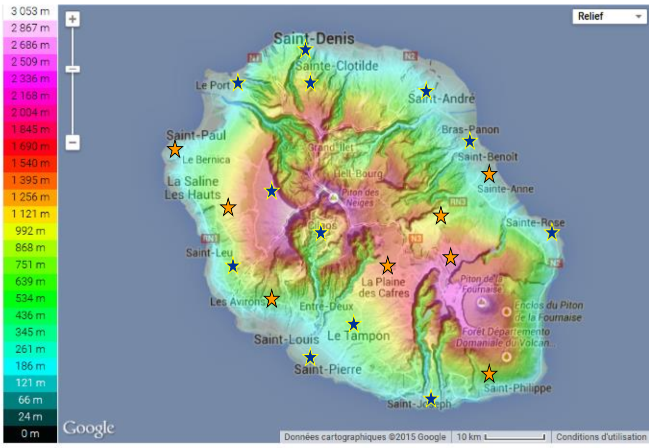

Figure 1 Localization of RCI_GS for past and on-going campaigns (yellow stars) as well as for forecast campaigns (black stars)

Figures 2 and 3 Pictures of a typical mobile station on the left and typical fixed station on the right (EDF plants)

TECHNOLOGY CHOICES

The overall required specifications of the network defined in 2010 were quite simple: the typical station is to be mobile, robust, easy to handle, easy to maintain, capable to resist to standard cyclonic winds with sensors offering an accuracy fine enough for solar radiation prediction works.

As the goal is to deploy a whole regional netwotk, the financial aspect is also important: equipment should also present an interesting price - quality ratio.

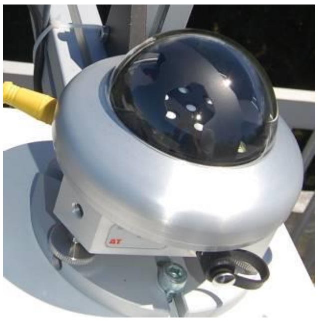

Figure 4 The SPN1 radiometer from Delta-T Devices

The SPN1 pyranometer [24] is fitted with an array of seven miniature thermopile sensors and a specific computer-designed shading pattern which allows to measure, at the same time, the direct and diffuse components of incident solar radiation.

This pyranometer has a spectral response set between 400 - 2700 nm with a solar radiation measurement range of 0 to > 2000 W/m² and an overall accuracy of ± 10 W/m². It is a compact, light weight and easy-to-use and easy-to-maintain instrument with no moving parts for tracking, no shade rings. Two analog voltage outputs are provided for global and diffuse radiations. The extended SPN1 features are shown in Table 1.

Response Time	0.1s
Zero off-set response	< 3W/m²
Resolution	0.6 W/m²
Non-stability	< 1%
Directional response	±20 W/m²
Spectral sensitivity	±10% (0.4-2.7 mm)
Temperature response	±1%
Achievable uncertainty	5%

Table 1 SPN1 specifications

Data from SPN1 may be collected via analog voltage outputs or digital RS232 signal. Besides, the instrument is equipped with an internal heater.

Figure 5
The 6-in-1 WXT520 from VAISALA for weather monitoring

The meteorological multisensor WXT520 is also a compact and light weight instrument. This is a VAISALA weather transmitter which measures temperature, relative humidity, barometric pressure, precipitation, and wind speed and direction.

The measurement range and accuracy are respectively of [-52 +60] ± 0.3 °C for temperature, [0 100] ± 3 % for humidity, [600 1100] ± 1 hPa for pressure, 0.01 mm for cumulative rain accumulation, [0 60] ± 0.3 m/s for wind speed, [0 360] ± 3° for wind direction. More details on WXT520 specifications are shown in Table 2.

Operating temperature	-52 … + 60°C
Storage temperature	-60 … + 70°C
Operation voltage	5 … 32 VDC
Typical power consumption	3 mA at 12 VDC
Heating voltage	5 … 32 VDC . / 5 … 30 VACRMS

Table 2 WXT520 general specifications

Communication with the sensors is possible via a SDI-12 digital link.

All information going from and to the sensors passes through the well-known data logger CR1000 from Campbell Scientific (see specifications in Table 3).

Maximum scan rate	100 Hz
Analog Inputs	16 single-ended/8 differential
Pulse counters	2
Switched excitation channels	3 V
Digital Ports	8 I/Os or 4 RS-232 COM
Communications/ Data storage Ports	1 CS I/O , 1 RS-232, 1 parallel peripheral
Switched 12 Volt	1
Input Voltage Range	± 5 VDC
Analog volatge accuracy	±0.06 % (0° to 40°C)
Analog resolution	0.33 mV
A/D Bits	13
Operating system memory	2 MB flash

Table 3 CR1000 general specifications

All our data loggers [19] are equipped with CompactFlash memory card as storage medium and use GPRS dual-band modem for sending or receiving information (data and alarms / errors to be downloaded; program, clock synchronization and instructions to be uploaded…). Access to Internet is also possible using TCI/IP protocol.

The communication is set using Campbell Scientific dedicated software, LoggerNet [20]. It consists in a server application and several client applications integrated into a single product that supports the connection to our data loggers networks.

Data are recorded every minute (as the average of the 6 previous measurements taken at 0.1 Hz), sent every 15 mn to a computer server to feed a database.

DATA QUALITY

One of our main concerns is relative to data quality [6, 10, 15]. If the selected sensors accuracies, as given by the manufacturers, are effectively compatible with what the data are used for (see next paragraph), it is of prime importance that the fleet of sensors is thoroughly maintained.

Therefore, our team decided to get organized in putting together whatever procedures and norms [7, 8, 11, 12], materials and staff training are necessary to be able to calibrate [9, 13, 14, 21] all our radiometers ourselves within our facilities.

It is an essential task that will be spread over a couple of years, mainly because of the SPN1 specificities (particular design and construction) and the geographical isolation of our lab. For the time being, we are capable to do our own outdoor calibrations.

In parallel, we work in making possible the candidature of Reunion Island in BSRN's WMO network [6, 16], which will request the purchase of a suntracker.

DATA PROCESSING AND WEBSITE

Data coming up from the field every quarter of an hour are both stored in a database and immediately filtered before feeding the different prediction tools specifically developed for the project.

The corner stone of these tools is the partitioning of the daily solar radiation performed together with LIM data mining team (LIM is the Mathematics and Computer Sciences lab of the University of La Reunion).

It is not the purpose of this article to develop the different tools, but we can summarize the major steps by the following:

- ⇨ we define our own experimental index, named k_b (for direct fraction). It is defined as follows:

$$k_b = 1 - \frac{f_{diff}}{f_{glo}} = \frac{f_{dir}}{f_{glo}}$$

This experimental index, computed directly from the two outputs of the SPN1 after filtering, integrates the physical characteristics of the atmospheric layer as seen by a solar power plant at ground level [1, 2, 5].

- ⇨ in Reunion, there are five classes presented in Figure 6 [3, 4]:
  - class 1: cloudy weather all day long (k_b close to 0)
  - class 2: the day starts with a sunny morning, diffuse radiation appear from 1 PM or so
  - class 3: variable weather with a non negligible amount of diffuse all day long
  - class 4: close to class 2, the drop of direct starting later (2 PM or so)
  - class 5: sunny weather all day long (k_b close to 1)

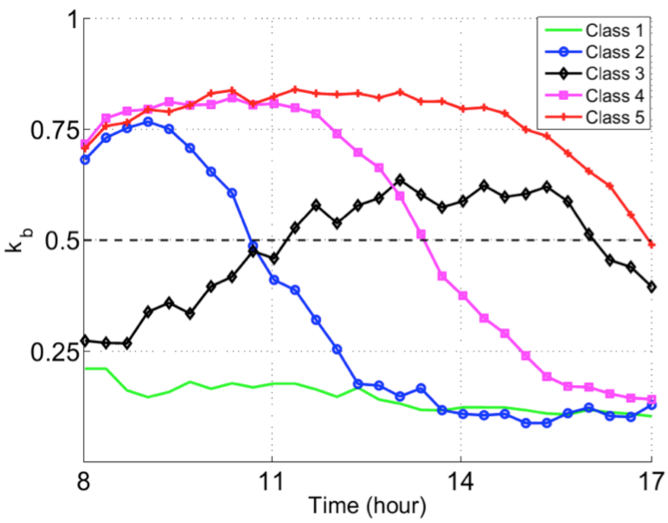

Figure 6
Average trend of direct fraction for each class

Solar prediction consists, for the time being, in H + 1 and D + 1 forecast. Information is provided for the whole territory thanks to mapping operations.

RCI_GS website (www.le2p-cc.org/RCIGS/) offers different complementary information:

- ⇨ for each station, real time monitoring of solar radiation and meteorological data
- ⇨ history of all data for each station
- ⇨ H + 1 prediction of k_b index for each spot, as well as of global / direct / diffuse components, along with spatial interpolation presented on a map (for examples, see Figure 7 for predicted versus observed data plot and Figure 8 for interpolation mapping)
- ⇨ map of the D + 1 predicted daily cumulative solar radiation (250 m x 250 m resolution). This application requiring all the data of the day D is not functional before 6 PM.
- ⇨ additional information: DNI…

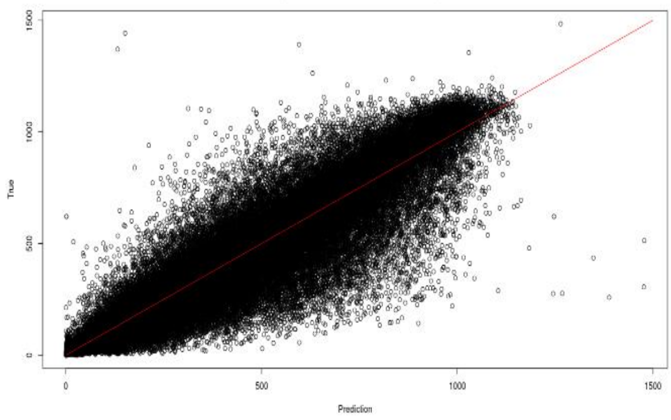

Figure 7
Predicted versus measured hourly global irradiance

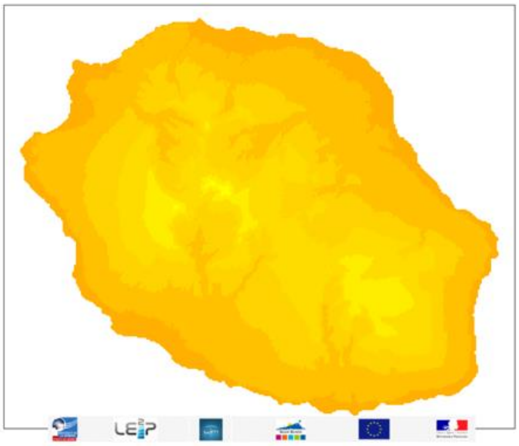

Figure 8
Mapping of Global Solar radiation (W/m²) for H + 1 prediction

CONCLUSION AND PERSPECTIVES

As already announced LE²P, our next goals, in the short term, consist in, firstly, spreading the network within the southwestern Indian Ocean area, and, secondly, reaching a high level of data quality (calibration, BSRN station).

In the long term, the prediction tools, once sufficiently consolidated, could be used in the managing of smart grids.

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