SOLAR ENERGY RESEARCH AND DEVELOPMENT PROGRAM ON THE EXPLOITATION OF THE SOLAR RESOURCE ON THE REUNION ISLAND AND ITS INTEGRATION INTO AN ELECTRICAL POWER GRID

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ABSTRACT

Reunion Island stands out by its specific energy context due to its growing population and a strong economic development. The main objective of this French region is to ensure that its exceptional potential for renewable power generation could meet an increasing energy demand. Regarding the energy development, the Regional strategy is to reach the energy independence by 2030 (SPL "Energies Réunion") without using fossil fuels.
In this context, the LE^{2}P is leading a solar resource research programme with the aim to use solar resource as a stable source of energy and ensure its management in a reliable and efficient way for its integration into an electrical power grid.
This paper aims to describe the methodology used for the development of this ambitious and challenging R&D program, projects articulation within the LE^{2}P roadmap's and the collaborations and partnerships initiated in UE and OI zone, permitting Eco city development especially in the IO area.

INTRODUCTION

Using solar resource as an electrical and stable source of energy address three scientific and technical points not still completely solved.
The first point concerns the solar irradiation variability characterization and its prediction.
Next point is to manage the solar PV production through storage systems with the objective to reduce the intermittent nature of the solar resource impact and thus to transform the solar resource into a stable source of energy. The final point is to dynamically manage this stable source of energy into a power grid so that it could able to meet the energy needs and to cope with the load fluctuations.

The particularities of the Reunion Island energy context of lies in the fact that as a part of Island areas not interconnected to the metropolitan power grid, this French region is dependant from fossil fuels while having a High potential in renewable energies. In this context, the French government and the region have set up the SPL "Energies Réunion" project, with objectives to reach the energetic autonomy by 2030 and to make Reunion Island an exceptional territory of all the environmental innovations interesting mobility, constructions, tourism, urban development and mainly energy and its practices. Another specific aspect is related to the Reunion Island socio economic conditions with high unemployment, a low income per capita, a growing population and increasing energy needs. Taking into account the whole Reunion context, the LE^{2}P has defined a solar energy development roadmap structured around the three points mentioned above.
The paper is composed of three main parts.
In the first one, we will describe the projects with their specific objectives, their connections with the scientific and technical points mentioned and how they hang together within the LE^{2}P Solar energy roadmap which comes along two lines. The first line is composed of two steps. The first step is the solar irradiation prediction and its management through storage systems in order to get a stable source of energy. The second step deals with the energy delivery management through an electrical power grid so that the tandem production consumption could be balanced, as does a smart grid.
The second line aims to bring together several scientific communities around the analysis and the characterization of the solar radiations through the extension of our existing ground sensors network to other territories of the southwest Indian Ocean area. Specific objectives associated to this line are first to provide solar radiation measurements with a high degree of

quality through a BSRN (Baseline Surface Radiation Network) application and secondly to develop specific data storage system like Data Warehouse able to dynamically manage an increasing volume of data.
In the second one, we will presented the specific methodology along several R&D lines, requires reaching the LE^{2}P roadmaps objectives.
The third part will focus on the micro-grid concept, seen as an alternative approach for integrating small scale distributed energy resources into low-voltage electricity system.
Finally, in the last part we will discuss about R&D lines identified in the solar energy roadmap along two points; the scientific and technical outlooks that could be open up then the scientific collaborations involved and those will be initiated.

THE LE^{2}P SOLAR ENERGY DEVELOPMENT ROADMAP

The solar energy development scientific research program undertaken by the LE^{2}P since 2011 is based on the RCI_GS project (Intelligent Sensor Network for a better knowledge of the solar resource all over the Reunion Island) dedicated to the solar irradiation measurement and the characterization of its spatial and temporal variability. The approach used to measure the solar radiations (Global, Diffuse and Direct) was to develop a ground sensors network distributed all over the Reunion Island. The RCI_GS project has been completed successfully, and from the experience gained in solar metrology, sensor network running and statistical classification methods, the LE^{2}P has defined a roadmap along two main steps (Figure 1). The initial step consists in turning an intermittent source of energy into a stable one through the solar resource characterization and prediction and the management of the resulted PV electrical production through storage units. The second step deals with the dynamic management of the energy delivery through a power grid. The concept that will be used for this part is the micro grid concept. A Micro grid can be defined as an integration platform for supply-side (micro-generators) and demand-side (storage units and controllable loads) located in a local distribution grid.
This emerging concept appears to meet growing customer needs for electric power with an emphasis on reliability, power quality and contribution to different economic, environmental ant technical benefits. In order to complete all the objectives (yellow on figure 1), the roadmap has been mapped out in several scientific and technical stages (green on figure 1) each of these associated to different projects (in blue on the figure 1).
The results of the RCI_GS project have led to characterize the solar irradiation variability on the Reunion Island through the development of a ground sensors network and classification methods.

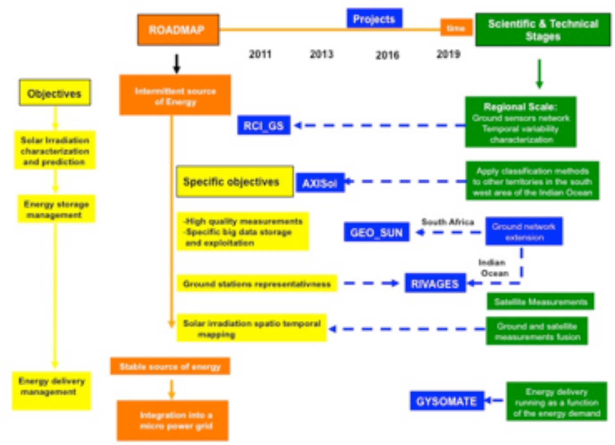

Figure 1 LE^{2}P Solar Energy Development Roadmap

These classifications methods have led to identify several classes of solar radiation timelines, covering all the sunshine profiles existing on the Island [1, 2];
Class 1 Cloudy day: It corresponds to a very low sunshine level all day.
Class 2 Intermittent bad day: a sunny beginning until mid-morning around 9:00-9:30 AM and a cloudy afternoon.
Class 3 Disturbed days: corresponds to a variable weather day with a high variability of the solar direct fraction.
Class 4 intermittent good day: similar to the class 2 but with a stronger sunny regime during all morning till early afternoon.
Class 5 clear sky day: regime of good weather throughout the day.
The main objective of the AXISoi project (Correlation analysis of the solar radiation in the Indian Ocean) is to test the robustness of the classification method developed for the RCI_GS project by applying it to South Africa. The results achieved through the RCI_GS and AXISoi projects enable the extension of the RCI_GS ground sensors network to other territories of the Indian Ocean southwest area, which is the aim of the GEO_SUN project with South Africa as initial partner. One objective besides the project is to bring together a large number of scientific laboratories around the solar radiation characterization and prediction in order to meet a solar radiation mapping across the Indian Ocean southwest area. To complete successfully the project and meet the objectives requires leading two R&D actions:

- To ensure a high degree of quality to the solar radiations measurements by
- To develop specific means able to store and dynamically manage an increasing volume of data as a Data Warehouse (DWH). Besides the DWH would be used as a decision and learning process support.
- To add an R&D line dedicated to the satellite imagery with the objectives:

- To assist in the choice of the ground station locations to maximize the representativeness in term of local climate.
- To fuse the satellite data with the ground stations data in order to meet a spatio-temporal cartography with a sufficiently fine resolution.

The GEO_SUN project will result in the end to predict accurately the solar resource and its management through storage units.

This project should enable the LE^2P to complete a crucial step and will allow preparing the implementation of the future projects linked to the LE^2P roadmap final step.

One of them is the RIVAGES project (Reunion Vanilla Islands Solar Resource), which will consist to expand the GEO_SUN ground sensors network through the southwest Indian Ocean area. Another future project that prefigures the solar resource management through a power grid is named GYSOMATE, which means "solar resource dynamic management for the energy consumption control through a smart city network composed of production and storage units".

THE R&D PROGRAM AND METHODOLOGY

The methodology used to complete the R&D program is structured around three main areas of study: 1) the solar irradiation prediction, 2) the electrical solar energy production management through storage units 3) Energy delivery management into an urban micro grid.

1) The Solar irradiation prediction

The solar irradiation prediction requires first to measure solar radiations with enough accuracy and to characterize its variability both spatially and temporally [3, 4]. Two approaches are studied: the first has been used for the RCI_GS project and consist in developing classification methods to identify several classes of solar radiation timelines, another approach consists in investigating multifractality of Solar Irradiance time series through wavelet based multifractal spectral analysis.

For the long-term solar irradiance prediction, the first approach base on classification methods is coupled with an artificial neural network technic. The architecture the most commonly used is the multilayer perceptron (MLP). One MLP consist of three or more layers (one input layer, one or more hidden layer and one output layer) in which each layer is fully connected to the next one. Except for the input nodes, each node is a neuron or a processing element with a non-linear activation function. Figure 2 shows a one hidden layer MLP. Short-term solar irradiation prediction requires a different approach based on two points. The first point lies in the fact that solar irradiation fluctuations are within several time scales. The second point that has to be taking into account is that solar irradiation fluctuations do not exhibit a simple monofractal scaling behavior. There might exist some crossover time scales separating regimes with different scaling exponents. The approach used in this case is based on investigating the multifractality of the solar irradiance data through wavelet based multifractal spectral analysis. The qualitative measure of the degree of multifractality of the solar irradiance signal will help us to decide which signal processing tools that can be used to extract the features of the signal.

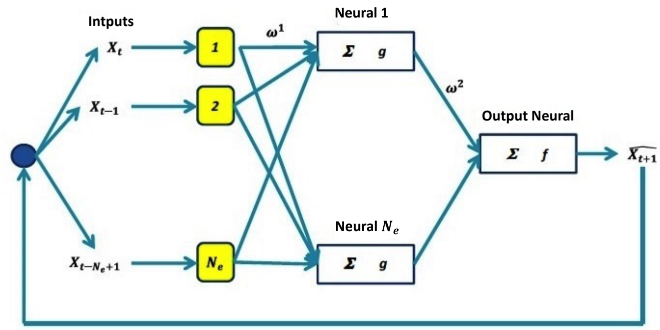

Figure 2: Multilayer Perceptron architecture

2) The electrical solar energy production management trough storage units

Storage systems permit to smooth the electrical production, make it flexible in its operation, and improve production's efficiency and quality. Thus producers use storage to compensate micro-cuts, to stabilize the grid frequency and voltage level and to improve load monitoring allowing the best park's production management. Storage often requires an intermediate energy form (gravity, compression, chemical kinetics, thermal ...) after conversion of basic electricity produced. This intermediate energy is subsequently converted into electrical energy according to the needs of the user. Among the storage means most commonly used, the storage of energy, hydrogen is distinguished by its ability to store a long time and in large quantities [5]. Moreover it's transportable as natural gas.

Towards exploring the use of Hydrogen as an energy vector, two ways for clean production at a large scale have reached a technological maturity: hydrogen production by water electrolysis and by thermo chemical biomass conversion [6].

Electrolysis, especially PEM electrolysis way is the most promising [7].

The excess electricity from solar energy over the amount used will be used to produce and store hydrogen in order to use it later as needed.

Contrary to fuel cells, electrolysers produce hydrogen and oxygen by water electrolysis according to the chemical reaction: $H_2O \rightarrow H_2 + 1/2\ O_2$

The electrolyse enthalpy is about 285 KJ/Mole at 298 K and 1 Bar. The theoretical potential threshold to ignite the decomposition process at 298K is 1, 48 V, using cells with potential in the range of 1, 7 to 2, 1 V.

Concerning water thermolysis, the thermal waters dissociation requires high temperatures (2500K), effective techniques to separate hydrogen and oxygen and prevent recombination.
Another technical solution to store energy is the battery, which is an electrochemical storage system. It can be used to get back the chemical energy created by electrochemical reaction as electrical energy.
These reactions are activated in a unit cell with two electrodes immersed in an electrolyte.
The battery is based on a reversible electrochemical system, which makes it rechargeable.

3) Energy delivery management into an urban micro-grid.

The main problems that smart grids are meant to solve are those of smaller operating margins accompanied by a more volatile supply. Operating margin can be defined as the excess electrical power over the amount used at any moment. Volatile supply can be seen as the result of using sources whose outputs cannot be precisely predicted or controlled. Together these two issues lead to an oversupply or an under supply at any given moment.

Actual specifications tend toward an energy consumption reduction or to meet a particular load curve while balancing two factors, energy surety and economics.

With these objectives, micro grid is an emergent concept providing numerous advantages relatively to insular contexts with areas little or not connected to an electrical grid distribution. A micro grid is defined as a small grid that can operate as a part of a larger grid or that can operate independently of the larger grid.

Rolling out micro grids offer several advantages:

- On a technical side, micro grid allows optimized management of the electrical production from renewable energies at a local scale. It helps to maintain the voltage stability of the public supply system and reduces its load when disconnected from the micro grid.
- On an economical side, the energy production and consumption closeness allows to optimize the energy transport. In addition, micro grids result in an increase of the flexibility and the quality of energy loads.
- On a societal side, the micro grid increases the reliability and the stability of the power grid and provides responses to the energy needs changing of a territory.
- On an environmental side, the micro grid concept is the solution to integrate renewable sources of energy in an electrical distribution network.

MICRO-GRIDS: A NEW PARADIGM FOR ELECTRICITY DELIVERY. CHALLENGES AND APPLICATIONS.

Micro-grids are much more than backup generation for residential customers. A micro grid is "a group of interconnected loads and Distributed Energy Resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.
DERs consist of distributed generation and Distributed Energy Storage (DES) installed at utility facilities, e.g., distribution substations, distributed generation sites or consumer premises. Micro grids may be operated in two modes:

1) Interconnected to the grid: The micro grid can import, export or have zero power exchange with the grid. This type of operation is designed as normal conditions. The objectives are to improve the grid performance and efficiency by using local DERs in order to defer capacity investments, reduce system losses and improve local reliability.

2) Disconnected from the grid: The micro grid is allowed to operate islanded mode. This operating mode requires the DERs within the micro-grid to be dispatched in a coordinated fashion to provide voltage and frequency regulation. Successful islanded operations may entail the implementation of energy demand management to achieve production load balance. The micro grid is expected to return to interconnected mode after the contingency has been addressed.
A conceptual illustration of a micro rid within the context of a smart grid is shown in Figure 3.

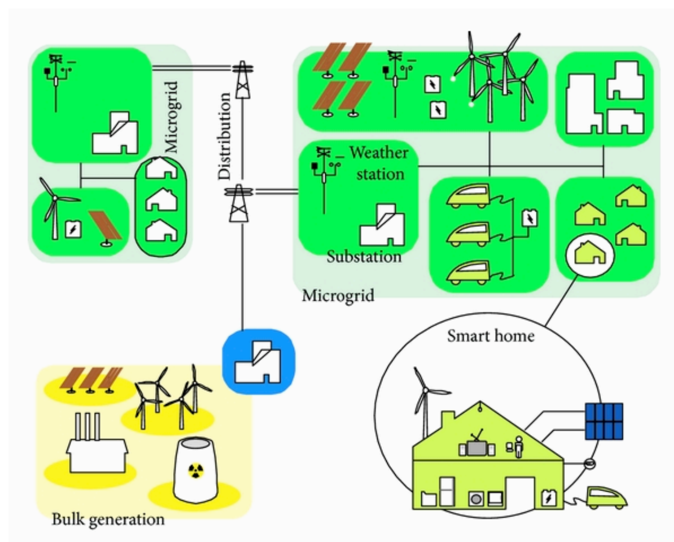

Figure 2: A conceptual illustration of a micro grid

Electric power can be generated at a distribution level in a micro grid. It usually includes a variety of small power generating sources, as well as energy storage systems such as batteries, flywheels, and super-capacitors. The power generating sources may include renewable sources such as solar panels and wind turbines, which are typically located close to the consumer sites. A micro grid can be coupled with the utility power grid through a single connection, known as point of common coupling (PCC). The electrical energy can flow in either direction through this coupling, based on the available energy generated within the micro grid and the demands of the consumers within the micro grid. A micro-grid, when disconnected from the main grid, is known as an “islanded micro grid." In an islanded micro grid operation, distributed generations (DGs) continue to power the users of the micro grid without requiring obtaining electric power from the utility grid. The micro grid connection and disconnection operations are decided by the PCC.

CONCLUSION AND PERSPECTIVES

This paper aims at highlighting the Reunion regional strategy regarding the solar energy sector through the LE^2P R&D program including several inter-linked projects drawing up a roadmap regarding the solar energy exploitation and its use as a stable electrical source of energy. The Laboratory expertise is clearly presented by describing all the future and current projects leaded in the Laboratory. We emphasize about the key role played by the GEO_SUN project conducted in partnership with UKZN (University of Kwazulu Natal, South Africa) both on a scientific and technical side and in terms of influence on the regional, national and international scientific community. With this in mind, the LE^2P has decided to initiate an important action of valorisation and communication showing our willingness to implement a long-term collaboration with South Africa as well as the southwest Indian Ocean Islands through the planed future projects RIVAGES and GYSOMATE.

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