Planning of Sustainable Urban Districts based on Smart Micro-Grids Concept: A Case Study in Brazil

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***Abstract* — The work presented in this paper is based on two converging trends worldwide: an increasing interest in sustainable solutions for urban districts and an increasing integration of distributed energy resource in the electric power system. The aim of this work is to analyze, adapt and combine existing methods used for power system planning in one easy-of-implement methodology suitable for rapid-planning of the deployment of distributed energy generation in urban districts. This paper also presents preliminary results of the application of the methodology for the case of a sustainable urban district in Brazil. The work is based on the concept of smart micro-grids, which are considered as building blocks of the "macro" smart grid and a potential solution for massive integration of distributed generation in the electric power system.**

Keywords – Micro-Grids; Sustainable Energy; Urban District

I. INTRODUCTION

As an important part of the Smart Grid deployment, Distributed Generation (DG) based on alternative energy resources and installed near the consumption has become increasingly interesting, from both technical and economic points of view. The benefits expected from DG applications include, for example, increase of power quality and energy supply reliability, reduction of power losses in transmission and distribution networks, reduction of greenhouse gas emissions, flexibility to choose between different energy sources (according with local environmental and commercial conditions), and creation of business opportunities for small and medium entrepreneurs. Due to these benefits, a massive insertion of DG connected to the power distribution network is expected in the near future.

On the one hand, this picture is very motivating; but, at the same time, it generates concerns with the possibility of a large amount of DG units, may cause negative impacts to the electrical system, as stability problems, protection, and technical and commercial relationship with a new kind of consumer /producer.

A promising solution to this concern arises with the concept of micro-grids. A micro-grid is defined as an integrated system, consisting of an interconnected set of distributed generators, different types of loads and smart grid technologies. In general, a micro-grid has one (or few) point of connection to the grid, and it is controlled by strategies of energy management that makes micro-grid introduce itself to a utility system as a single customer, consumer and producer, "well behaved".

Micro-grids are regarded as building blocks of the "Macro" Smart grid, enabling the deployment of smart grid gradually / modular (blocks), and promoting the coordinated integration of distributed generation without affecting the system and propose new commercial arrangements interest of the distributor and its customers. In Figure 1, the concept of micro-grid is represented differently, highlighting some potential applications, such as, commercial and industrial districts, campus and technology parks, urban districts and rural locations that require better security and energy efficiency, and quality sustainability in energy supply.

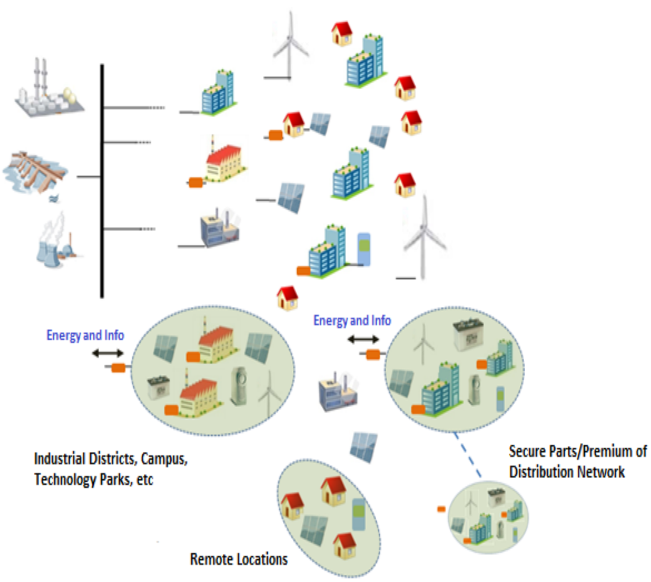

Figure 1. Examples of micro-grids applications.

Some technical characteristics of micro-grids:

- They have two main modes of operation: connected mode and islanded mode. In case of the island mode, the DG inside micro-grid should be able to maintain the local loads, mainly the critical load

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- Enable better management of the integration of distributed generators (including those dispatchables, non-dispatchable, intermittent) and energy storage.
- Provide customers (consumer / producer) inside the micro-grid with improved energy service: better power quality, energy efficiency, optimizing the use of local energy resources, supply security.
- They enable the provision of ancillary services to the distribution network (main grid), while micro-grid is operating in connected mode.

It is estimated that by 2017, more than 4,7 GW of micro-grid will be operating in the world, with a total cumulative investment of over $ 17 billion [1].

There are already some known cases of worldwide applications of micro-grids, as: a campus in the city of Sendai (Japan); a pilot system installed in a laboratory of the Institute of Solar Energy Technology – ISET (Germany); a remote system placed in the north of British Columbia (Canada) and a neighborhood of vacation homes near to Amsterdam, in which homes are equipped with roof mounted photovoltaic systems (Holland). Since the results of these earlier application cases are showing the feasibility of micro-grids, the next step shall be the scale-up and increasing number of micro-grid installations as part of the electric power system.

A potential application of micro-grids should arise with the development of Sustainable Urban Districts (or Smart Cities/Communities), such as the solutions planned to be implemented in *Masdar City* (Arab Emirates) and *Tianjin Eco City* (China) [2]-[5]. In general the objective of a micro-grid in a Smart City/Community should be to locally provide energy with high level of power quality, energy efficiency and reliability, taking advantage of local energy resources (including solar, wind and urban residues) and, at the same time, promoting environmental and socio-economic benefits.

The work presented in this paper has been realized in this context of micro-grids deployment in Sustainable Urban Districts. Specifically, the urban district considered in this work, is an Innovation and Tech Park (named Sapiens Park) which nowadays is under construction in Florianópolis, southern Brazil. This district/park is located in an urban environment that requires more intelligent, practical and sustainable solutions, whether from the point of view of energy generation, power consumption, as well as the rational use of water, treatment and reuse of waste and local socioeconomic development.

The main objectives of this work are: (i) study of micro-grid solutions suitable for urban districts; (ii) analyze, adapt and combine existing methods and tools used for power system planning in one easy-of-implement methodology suitable for rapid-planning of the deployment of distributed energy generation in urban districts and (iii) pilot application of the methodologies, for the planning of a real micro-grid, to be implemented in Sapiens Park (Figure 2) as a model of sustainable urban district and living laboratory/showroom for demonstration and dissemination of innovative technologies.

The sections presented in this paper are organized according to the steps of the methodology used for planning micro-grids for sustainable urban districts. In Section II, methods and information about the characterization and growth projection of electrical loads are presented. Section III shows content regarding the identification and projection of energy resources available locally. In Section IV, a roadmap micro-grid technologies is briefly presented. In Section V, the paper presents preliminary results about the project of the micro-grid to be implemented in Sapiens Park. These results include simulations, analysis for the optimization of renewable energy generation and additional information about the urban district. Finally, Section VI presents conclusions and comments about future works.

Figure 2. Sapiens Park Overview

II. Electrical Loads Characterization and Demand Growth Projection

The *Step 1* adopted for the planning of the micro-grid has been the characterization of local loads, presented in the urban district, and the projection of energy demand growth. The study of the demand growth should be realized for both systems: the urban district (where the micro-grid is intended to be implemented), but also for the region in which the district is inserted, in order to allow analysis about the impact that the micro-grid should have in the region and vice-versa. The following subsections present the methods for the study of both systems: the region (Method of Trends Extrapolation) and the urban district (Method of Land Use)

A. *Method of Trends Extrapolation*

The method of trends extrapolation, selected in this work because its practical application, is based on a study of demand forecasting, conducted by Brazilian researchers [5]. Initially, it is necessary to collect a set of information, comprehending:

- Population growth in the region.
- Gross Domestic Product (GDP) in the region.
- Price index for consumer durables.
- Data regarding electricity rates.
- Per capita consumption of electricity in the region.

From this set of data (historical), it is possible then to use an econometric analysis tool. The result should be determining consumption and demand for electricity in a considerably large area, in which the urban district is inserted. In the case of the project, this region refers to the northen of the island of Florianópolis.

B. *Method of Land Use*

The Land Use Method is designed to regions of smaller geographical area (as the Sapiens Park – Sustainable Urban District considered as model of urban district in this work), allowing a more detailed energy consumption characterization and projection.

The method takes into account the rate of occupation of the land in relation to parameters such as, example, activity type of building, architectural and constructions characteristic, socioeconomic parameters, kind of installed loads, climatic characteristic, etc. A simplistic way of applying the Method of Land Use is based solely on energy intensity (kWh/m²), ie, the average consumption (kWh) per unit area (m²), which is dependent on the type of final energy use/building (ie. industrial plants, commercial buildings, restaurants, schools, hospitals, etc.).

In this work, the Energy Plus software has been used as platform for the study of load characterization and growth projection at Sapiens Park [6]. The study resulted in very detailed information, providing for example forecasts of energy demand by economic sector/activity and load curves during the period analyzed.

In Figure 3, daily power demand curves are show, considering the status of Sapiens Park in 2015 and 2030. In Figure 4, the share of different types of loads in Sapiens Park is presented.

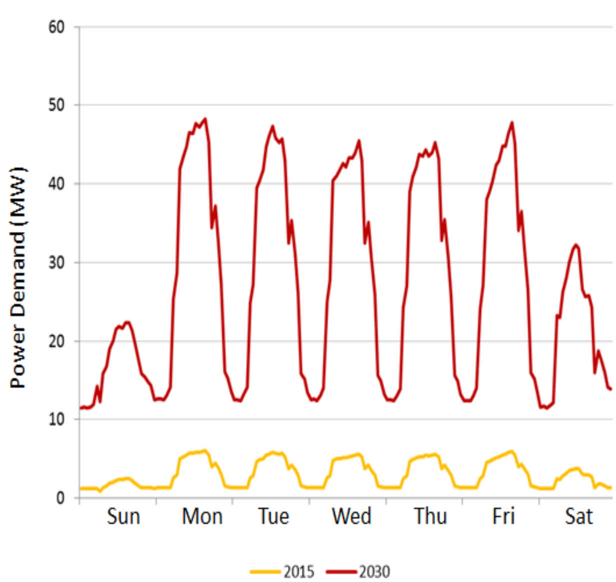

Figure 3. Predicted demand for Sapiens Park on 2015 and 2030.

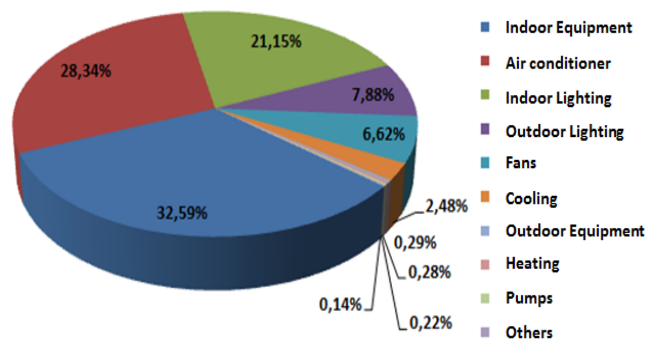

Figure 4. Share of different types of loads in Sapiens Park.

In Figure 5, it is shown the projected demand (peak demand) of both systems: the region (at the substation that supply energy to the region where Sapiens Park is located) and the urban district (Sapiens Park). Among other important conclusions resulted from this step of the methodology, it was possible to verify that in 2018, the demand of Sapiens Park added to the demand of the region will exceed the capacity of the existent substation that supply all the region. Therefore, it is worth to consider the application of a micro-grid with local DG in the Sapiens Park. The micro-grid would guarantee energy supply to the district, while at the same time it would allow utility postpone investments with additional infrastructure to increase the supply capacity.

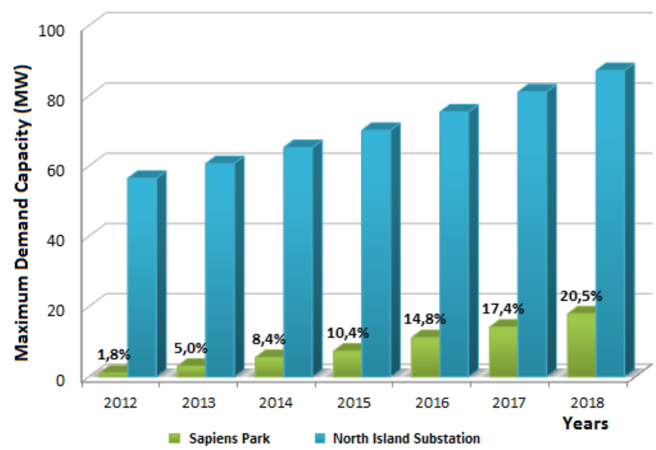

Figure 5. Predicted Demand for North Island Substation and Sapiens Park over the years.

III. Identification and Projection of Available Energy Resources

The *Step 2* of the methodology for micro-grid planning aims to identify the available resources that could be used for energy generation. The identification is firstly realized by collecting information about the energy sources available locally, for example: wind (speed, direction, etc.), solar

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(radiation, daily curve, climate, etc.), urban residues (amount of waste and sewage, forecasts, population, etc.).

In order to quantify the energy resources available in the urban districts, it is necessary to make use of local weather stations (for solar and wind resources), and a survey of water quantity and waste production (for questions related to sewage and solid waste, respectively).

Once the potential of the energy resources were calculated (in terms of radiation/m2, wind speed and direction, etc.) the next task is to determine the potential in terms of power and energy production (watts and watts per hour, respectively). This task can be accomplished by calculating power/energy production, considering the utilization of commercially available technologies for electricity generation [2]-[10]. Besides the type of technologies, it is important also to consider other particular features of the local. For instance, the micro-grid at Sapiens Park should respect the park constructive issues, such as the height limit of 25 meters to the buildings in the region, which prevents the use of large wind turbines.

For the conditions of Sapiens Park the following technologies have been chosen for the determination of the potential of local generation: polycrystalline silicon modules, vertical axis wind turbines and generation systems for urban solid waste and sewage, composed by digesters and generator group. Table 1 presents the potential for the electricity generation of Sapiens Park as well as indicators to compare the technical feasibility of using different sources of renewable energy in the region.

TABLE I. RESUME OF ANNUAL ENERGY RESOURCES POTENCIAL IN SAPIENS PARK

Generation Type		Maximum Capacity [MW]	Amount of Energy Generated [MWh]		Capacity Factor[a]	Productivity[b]
Wind		19.98	26.838		0,09	1344
Solar	Roofs	0.31	432	0,29%	0,16	1395
	Lakes	7.71	10.749	7,13%		
	Parking	5.24	7.303	4,84%		
	Common Area	94.83	132.298	87,74%		
Urban Solid Waste		0.02	125		0,66	5808
Urban Sewage		0.33	1.897		0,66	5808

a. The Capacity Factor (FC) reflects the annual capacity of a system to produce energy has operated at their rated power for 24 hours per day.
b. The Productivity reflects how many energy can be produce for each kW installed.

From Table 1 it is possible to realize that Sapiens Park has a great potential of local energy generation, highlighting the numbers found for the potential of photovoltaic systems.

IV. TECHNOLOGIES ROADMAP

Based on the information of the *Step 1* (characterization of energy demand) and *Step 2* (identification of energy resources), presented respectively in Sections II and III, the aim of the *Step 3* described in this Section is to analyze different types of technologies that could be used for the implementation of the micro-grid in the urban district. This Section evaluate existing solutions and the solutions to come, based on trends of cost reduction, efficiency improvement, market acceptance, life cycle, etc. The consolidation of the knowledge gained in this Step can be summarized into three themes:

- Distributed Generation based on Renewable Energy
- Solutions for Smart Grids
- Storage Devices and New Technologies.

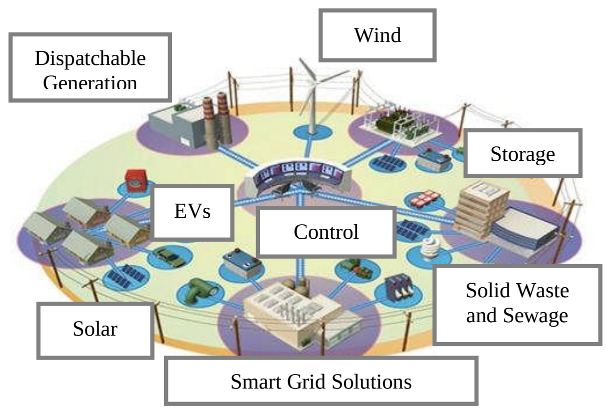

Figure 6. Overview of important themes presents in micro-grids.

TABLE II. TRENDS IN DISTYRIBUTED GENERATION BASED ON RENEWABLE ENERGT.

Photovoltaic Energy	• Cost savings of up to 60% in 2030 compared to the current scenario. • Efficiency increasing of thin film technologies, CIS / CIGS, and monocrystalline silicon.
Wind Energy	• Improvement in the manufacturing process of wind turbines with increased lifespan and capacity factor. • New solutions for harnessing wind power through mini and micro wind turbines, with emphasis on the vertical axis wind systems.
Energy harvesting from Solid Urban Waste and Sewage	• Use of decentralized biodigesters in urban districts for the available volumes of sewage and organic part of municipal solid waste. • More feasible solutions for gasification and other advanced technologies.

TABLE III. TRENDS IN SOLUTIONS FOR SMART GRIDS

Electric System Topologies	• Improved reliability of energy supply should be achieved through more flexible topologies, including mesh networks, and new approaches to energy distribution, as in the case of Microgrids.
AC and CC Power Systems	• Increase the use of energy directly into direct current, which points to a trend of DC power distribution.
Aerial and Underground Distributions Systems	• Increased adoption of underground networks, due to the context of urban forestry and visual pollution. Note to reduced costs of these systems, and already existent technologies allow easy control and maintenance.
Protection	• More autonomy and intelligence with application of so-called "adaptive protections," which fit the real-time operation of electrical systems.
Communication Infrastructure	• Implementation of an effective communication and advanced metering infrastructure. • Complete replacement of all legacy infrastructure for measuring smart meters, multi meters in the same residence given greater “energy education”, and demand response features. • Adoption of media and protocols that ensure interoperability between systems, including IEC61850 LV networks.
Control and Automation	• Implementation of solutions for demand response and demand side management • Distributed control and dispatch centers distributed generation. • Trend of use of Multi-agents systems for distributed control • Dissemination of advanced distribution automation.

TABLE IV. TRENDS IN STORAGE DEVICES.

Batteries	• Greater use of sodium-sulfur batteries (NaS) batteries and lithium in solutions integrated with the electrical grid, as well as in stationary electric vehicles.
Flywheels	• It is expected that the market begin to see the advantages of flywheels and provide greater feasibility for the technology, which provides high initial cost but a low cost of maintenance and ability to operate in very adverse conditions.
Supercapacitors	• Reduced costs will facilitate the application of supercapacitors in solutions in which they want high power density with fast dynamics

V. ANALYSIS AND DESIGN OF THE MICRO-GRID FOR THE SUSTAINABLE URBAN DISTRICT

This Section refers to *Step 4* of the methodology for micro-grid planning. It starts with the creation of possible scenarios for micro-grid implementation, defining, for example, the amount of renewable energy it is desired to generate locally at the urban district, the price of energy negotiated with the main utility etc. In the pilot application in Sapiens Park, the scenarios are related to the installed capacity of each source, and are established for short, medium and long terms (respectively 2015, 2020 and 2030). For 2015, the scenarios consider to attend 10%, 20% or 30% of energy consumption. But in 2020 the initial scenario becomes with the optimal solution in 2015 and the others are kept and so on (Figure 7).

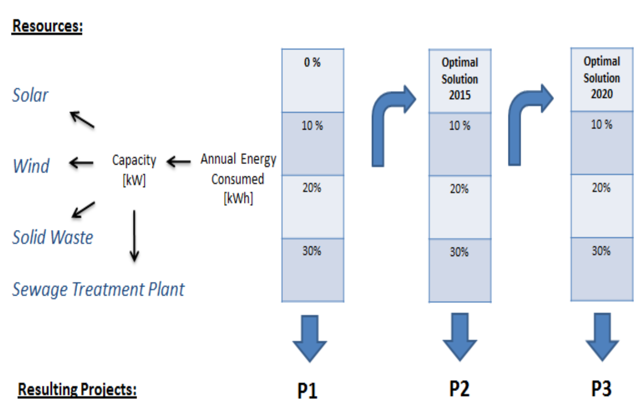

Figure 7. Solution Problem Description.

Based on the proposed scenarios, the next task is to specify the technologies to be used (supported by the roadmap created in Step 3) and other technical and economic parameters, and then simulate the system in order to find the best solution for the micro-grid deployment (ie, mix of energy resources, technologies to be adopted, amount of local generation, commercial relationship with the main utility, etc.). In this work, the software Homer Energy has been used. The software Homer Energy [17] seeks to assist in determining the more viable technically and economically solution to attend the local loads in the years 2015 to 2030.

With the results of the consumption and demand for electricity over the years compared with the technology roadmap in terms of efficiency and cost of systems for electricity generation, it is possible to create enhanced simulation scenarios. One of the results obtained with Homer Energy can be seen in Figure 8, where the optimal solution is identified in 2015. It is possible observe the presence of main grid and photovoltaic systems in the optimal solution. The system in question has an installed capacity of 170kW and has a share of 10% of all energy produced in that year.

Double click on a system below for simulation results.

PV (kW)	VAWT	Label (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Label (hrs)
177...			8400	$ 15,553,571	4,221,445	$ 53,871,788	0.231	0.10		
177...		64	8400	$ 15,703,171	4,216,455	$ 53,976,096	0.231	0.10	9	69
	305	64	8400	$ 22,536,360	4,561,150	$ 63,938,096	0.274	0.20	12	92
177...	153		8400	$ 25,483,272	4,316,521	$ 64,664,504	0.277	0.20		
177...	153	64	8400	$ 25,632,872	4,312,807	$ 64,780,392	0.278	0.20	4	29
355...			8400	$ 28,379,168	4,158,298	$ 66,124,200	0.283	0.19		
355...		64	8400	$ 28,528,768	4,154,707	$ 66,241,204	0.283	0.19	4	35
	457		8400	$ 32,251,560	4,722,443	$ 75,117,360	0.317	0.30		
	457	64	8400	$ 32,401,160	4,718,926	$ 75,235,032	0.318	0.30	9	73
177...	305		8400	$ 35,348,072	4,456,239	$ 75,797,528	0.323	0.30		
177...	305	64	8400	$ 35,497,672	4,452,362	$ 75,911,944	0.324	0.30	3	21
355...	153		8400	$ 38,308,868	4,258,091	$ 76,959,728	0.328	0.29		

Figure 8. Homer Energy window with the viable solutions based on Total NPC

In Figure 6, the first line show the optimal solution based on the less Total Present Cost of Micro-grid (Total NPC) that is R$53.871,788 for proposed problem. Besides the costs related to the power grid and renewable sources, this cost are composed of annual real interest, project life, cost of the system and another economics variable. The best way to represent the distribution cost of this project is shown in Figure 9 that related Capital, Replacement, Savage and Operating costs over the years.

It is important to emphazise that Homer Energy has a lot of ways to present the results, including reports generation, comparing the investing in micro-grids with the benefits to stakeholders.

As other years are simulated, other generation sources can be found most viable than those chosen for 2015 simulation. This work is currently in time to implement scenarios adjustment in order to allow further studies and the creation of a computational platform for investment evaluation and quantification of benefits (to the local distributor, urban district and investors), so that it can be replicated to any urban district to submit interest in making use of renewable sources for electricity generation.

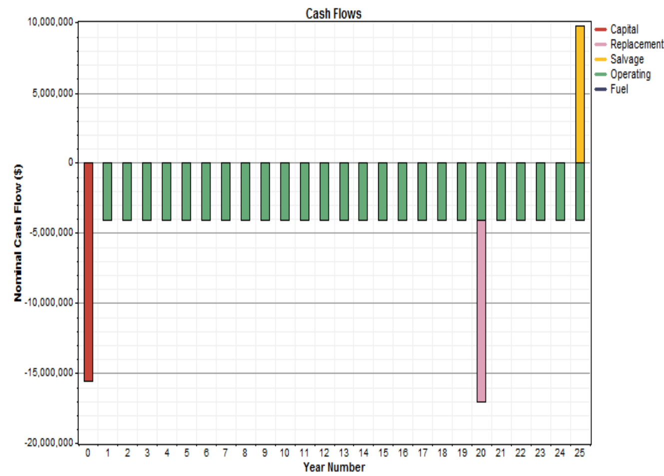

Figure 9. Homer Energy window with the Cash Flow based on optimal solution considering the Total NPC

VI. Conclusion and Future Work

This paper presented a methodology for planning the deployment of micro-grids in sustainable urban districts. Also, the work includes a pilot application of the methodology, considering an urban district located at Florianópolis, southern Brazil.

The methodology has been subdivided in four main Steps: (1) characterization and growth projection of electrical loads, (2) identification and projection of available energy resources, (3) technology roadmap and (4) design and simulations of technical and economic aspects of the chosen solutions for the micro-grid. The *Step 4* is currently under development, but earlier results of the pilot application have shown that the methodology and the chosen computational tools are worthy for the objective of sustainable urban district planning, and could be applied in the context of other applications of micro-grid (industrial and commercial, districts, institutional campus, others) .

Parallel to this work, a project to implementing a pilot plant composed by renewable energy resources is currently under development. The pilot plant will include photovoltaic panels, small wind system, microturbine and batteries, totalizing approximately 100kW. The main objective of this new project is to develop, implement and evaluate control strategies for the optimal use of renewable resources and supply of priority loads in Sapiens Park.

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