A SMART MICROGRID LABORATORY PLATFORM CONCEPTUAL DESIGN FOR UNIVERSITY CAMPUS

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DISSERTAÇÃO DE MESTRADO SUBMETIDA AO DEPARTAMENTO DE ENGENHARIA MECÂNICA DA FACULDADE DE TECNOLOGIA DA UNIVERSIDADE DE BRASÍLIA COMO PARTE DOS REQUISITOS NECESSARIOS PARA OBTENÇÃO DO GRAU DE MESTRE EM SISTEMAS MECATRÔNICOS.

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“O SENHOR com sabedoria, fundou a terra; preparou os céus com inteligência.”

Provérbios 3: 19

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RESUMO

Esta pesquisa tem como objetivo a apresentação de uma estrutura para um microrede inteligente num campus universitário. A metodologia usada é baseada no processo de projeto modular. O trabalho se inicia com uma revisão da literária sobre o estado da arte de microgrids e smartgrids, um sistema de monitoramento de dados de energia como uma instalação de cama de teste, e em seguida um método de projeto de sistemas modulares para desenvolver um conceito da plataforma smart microgrid (SMGP). Esta pesquisa apresenta as duas fases do projeto modular: o projeto informacional e o projeto conceitual. Os resultados do projeto informacional são as especificações técnicas do SMGP proposto, e o projeto conceitual apresenta as funções básicas contribuindo aos conceitos da SMGP, por meio da decomposição de uma estrutura funcional global da SMGP. Para identificar os módulos na fase de projeto conceitual um método heurístico é usado. A implementação deste método resultou na identificação de quatro módulos da SMGP: o módulo de geração de energia renovável e armazenamento, o módulo de geração de backup de energia, o módulo de alimentação da distribuidora e o módulo de gerenciamento, monitoramento e controle de energia. Um laboratório de smart microgrid para o curso de Engenharia de Energia do campus Gama da Universidade de Brasília para fins educacionais é uma necessidade clara. A proposta de usar a rede elétrica deste campus e integrar nela fontes de energia renováveis como parte do laboratório é feita nesta pesquisa. Esta plataforma de smart microgrid é uma estrutura básica a ser implementada em qualquer campus universitário para atender a sua necessidade de um ambiente de laboratório smart microgrid. A abordagem SMGP justifica uma proposta esquemática e estruturada do sistema previsto, e suporta o projeto do SMGP em módulos. Inicialmente o SMGP é apresentado como um sistema geral em qualquer campus universitário, e finalmente o projeto do SMGP a ser implementado no campus Gama é apresentado. No presente trabalho três conceitos de SMGP são gerados como alternativas, usando o conceito selecionado como base de projeto modular do ambiente de laboratório do campus Gama.

Palavras-chave: plataforma microgrid inteligente; abordagem modular; integração de energias renováveis; projeto conceitual.

ABSTRACT

This research work aims to present a basic framework for a smart microgrid on a university campus. The methodology used in this research is mainly based on the modular design process. This work is initiated with a literature review of the state of the art of microgrids and smartgrid, an implemented energy data monitoring system as a testbed installation, and followed with a modular system design method to develop a concept of the smart microgrid platform (SMGP). This research presents the two phases of the adapted modular system development method: the informational and the conceptual design. The informational design results in the technical specifications of the proposed SMGP and the conceptual design method presents through decomposing of a global functional structure of the SMGP, the elementary functions which will attribute to the generation of concepts of the SMGP. To identify the modules in the conceptual design phase the heuristic method is used. This heuristic method was invented by Stone (1997) and depends on the functional structure of the system or product to be developed. The implementation of this method resulted in the identification of four modules of the SMGP: the renewable energy generation and storing module, the backup-energy generation module, utility power supply module and, the energy management, monitoring and control module. A smart microgrid laboratory for the Energy Engineering course of the campus Gama University of Brasília is a clear necessity for educational purposes. A proposal was made to use the complete electrical grid of the campus and to integrate renewable energy sources as part of this micro grid laboratory. This smart microgrid platform design concept is a basic structure to be implemented by any university campus to suit their needs for a smart microgrid laboratory environment. This SMGP modular approach justifies in a schematic and structural proposal of the needed system, and supports the SMGP design in modules. This SMGP system is firstly presented as a general system to be implemented at any campus university and finally is presented the SMGP on the campus Gama to be implemented. In this work three concepts for the SMGP are generated and the selected concept alternative is used as modular design to be applied as a laboratory environment on the campus Gama.

Keywords: smart microgrid platform; modular approach; renewable energy integration; conceptual design.

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LIST OF SYMBOLS AND ABREVATIONS

A	Ampére
V	Voltage
W/m^2	Irradiance
UnB	Universidade de Brasília
SMG	Smart MicroGrid
SMGP	Smart MicroGrid Platform
W	Watt
KWh	kiloWatt hour
PV	Photovoltaic
SCADA	Supervisory Control And Data Acquisition
AC	Alternating Current
DC	Direct Current
DG	Distributed Generation
DER	Distributed Energy Resources
GW	Giga Watt
MW	Mega Watt
DOE	The US Department Of Energy
QFD	Quality Function Deployment
KWp	Kilo Watt peak
IEEE	Institute of Electrical and Electronics Engineers
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
El.	Electrical

CHAPTER 1. INTRODUCTION

1.1 TRANSFORMATION OF ENERGY GENERATION

Electrical energy has become of great importance to humanity over the past century and defines the features of a modern society. Electricity consume is rooted in many aspects of our lives. The technology evolution has provided people with a varied amount of inventions that establishes our daily tasks and industrial activities (NASCIMENTO et al., 2012).

The electricity generation is undergoing a transformation with the scarcity of resources for the construction of large civil works (dams) and the environmental problems caused by large areas flooding, which are events that motivate to use new technologies for electricity generation. The solution to the problem of scarcity of resources and antique electrical grid constructions that the scientific research community in the energy area is developing, and which is already being tested in some cities in the world, is called Smart Grid, also known as intelligent network (JÚNIOR, 2005).

The expression “Smart Grid” is to be understood more as a concept instead of a specific technology or equipment. It is based on intensive use of automation technology, computing and communications to monitor and control the power grid, which will allow the implementation of control strategies and network optimization much more efficient than those currently in use (FALCÃO, 2009 apud NASCIMENTO et al., 2012).

This technology revolution in the electrical power industry brings new challenges and new claims for quality, safety, flexibility and sustainability. It is the inclusion of current electronic techniques, telecommunications and information technology aimed at automation and improvement of electricity services. This revolution in the energy sector, especially in the distribution segment, allows a number of possibilities: more active participation of consumers, providing more information, provision of new services, improving asset management, energy efficiency, improve power quality and fighting some problems experienced in Brazil, for example; non-technical losses. The benefits of smart grids are spread throughout society and cover both distributors and consumers (LAMIN, 2013).

Another aspect of smart grid is the possibility to introduce renewable generation in existing distribution networks. The renewable energy sources are based on alternative energy generation from sources such as wind, solar or photovoltaic (PV), hydro and biomass. The introduction of renewable energy generation involves integration of a large number of distributed energy sources in existing distribution networks, which have a limited energy transport capacity and a unidirectional behavior of power flow. Distributed generation (DG) systems are generally noticed as rather small electrical generation units which are spread over an electrical network or as independent functioning remote systems (JOSKOW, 2012).

Within this technological revolution a special kind of smart grid is gaining more interest, called the microgrid. The micro grid are gaining more interest since they will have a valuable role in the technology for improvement of the smart grid and for fulfilling the requirements such as control, efficiency, sufficient and reliable power supply (HAYDEN, 2013). This microgrid is integrating distributed generation and loads associated with them in a single subsystem. The characteristics of microgrids depend primarily on the size and nature of distributed generation units, such as where they are installed and their respective availability of primary power (HAYDEN, 2013).

The microgrid is an excellent contribution for research and studies of real main utility grid problems and for the implementation of intelligent systems, because it is a smaller grid and consists almost all the components of the main centralized grid in a small scale (BRACCO et al., 2013; RADUCAN et al., 2011).

Micro grids use local sustainable power resources and can also provides energy security for a local community as it can be operated without the presence of a wider utility grid. The technology of micro grid withholds three important goals of a society such as reliability (physical, cyber), sustainability (environmental considerations), and economics (cost optimizing, efficiency) (HOSSAIN et al. 2014).

The electricity sector has undergone several changes in order to seek to improve the reliability, safety, efficiency and quality of their services. These transformations have been causing an increase of its complexity and the need for further technical relationships between suppliers and consumers. The current electrical infrastructure is insufficient to meet the growing needs and consumer expectations. In Substantial updates of the system are necessary to ensure that services have the level of reliability and quality required and expected by consumers. Information provided to many consumers nowadays, are limited to their monthly consumption, they do not have detailed information about patterns and amounts of consumption. Many customers also do not have information about options for alternative tariffs or other services and that makes it impossible for them to manage and streamline their electricity costs. New technologies such as smart grid are a solution for these events, which are intended to contribute to energy management and that management can be shared from the utility point of view and also from consumers. This concept refers to the integration of large-scale new technologies and digital elements in the electricity sector form (GALO, 2014).

The power systems are transforming into very complex systems and operators have to deal with this complexity in the operations. This complexity keeps growing due to the developments of energy demand response, renewable energy sources, energy storage and electric vehicles. The existing techniques for the scenes such as analysis, monitoring, managing and control of power systems, may be incapable to meet the transformations in the power systems. Improvement of the system operation will be acquired to guarantee the power system reliability and quality (ZHANG et al., 2010).

The rapid growth of electricity consumption and growing environmental concerns, have motivated researchers around the world to develop distributed generation systems using renewable energy which have an intermittent character. Distributed generation, energy storage and demand-side load management all are evolving modern technologies that transform the power networks and the methods how energy is being consumed and utilized. By introducing smart technologies in the power system, the stability, reliability and efficiency of the electrical power system can be (MOLDERINK, et al., 2010).

In this context as explained above, this work will present a conceptual smart microgrid to function as a real-time laboratory platform for the energy engineering course at the University of Brasília. There is a need to be engaged in the research of intelligent systems used for micro grid technologies and the university wants to contribute to this urge by educating their students with the appropriate tools. Without this facility the students will have no adequate experiences on the field of real-time monitoring of local energy consumption, managing the system at distance by control systems and fault detection scenarios of unexpected problems in the distribution of energy. This micro grid platform will be a basic structure for teaching, research, practical tests, analysis and an energy support for the laboratory itself. This proposed model will be designed for future development plans of the micro grid laboratory as a plug-and-play platform to add future suggested units as for example an electrical vehicle to grid system and other renewable energy systems such as wind and fuel cells. This platform will make it accessible to the students, professors and others related to the campus, to operate a small scaled smart electrical network in real-time, with the features of the main utility grid and renewable energy integration.

1.2 MOTIVATION

The University of Brasilia started the construction of a new campus at Gama in 2008, mainly with the objective to accommodate the undergraduate courses Aerospace engineering; Automotive Engineering, Electronic Engineering, Energy Engineering and Software Engineering. These Five courses count for almost 560 students yearly and the numbers are expected to grow to a total amount of 2,800 students when the campus is fully implemented.

Besides these five undergraduate courses, there are also four graduate courses offered: Clinical Engineering, Modeling of Complex Systems (distance), Biomedical Engineering and Materials Integrity Engineering.

The area of campus Gama contents 40 ha of green land. The planned construction embeds 24 buildings with a constructional area of 122,925 square meters of which 3 buildings are already established. The implementation of the campus is planned to be deployed in stages, which will be carried out related to the growth on the campus. The main objective of this planning is to conserve the natural green environment for a green infrastructure (FUB, n.d.).

The proposal related to this work began in 2012. In that year the Faculty Campus Gama, approved a research project with funding from the electric utility of the Federal District (CEB), with the title "Eletroposto Solar", to install 10kW of electricity micro generation through panels PV connected to the network and to implement an electric vehicle charging station on campus range.

In 2013 a second project was made in the context of this work, and submitted to the call for applicants of MCTI / CNPq / CT-ENERG No. 33/2013, Technology in Smart Grids Project Proposal with the title “Implantação de um Laboratório de Redes Elétricas Inteligentes no Centro-Oeste Brasileiro”. This work had as main objective the creation of research of smart grids in graduate engineering programs at UnB.

The previous efforts for the establishment of smart grid and a renewable energy generation facility on the campus, have not yet been implemented and they justify the need for a smart microgrid laboratory platform, that compasses all the aspects of the two before mentioned efforts to introduce smart grid on a campus. In the scope of these earlier mentioned proposals, came the idea to develop a laboratory platform based on smart micro grid. This dissertation , called “A smart microgrid laboratory platform conceptual design for university campus”, justifies the next stage to get closer to the implementation of both earlier mentioned projects with this smart micro grid laboratory and fulfill a wish of the campus Gama to provide an appropriate facility to their students for further development in the scope of smart grid and micro energy generation with renewable energy in order to contribute to the sustainability goals of the campus infrastructure.

An intelligent network (smart grid) laboratory with power systems-based courses, control and automation systems, communication, electrical vehicles, and to carry out research projects in the area of smart grids involving electricity, electronics and software is required. An advantage to integrate a smart microgrid at the campus of UnB is the reason that the existing grid is not old, installed since 2008, which creates a better opportunity to build a smart micro grid without enormous changes in the existing network. Also added to this event is their weather station. Since the year 2011, a meteorological station monitors amplitude and direction of the wind, solar irradiance and other weather variables to assess the potential of alternative energy sources on the FGA campus.

A smart microgrid laboratory is very essential on a campus with engineering courses. This facility will be very useful for the different departments, because this laboratory covers various engineering courses such as control, automation, computer, electronics and energy. With the absence of this laboratory, the students will not gain enough practical experience on the integrated education field of smart microgrid and will not have the opportunity to use the knowledge of their specific engineering background in a real-time environment on the campus during their years of study. At the same time is taken also into consideration that this campus Gama is a campus in development, with plans for expansion and thereby a growing number of students and professors, where a facility for research, training and education programs in the scope of smart micro grids is a must to keep pace with the growing interest in (smart) micro grid technologies, where many intelligent systems can be integrated in trial. With the SMG laboratory, the experiments and their analysis will deliver students a high level of knowledge to understand the concepts of power system engineering fundamentals and the required demonstrations needed for smart grid implementation in the real world. At the same time another motivating factor is the increase of energy availability at moments of failure in the centralized utility grid. With this smart micro grid, there could be studies done on the behavior of the total demand and consume of the laboratory itself and the rest of the campus Gama. Thereby these studies could result in development of methods for energy back-up for the laboratory and other facilities on the campus Gama. For these studies a good monitoring system, with automatic control system should be implemented to be able to switch the micro grid on and off the utility grid when necessary. These before mentioned aspects could increase the energy efficiency on the campus Gama and even lower the energy costs in the future.

This proposed laboratory facility in this work will be considered a living laboratory since it will offer real-time data, measurements and energy control and management. With this smart micro grid platform, the campus will be able to offer highly qualified programs and trainings in the scope of smart grids in micro scale (smart micro grid), to students and stakeholders and increase their performance in the global challenge to the evolution of energy infrastructure based on efficiency, sustainability and reduced environmental impact, creating a greener university campus.

1.3 OBJECTIVES

This proposed work has as general objective the conceptual design of a smart microgrid platform (SMGP), which will function as a real-time laboratory structure for power system monitoring and control on a university campus. This platform will enable the campus to increase their research and education capabilities based on the electrical energy distribution.

The specific objectives are:

- To evaluate microgrids and microgrid technologies to relate them to the smart microgrid developments;
- To develop and implement an experimental real-time energy data acquisition setup on a university campus;
- To adapt the modular design methodology to develop an informational and conceptual phase for the design process of a proposed SMGP (Smart MicroGrid Platform);
- To specify and identify the modules in the SMGP and create alternative concepts for the SMGP to develop the best system structure possible.

1.4 STRUCTURE OF DISSERTATION

This research work is divided in 6 chapters:

- Chapter 1 presents the contextualization of the research, the motivation and objectives.
- Chapter 2 presents the state of the art of smart grids and microgrids; their challenges and technologies and the modular design methodologies, the terminology and definitions.
- Chapter 3 presents the informational design phase of the SMGP, whereas the problem is defined for a campus university, presented by the campus Gama of the University of Brasília here. In context of the campus Gama are described the electrical energy classification structure and tariff structures, the tariff structure of the campus Gama and the experimental set-up of the real-time energy data acquisition system to introduce real-time energy monitoring. In the informational phase the different stages are further developed to establish the stakeholders, necessities and requirements of the clients and final technical requirements and specifications of the SMGP.
- Chapter 4 contents the conceptual design phase of the smart micro grid platform (SMGP) model and presents the methods and tools to establish the modules of the SMGP and finally presents the generated concepts of the SMGP and the modules.
- Chapter 5 presents the final considerations and recommendations for future works.

CHAPTER 2. STATE OF THE ART OF MICRO GRIDS AND THE MODULAR DESIGN APPROACH

This chapter is organized in the subjects concerning the electrical energy system; microgrids, smart grids and examples of smart grid, (smart) microgrids projects over the world. The definitions, characteristics, basics and technologies are explained of each section in separate paragraphs. This chapter must give a complete understanding microgrids state of the art with its functionality and challenges in the world with an exponentially growing demand where electrical energy is a basic necessity for everyday life in all countries especially for industries, commercial activities, public sector and households. The modular design approach is also enlightened in this chapter, which will be the method used for the development of the SMGP in this work.

2.1 MICROGRID

There is not just one exact definition for microgrid, since researchers have created various definitions for micro grid based on the functions and technology. They all come down to the fact that a micro grid contains a few main characteristics, which will be described after a few examples of commonly used definitions for micro grid are given in this section.

A definition of microgrid created by of the U.S. Department of Energy (DOE) as used in The Office of Electricity Delivery and Energy Reliability (OE) report is:

> ´´Micro grid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. It can connect and Disconnect from the grid to enable it to operate in both grid-connected or island-mode´´ (SMITH, 2011).

Published by IEEE in a paper of 2007, is the micro grid defined as follows:

> ´´ Micro grids are networks of small, distributedpower generators operated as a collective unit of a system of energy systems´´ (BARNES et al., 2007).

The next definition of the microgrid given in a report of the Siemens AG, is the following:

> ´´ A micro grid is a regionally limited energy system of distributed energy resources, consumers and optionally storage.

> It optimizes one or many of the following: power quality, reliability, sustainability and economic benefits and it may continuously run in off-grid- or on-grid mode, as well as in dual mode by changing the grid connection status´´, (DOHN, 2011).

After analyzing all these definitions, it can be concluded that a micro grid can be described as a low or medium voltage distribution systems with controllable loads, alternative energy sources and possibly an energy storage capacity.

A microgrid can also be seen as a new way of powering remote areas, distinguishing the necessity to construct long-distance transmission lines to the area, which has very high costs if the load is small with a low number of end-users like in some remote areas, (MAH et al., 2014).

For micro grids with their different micro generators there are specific requirements before finally distributing the energy trough the micro grid lines to the loads. The photovoltaic systems for example, generates direct current (DC) which needs an inverter to invert the DC to AC, alternating current and a wind turbine generates asynchronous AC energy and needs an AC-DC-AC inverter before coupling on the grid for energy distribution. Distributed generators can have a negative impact on the main utility grid when you have them introduced in all levels of the main grid (the high voltage, medium and low voltage), especially those imbedded with power electronics interface, because the main grid isn´t constructed with these factors in mind. To keep the main utility grid functioning as one complete network, the micro grid concept is introduced and operates as a load or power generator unit to the main utility grid, without endangering the reliability and safety of the main utility or conventional grid. Power electronic components are a must in micro grids for the coupling of distribution generators and storage devices to the grid. Micro grids need storage capacity to guarantee the energy supply in times of outages and load -shedding and this element also puts them apart from the conventional grid, which has no energy storage capability, (USTUN et al., 2011).

A few of the main characteristics of a micro grid system are as follows:

- exploitation in both on-grid or off-grid mode;
- arrangement of diverse grades of power quality and reliability for customers;
- connected to the main distribution grid as one (a single) collective unit of energy system;
- created to contain all energy system essentials;
- a junction of attached loads and energy resources, (KULKARNI & SONTAKKE, 2015).

To control and manage the available energy, the loads and the growing consumption there is advanced technology needed to accomplish the communication and control of these devices to be smartly interfaced together with power conditioning units to guarantee the electrical energy supply of these micro grids. Here is where the intelligent systems are integrated in the micro grids and provide a promising future for the growing energy demand in the world with its increased reliability and efficiency, (AGRAWAL & MITTAL, 2014).

Microgrids are gaining more recognition due to their advantages, one important advantage is that they are able to reduce the Carbon emissions compared to the main centralized utility grid by adopting renewable energy sources. The goal to reduce global warming as a result from the Carbon emissions, will require great impact in the electrical engineering field explicitly in relation to the aspects of the Transmission and distribution (T&D) of this renewable electricity, (USTUN et al., 2011; SU, 2009).

Another important factor that contributes to the increased interest in micro grids is their advantage of generating electrical energy nearby their loads which reduces the energy losses in the transmission and distribution lines. Due to this advantage micro grids can produce electricity of higher quality than the centralized main utility grid and increase the reliability of the electrical energy supply in a specific area. Amongst their many advantages the micro grids with their renewable energy sources can also reduce the costs on fossil fuels and the high infrastructure costs for expansion of main utility grid, (SIEMENS, 2011).

The diffusion of the distributed generation or micro grids led to improvements for the electric network giving the opportunity to reduce overloads of transmission lines, improving the energy security and stability of the electricity grid and the integration of renewable sources can be utilized for ancillary services too, (RIZZO, 2013).

In Figure 1 is presented a visualization of the architecture of a micro grid with its distributed generation resources and monitor and control system with a coupling point to the main grid, suited between the main grid and the substation, to operate connected to the main grid or in off-grid mode. This presented microgrid consists on the left side, the loads (consumers): commercial buildings, residential area, light industry and supports a electric vehicle infrastructure to charge these vehicles.

On the right side of Figure 1 is presented the Combined Heat and Power (CHP) system, the energy storage, the solar PV array(s), another energy storage unit and small wind turbine units. As presented in Figure 1, the microgrid is being monitored and controlled from one point and is connected with all the subsystems trough their individual connection points, which could be power electronic devices are installed sensors.

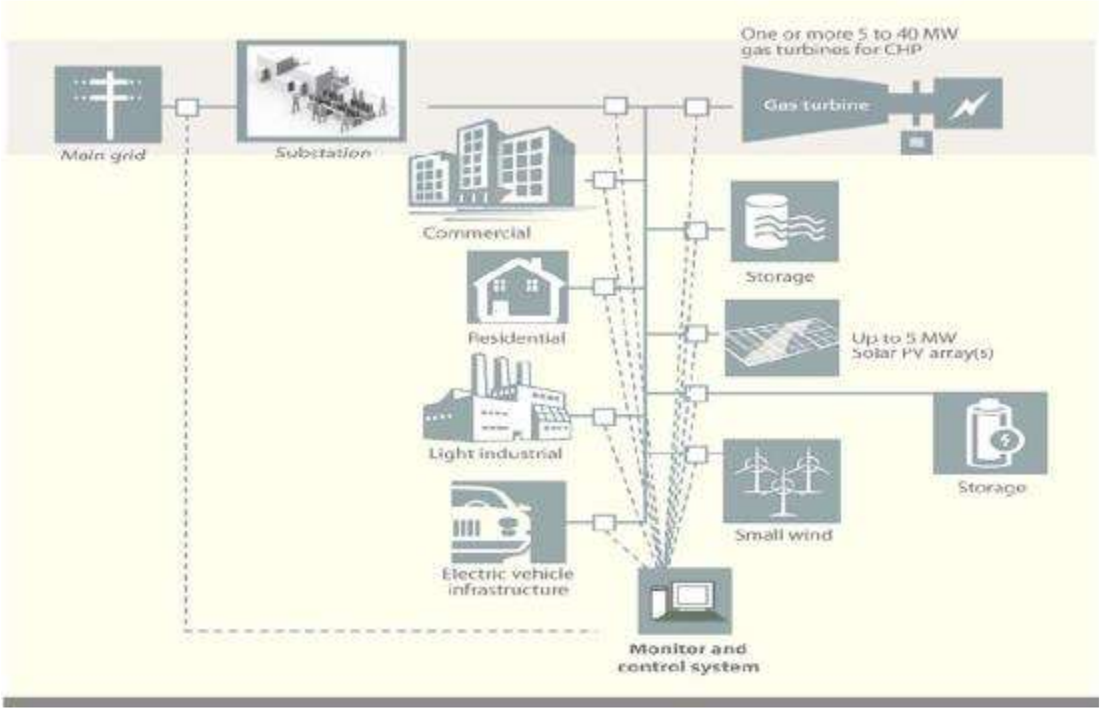


Figure 1: A physical view of the Microgrid with its individual elements. Source: Adapted from DOHN, (2011).

2.1.1 MICROGRID CLASSIFICATIONS AND TYPES

Considering the operation states of microgrids, they can be classified into two:

1. Grid-connected mode microgrids
2. Island-mode microgrids

The **grid-connected mode** microgrids can operate connected to the main power grid or off-grid in island-mode also when there is a fault, maintenance, voltage or frequency drop on the main grid and it is disconnected from the main grid to supply energy to the customers during the time of electric energy interruption, (USTUN et al., 2011). However this type of operation requires complex control, communication and protection systems to fully isolate the micro grid from the main grid, while the utility grid operations can have a secured grid for maintenance or fault clearance operations without the fear of having an electrical energy reversed flow from a micro grid, (VACCARO et al., 2011).

The **island-mode** micro grid is functioning independent from the utility power grid and has no coupling to the main grid. Usually these micro grids are applied in remote areas where there is no main grid available and the customers only depend on the micro grid with their DG resources, energy storage, diesel/gas generators for their electric energy supply (USTUN et al., 2011; SIEMENS 2011).

According to research as mentioned by Hayden, (2013) and Siemens, (2011) there are five important microgrids types or market segments:

- **Commercial and Industrial (C&I) MicroGrids**

  This type of microgrid (see Figure 2)is more found in north America and Asia Pacific and is comparable to the Campus and Institutional micro grid if includes one owner. This micro grid becomes very complicated if settled in a commercial or industrial region and involves various shareholders.

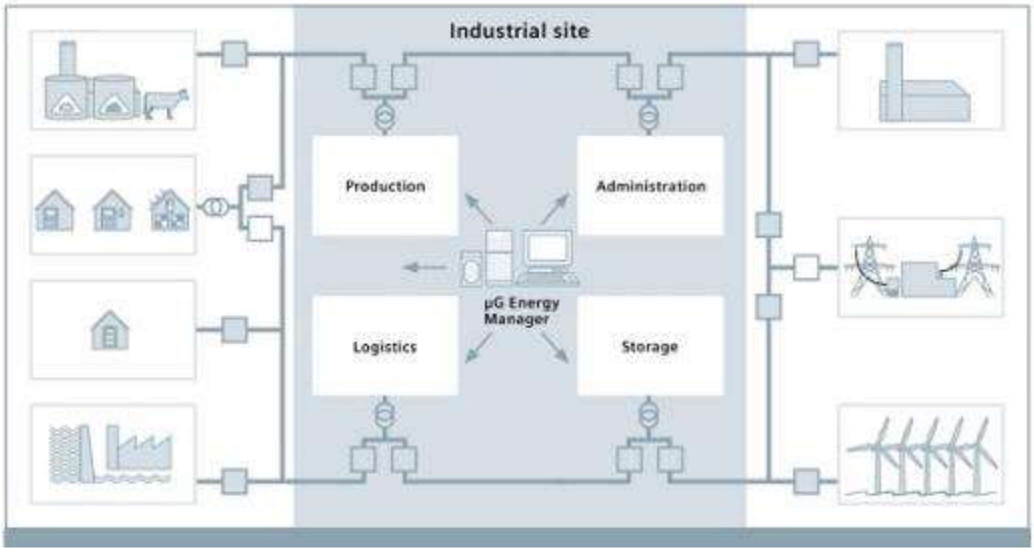


Figure 2: Industrial Microgrid. Source: Adapted from SIEMENS, (2011).

- **Campus and Institutional MicroGrids**

  This microgrid type (see Figure 3) is constructed topological at an institutional or campus region and consists of several loads at the campus or institutional environment in a restricted area. These microgrids type are gaining the most attention, because they have a single owner which diminishes the difficulties with regulations and managing. The demands for the power quality and reliability will rely on the type of institution such as research institutions.

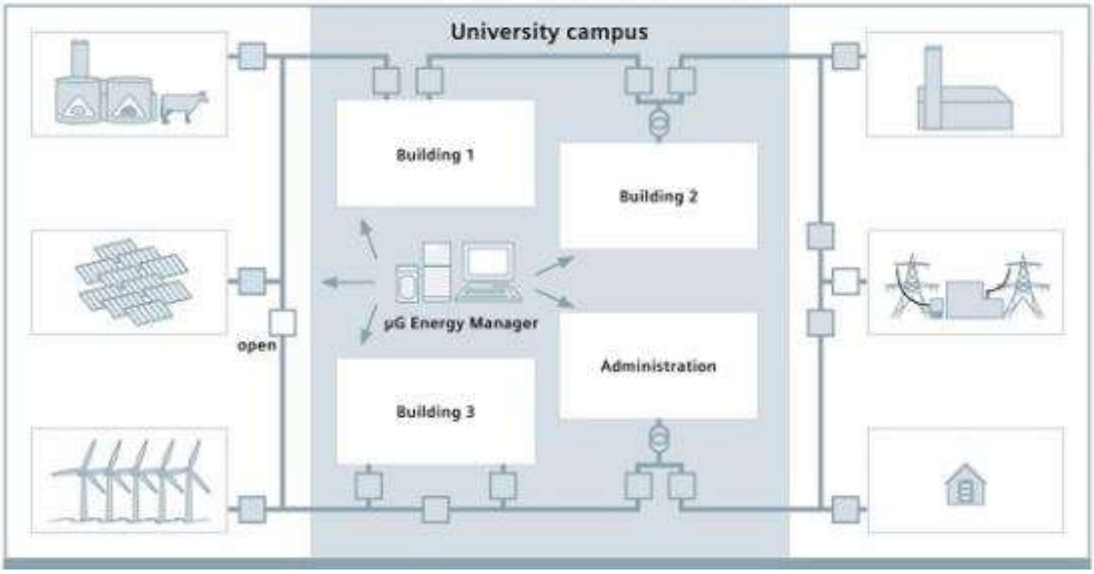


Figure 3: Campus/Institutional Microgrid. Source: Adapted from SIEMENS, (2011).

- **Island and remote ‘‘off-grid’’ Micro Grids**

  This micro grid type (see Figure 4) is not connected to the utility grid and is usually located on islands or remote areas where a connection with the main grid is commonly absent and the aim is on distributed and various power sources. In the developing world these micro grids can get extended and transformed to micro grids connected to the main grid, while others keep their island-mode operation. These micro grids are the largest number of operational micro grid types nonetheless within villages with the lowest capacities.

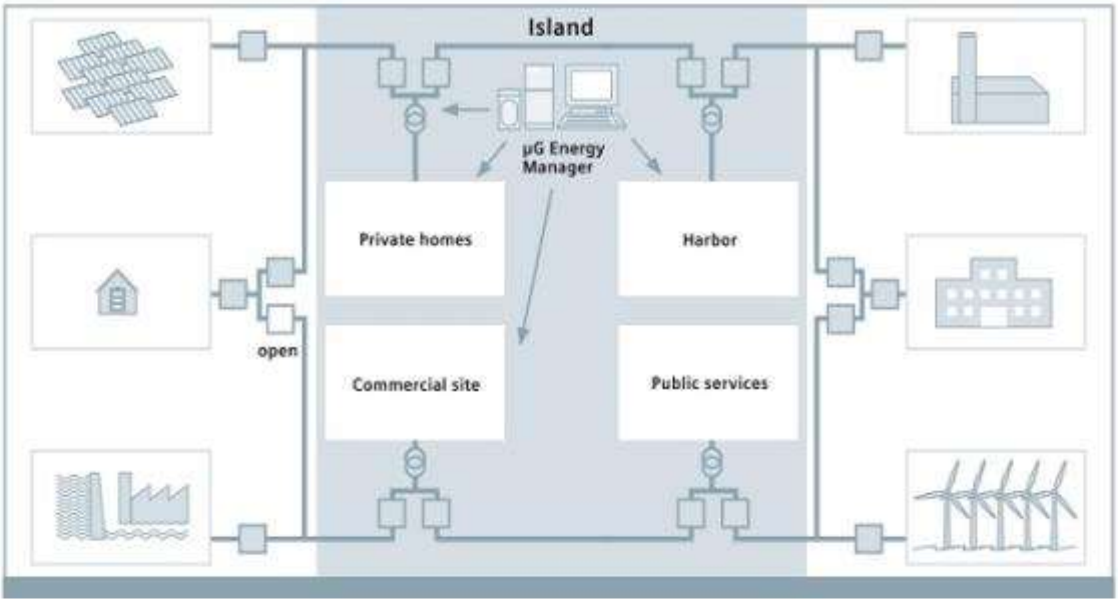


Figure 4: Island Microgrid. Source: Adapted from SIEMENS, (2011).

- **Community/Utility Micro Grids**

  This type of micro grid (see Figure 5) enhances the energy supply in residential areas, or even commercial and industrial areas. These micro grids can also be deployed in rural or urban communities that are grid-connected. Renewable or fossil-fueled distributed energy sources are mainly applied within these micro grids. There´s a large number of stakeholders in these micro grids, which makes processes complicated. They also do not operate in island-mode, which excludes them of the classic concept of a micro grid.

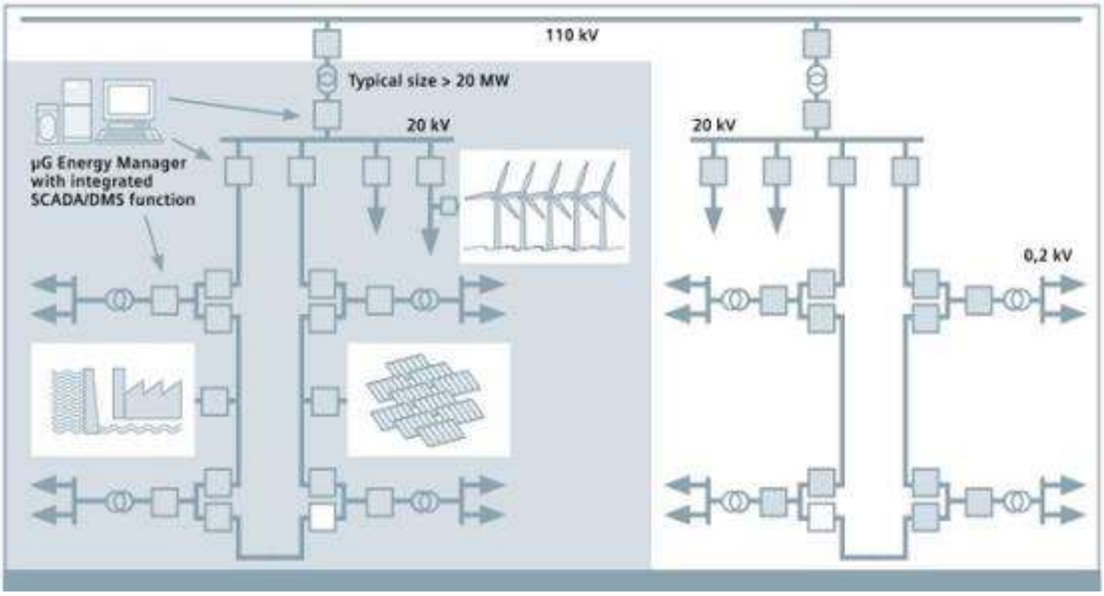


Figure 5: Utility microgrid. Source: Adapted from SIEMENS, (2011).

- **Military Micro Grids**

  The main focus for employment of these micro grids is on reliability, and on physical and cyber security for military stations. Renewable energy sources are applied for fuel cost reduction and acquired power supply.

2.2 MICROGRID TECHNOLOGY

Microgrids have an identical structure compared to a conventional grid considering the power generation, distribution, transmission, and control features, only in a smaller scale than the main grid. At the same time, the microgrid technology is not identical to that of the conventional grid, due to their near load energy generation features, (HOSSAIN et al., 2014).

The following micro grid technologies required to have the microgrid functioning as expected in both island- and on- grid mode are the following, (HAYDEN, 2013):

- Substation Automation

- Microgrid Control Systems
- Distributed Generation (DG)
- Islanding and Bi-Directional Inverters
- Smart Meters
- Distribution Automation (DA)
- Smart Transfer Switches
- Advanced Energy Storage

As mentioned by Hayden (2013), the most important technologies for improving the development of microgrids are: communication technologies, management systems for distribution and energy and sensors for control management.

A point of common coupling (PCC), which is the interconnection of a conventional grid and the distribution/generation side of a microgrid, is one of the main technologies required in a microgrid with both island mode and on-grid mode capabilities (see Figure 6). The microgrid technologies as mentioned earlier are hereby related to the different functioning units of the microgrid as presented in microgrid architecture Figure 6.

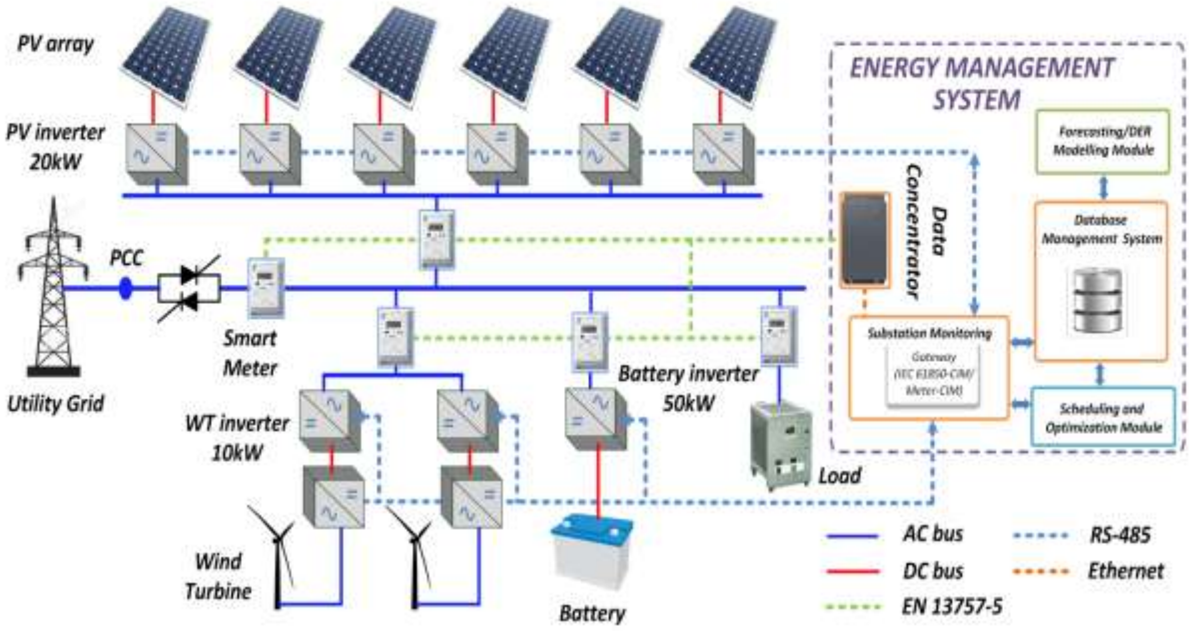


Figure 6: Architecture of a microgrid based on the technologies. Source: http://www.et.aau.dk/research-programmes

2.2.1 MICROGRID ENERGY GENERATION TECHNOLOGIES

The distributed energy generators (DG) are the energy generation units in the microgrids and there are two classifications known:

1. Renewable DG, such as: solar thermal, photovoltaic (PV), wind, hydro, biomass and biogas.
2. Non-renewable DG, such as diesel engine, stream turbine, gas engine.

In Table 1, is presented a summary of distributed generation technologies with their components, characteristics and costs. This table enhances a selection of the microgrid technologies in the functional unit of DG, where the electrical energy is being generated by these DGs from their different sources (renewable and non-renewable), (HOSSAIN et al., 2014).

2.2.2 MICROGRID ENERGY STORAGE TECHNOLOGIES

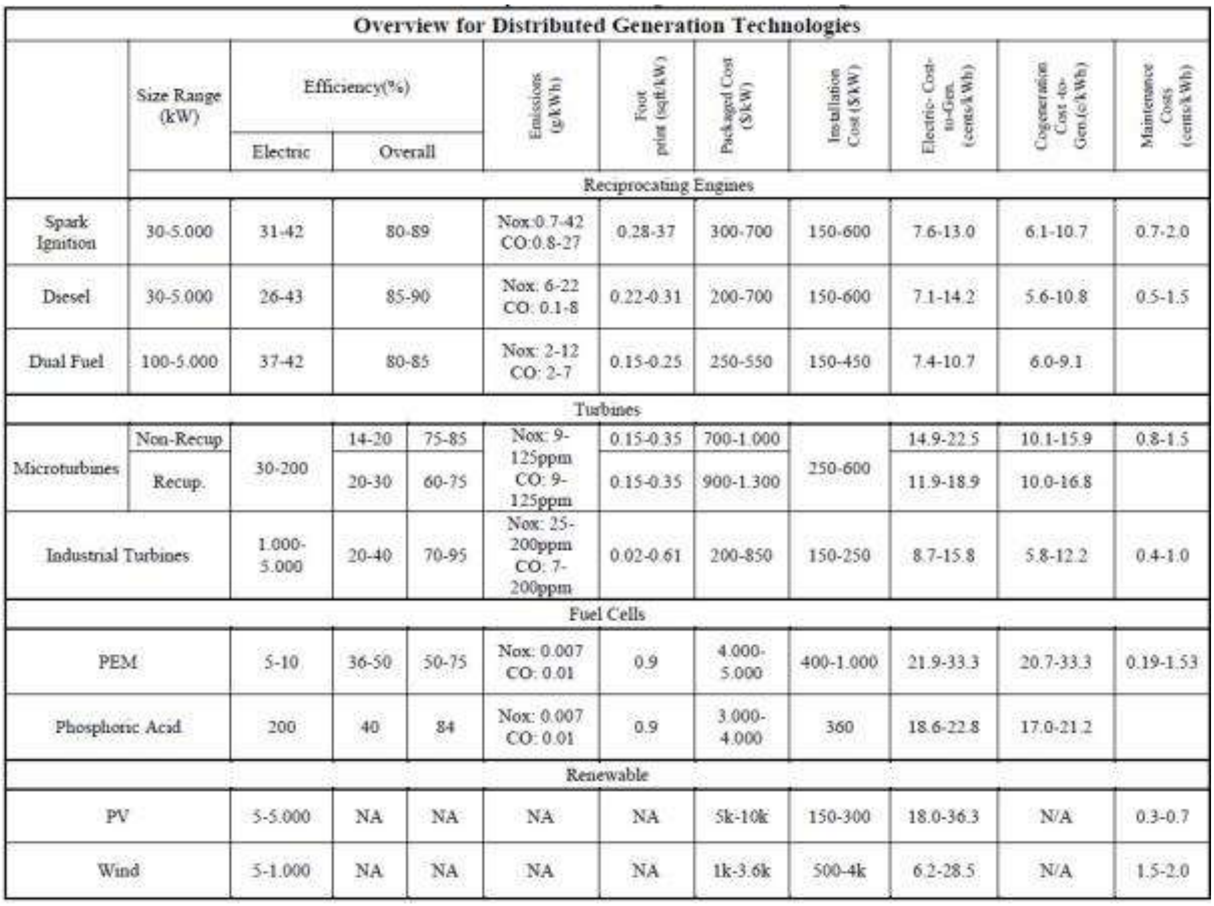
Energy storage is an essential element of microgrids. The energy storage technologies are mainly categorized as electrochemical systems (batteries and capacitor banks), potential energy storage (pumped hydro or compressed air storage), kinetic energy storage systems (flywheel energy storage) and fuel cells or traditional generators with their effectively large inertia. The energy storage cost of a microgrid is based on their reliability and resiliency requirements. With the necessity of energy storage in low-inertia power systems comes along the need for more advanced control systems for a robust system with adequate response times. Diminishing the amount of power conversions in microgrids is a system efficiency objective, hereby long-term investments in microgrid technologies are acquired for DC and hybrid (AC/DC) architectures to optimize the system efficiencies completely, (BOWER & REILLY, 2014).

In Table 2 is presented a summary of existing storage technologies. The batteries, flywheels and super capacitors are more appropriate for microgrid application. The reasons why these technologies are more adequate are:

- For energy reliability by ensuring sustainability of fixed voltage and frequency operation while using renewable energy sources, the energy storage systems based on batteries are the best solution.
- Since the flywheel has the ability to absorb and release energy quickly, it is a good alternative method as central storage element. The price of the flywheel method is not convenient for large-scale power system applications when used in an advanced design.

There is a competition between storage systems with both batteries and flywheels in uninterruptible power supply applications, with regard to high power demands, power density and efficiency, (HOSSAIN et al. 2014).

Table 1: Distributed Generation Technologies of microgrids.



Overview for Distributed Generation Technologies

		Size Range (kW)	Efficiency(%) Electric	Efficiency(%) Overall	Emissions (g/kWh)	Foot print (sqft/kW)	Packaged Cost ($/kW)	Installation Cost ($/kW)	Electric- Cost-to-Gen. (cents/kWh)	Cogeneration Cost-to-Gen.(c/kWh)	Maintenance Costs (cents/kWh)
Reciprocating Engines											
Spark Ignition		30-5.000	31-42	80-89	Nox:0.7-42 CO:0.8-27	0.28-37	300-700	150-600	7.6-13.0	6.1-10.7	0.7-2.0
Diesel		30-5.000	26-43	85-90	Nox: 6-22 CO: 0.1-8	0.22-0.31	200-700	150-600	7.1-14.2	5.6-10.8	0.5-1.5
Dual Fuel		100-5.000	37-42	80-85	Nox: 2-12 CO: 2-7	0.15-0.25	250-550	150-450	7.4-10.7	6.0-9.1	
Turbines											
Microturbines	Non-Recup	30-200	14-20	75-85	Nox: 9-125ppm CO: 9-125ppm	0.15-0.35	700-1.000	250-600	14.9-22.5	10.1-15.9	0.8-1.5
	Recup.		20-30	60-75		0.15-0.35	900-1.300		11.9-18.9	10.0-16.8	
Industrial Turbines		1.000-5.000	20-40	70-95	Nox: 25-200ppm CO: 7-200ppm	0.02-0.61	200-850	150-250	8.7-15.8	5.8-12.2	0.4-1.0
Fuel Cells											
PEM		5-10	36-50	50-75	Nox: 0.007 CO: 0.01	0.9	4.000-5.000	400-1.000	21.9-33.3	20.7-33.3	0.19-1.53
Phosphoric Acid		200	40	84	Nox: 0.007 CO: 0.01	0.9	3.000-4.000	360	18.6-22.8	17.0-21.2	
Renewable											
PV		5-5.000	NA	NA	NA	NA	5k-10k	150-300	18.0-36.3	N/A	0.3-0.7
Wind		5-1.000	NA	NA	NA	NA	1k-3.6k	500-4k	6.2-28.5	N/A	1.5-2.0

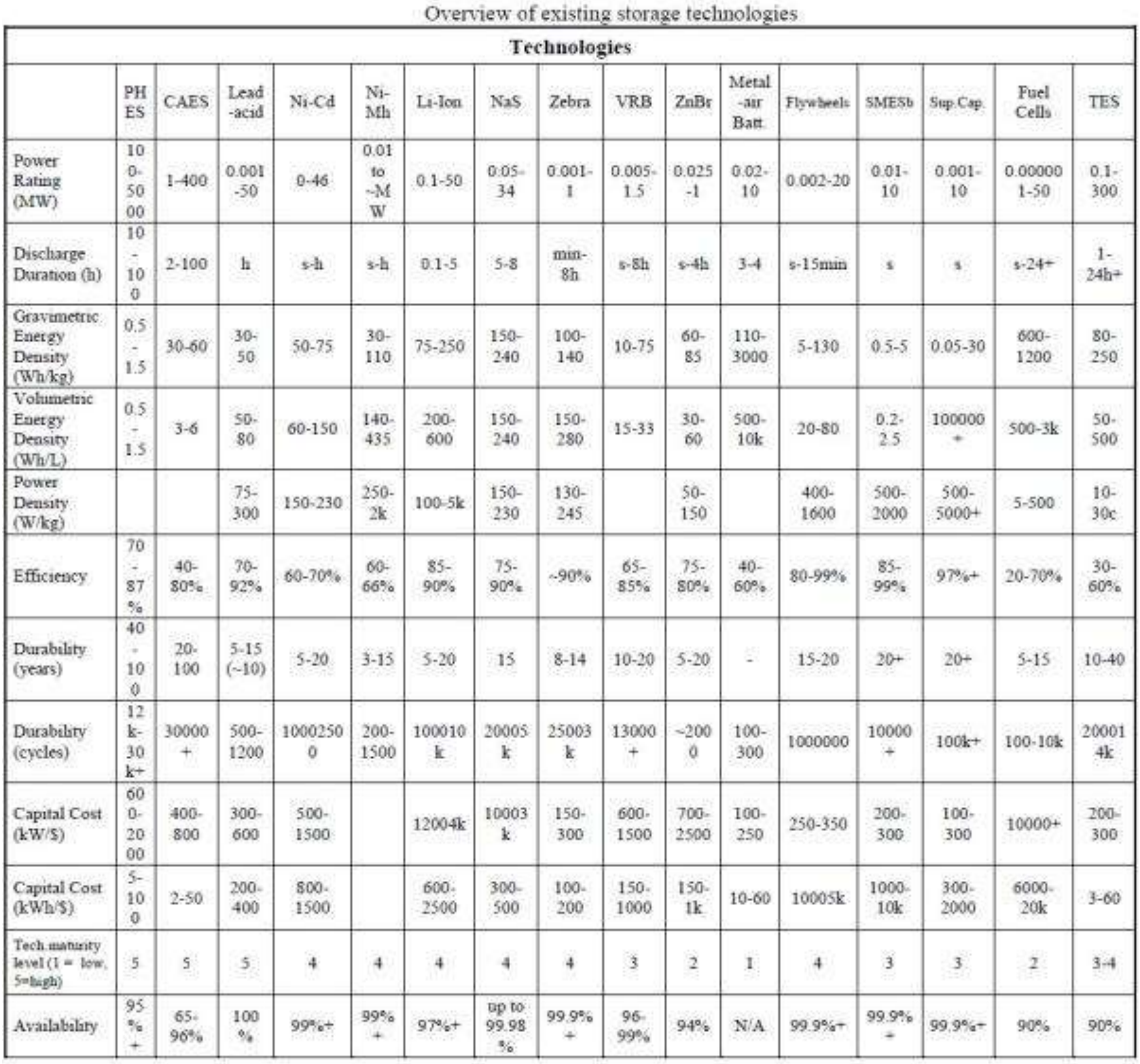
Source: Adapted from Hossain et al., (2014).

2.2.3 MICROGRID INTERFACE TECHNOLOGY

The main components of AC microgrids are renewable DG units, loads and energy storage units, which are integrated by a network of AC transmission lines and transformers. The interface technology of the microgrids involves the DER (Distributed Energy Resources) unit, where the interconnection of most DGs, storage units, specific equipment and components could be made by power converters. For the conversion of generated energy of the DER to appropriate power types for distribution to a grid or clients, specific converters and power electronic interfaces are needed. DER inhibits DG (renewable and non-renewable) and energy storage technologies. In many DER technologies the grid-tied inverters are needed for grid control-actions, such as to convert the generated energy into grid compatible AC power, capable of controlling the voltage and frequency of a microgrid through respective control interfaces. The various functions of power electronics interface units are namely power conversion power conditioning (PQ), protection of output interface and filters, DER and load control, ancillary services, and monitoring and control. Power electronics are applied in microgrids for the objective of converting the features of electrical power such as voltage and current magnitude, phase and/or frequency to adapt to any specific utilization.

In Table 3 is shown a review of the various energy conversion technologies in microgrids as explained earlier in this section, with their characteristics. In Table 4 is further summarized the interface configurations and power flow methods for DERs. Among these, the bi-directional converters are the most frequently utilized power electronic interfaces mainly for their power-flow control ability. Another important aspect of these converters is their ability to maintain the generated power stable in overload or no-load operation schemes, (SCHIFER et al., 2015).

Table 2: A summary of existing energy storage technologies.

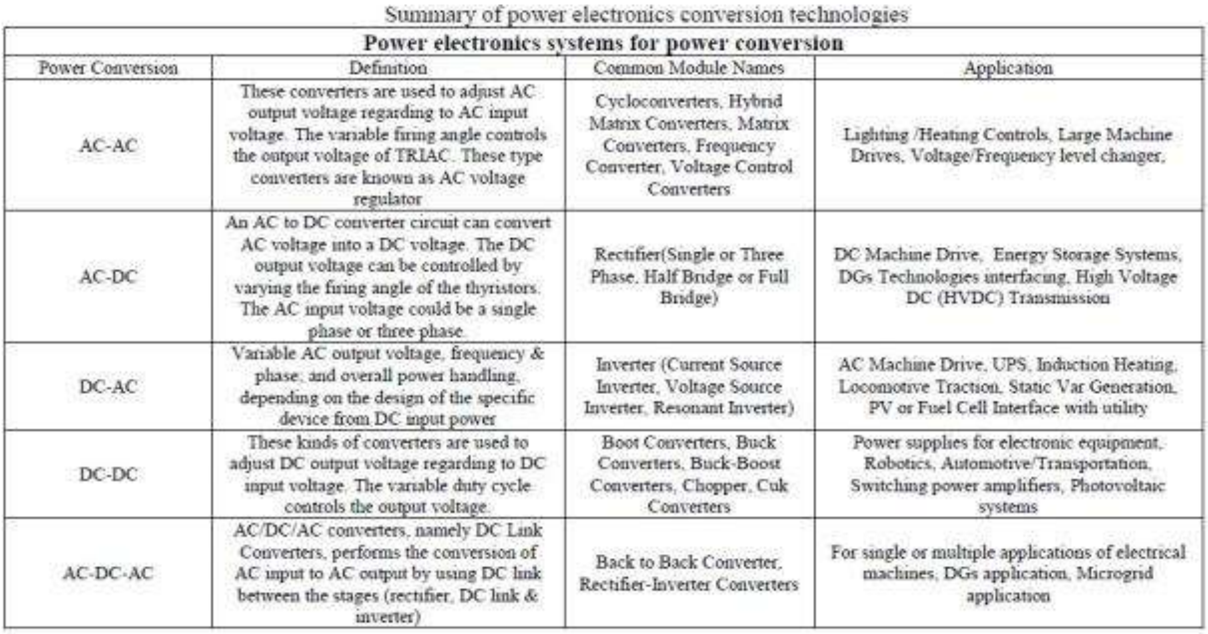


Overview of existing storage technologies

	Technologies															
	PHES	CAES	Lead-acid	Ni-Cd	Ni-Mh	Li-Ion	NaS	Zebra	VRB	ZnBr	Metal-air Batt.	Flywheels	SMESb	Sup.Cap.	Fuel Cells	TES
Power Rating (MW)	100-5000	1-400	0.001-50	0-46	0.01 to ~MW	0.1-50	0.05-34	0.001-1	0.005-1.5	0.025-1	0.02-10	0.002-20	0.01-10	0.001-10	0.000001-50	0.1-300
Discharge Duration (h)	10-100	2-100	h	s-h	s-h	0.1-5	5-8	min-8h	s-8h	s-4h	3-4	s-15min	s	s	s-24+	1-24h+
Gravimetric Energy Density (Wh/kg)	0.5-1.5	30-60	30-50	50-75	30-110	75-250	150-240	100-140	10-75	60-85	110-3000	5-130	0.5-5	0.05-30	600-1200	80-250
Volumetric Energy Density (Wh/L)	0.5-1.5	3-6	50-80	60-150	140-435	200-600	150-240	150-280	15-33	30-60	500-10k	20-80	0.2-2.5	100000+	500-3k	50-500
Power Density (W/kg)			75-300	150-230	250-2k	100-5k	150-230	130-245		50-150		400-1600	500-2000	500-5000+	5-500	10-30c
Efficiency	70-87%	40-80%	70-92%	60-70%	60-66%	85-90%	75-90%	~90%	65-85%	75-80%	40-60%	80-99%	85-99%	97%+	20-70%	30-60%
Durability (years)	40-100	20-100	5-15 (~10)	5-20	3-15	5-20	15	8-14	10-20	5-20	-	15-20	20+	20+	5-15	10-40
Durability (cycles)	12k-30k+	30000+	500-1200	10002500	200-1500	100010k	20005k	25003k	13000+	~2000	100-300	1000000	10000+	100k+	100-10k	200014k
Capital Cost (kW/$)	600-2000	400-800	300-600	500-1500		12004k	10003k	150-300	600-1500	700-2500	100-250	250-350	200-300	100-300	10000+	200-300
Capital Cost (kWh/$)	5-100	2-50	200-400	800-1500		600-2500	300-500	100-200	150-1000	150-1k	10-60	10005k	1000-10k	300-2000	6000-20k	3-60
Tech maturity level (1 = low, 5=high)	5	5	5	4	4	4	4	4	3	2	1	4	3	3	2	3-4
Availability	95%+	65-96%	100%	99%+	99%+	97%+	up to 99.98%	99.9%+	96-99%	94%	N/A	99.9%+	99.9%+	99.9%+	90%	90%

Source: Adapted from Hossain et al., (2014).

Table 3: A summary of power electronics conversion technologies.

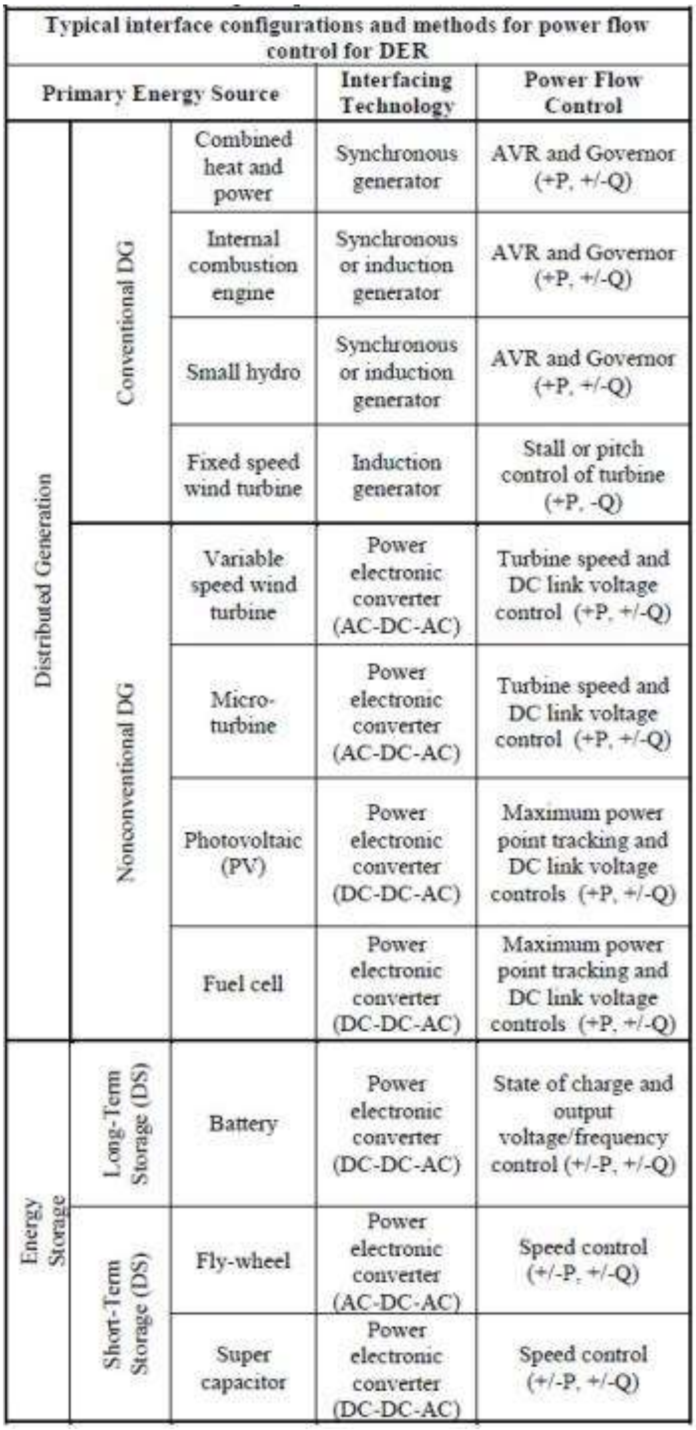


Summary of power electronics conversion technologies

Power electronics systems for power conversion			
Power Conversion	Definition	Common Module Names	Application
AC-AC	These converters are used to adjust AC output voltage regarding to AC input voltage. The variable firing angle controls the output voltage of TRIAC. These type converters are known as AC voltage regulator	Cycloconverters, Hybrid Matrix Converters, Matrix Converters, Frequency Converter, Voltage Control Converters	Lighting /Heating Controls, Large Machine Drives, Voltage/Frequency level changer,
AC-DC	An AC to DC converter circuit can convert AC voltage into a DC voltage. The DC output voltage can be controlled by varying the firing angle of the thyristors. The AC input voltage could be a single phase or three phase.	Rectifier(Single or Three Phase, Half Bridge or Full Bridge)	DC Machine Drive, Energy Storage Systems, DGs Technologies interfacing, High Voltage DC (HVDC) Transmission
DC-AC	Variable AC output voltage, frequency & phase; and overall power handling, depending on the design of the specific device from DC input power	Inverter (Current Source Inverter, Voltage Source Inverter, Resonant Inverter)	AC Machine Drive, UPS, Induction Heating, Locomotive Traction, Static Var Generation, PV or Fuel Cell Interface with utility
DC-DC	These kinds of converters are used to adjust DC output voltage regarding to DC input voltage. The variable duty cycle controls the output voltage.	Boot Converters, Buck Converters, Buck-Boost Converters, Chopper, Cuk Converters	Power supplies for electronic equipment, Robotics, Automotive/Transportation, Switching power amplifiers, Photovoltaic systems
AC-DC-AC	AC/DC/AC converters, namely DC Link Converters, performs the conversion of AC input to AC output by using DC link between the stages (rectifier, DC link & inverter)	Back to Back Converter, Rectifier-Inverter Converters	For single or multiple applications of electrical machines, DGs application, Microgrid application

Source: Adapted from Hossain et al., (2014).

Table 4: Summary of interface technologies of the microgrid.



Typical interface configurations and methods for power flow control for DER				
Primary Energy Source			Interfacing Technology	Power Flow Control
Distributed Generation	Conventional DG	Combined heat and power	Synchronous generator	AVR and Governor (+P, +/-Q)
		Internal combustion engine	Synchronous or induction generator	AVR and Governor (+P, +/-Q)
		Small hydro	Synchronous or induction generator	AVR and Governor (+P, +/-Q)
		Fixed speed wind turbine	Induction generator	Stall or pitch control of turbine (+P, -Q)
	Nonconventional DG	Variable speed wind turbine	Power electronic converter (AC-DC-AC)	Turbine speed and DC link voltage control (+P, +/-Q)
		Micro-turbine	Power electronic converter (AC-DC-AC)	Turbine speed and DC link voltage control (+P, +/-Q)
		Photovoltaic (PV)	Power electronic converter (DC-DC-AC)	Maximum power point tracking and DC link voltage controls (+P, +/-Q)
		Fuel cell	Power electronic converter (DC-DC-AC)	Maximum power point tracking and DC link voltage controls (+P, +/-Q)
Energy Storage	Long-Term Storage (DS)	Battery	Power electronic converter (DC-DC-AC)	State of charge and output voltage/frequency control (+/-P, +/-Q)
	Short-Term Storage (DS)	Fly-wheel	Power electronic converter (AC-DC-AC)	Speed control (+/-P, +/-Q)
		Super capacitor	Power electronic converter (DC-DC-AC)	Speed control (+/-P, +/-Q)

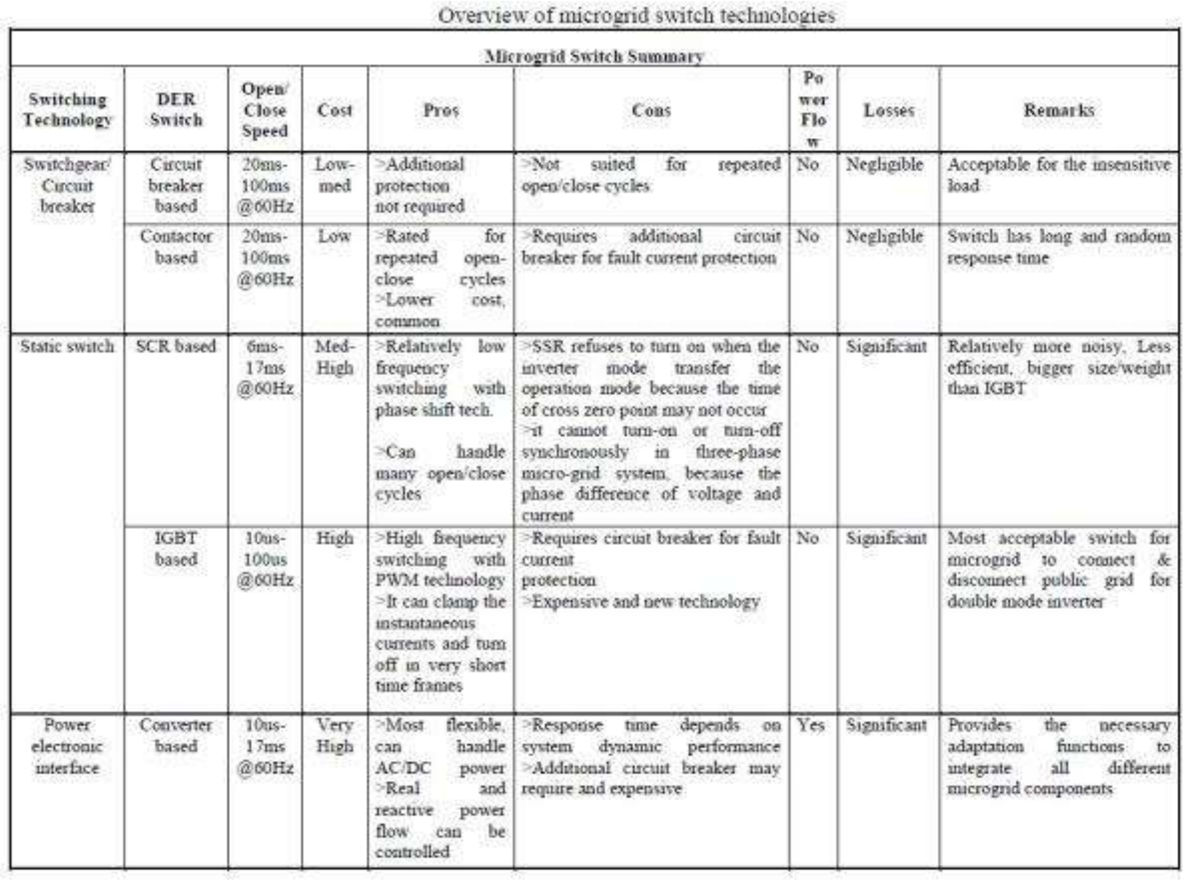
Source: Adapted from Hossain et al., (2014).

2.2.4 MICROGRID SWITCH TECHNOLOGIES FOR INTERCONNECTION

To maintain the microgrid functioning in on-grid as off-grid or island mode, the microgrid has to have specific control strategies implied to be able to switch seamlessly from one scheme to another in case of utility power failure or other circumstances. In the operations, the microgrids are frequently operated in on-grid mode, but in situations of any faults, it could be disconnected from the main grid at the PCC (Point of Common Coupling), to operate as island or the other way around.

Microgrids usually have a rated peak power of less than 10MVA and their interconnection relay that interfaces the microgrid and utility service holds the great responsibility for success of transition management through the grid, by its switching control method (HOSSAIN et al. 2014). The various switch technologies and control technologies of microgrids are shown in summary in the Tables 5 and 6.

Table 5: A summary of the microgrid switch technologies.



Overview of microgrid switch technologies

Microgrid Switch Summary

Switching Technology	DER Switch	Open/ Close Speed	Cost	Pros	Cons	Power Flow	Losses	Remarks
Switchgear/ Circuit breaker	Circuit breaker based	20ms-100ms @60Hz	Low-med	>Additional protection not required	>Not suited for repeated open/close cycles	No	Negligible	Acceptable for the insensitive load
	Contactor based	20ms-100ms @60Hz	Low	>Rated for repeated open-close cycles >Lower cost, common	>Requires additional circuit breaker for fault current protection	No	Negligible	Switch has long and random response time
Static switch	SCR based	6ms-17ms @60Hz	Med-High	>Relatively low frequency switching with phase shift tech. >Can handle many open/close cycles	>SSR refuses to turn on when the inverter mode transfer the operation mode because the time of cross zero point may not occur >it cannot turn-on or turn-off synchronously in three-phase micro-grid system, because the phase difference of voltage and current	No	Significant	Relatively more noisy, Less efficient, bigger size/weight than IGBT
	IGBT based	10us-100us @60Hz	High	>High frequency switching with PWM technology >It can clamp the instantaneous currents and turn off in very short time frames	>Requires circuit breaker for fault current protection >Expensive and new technology	No	Significant	Most acceptable switch for microgrid to connect & disconnect public grid for double mode inverter
Power electronic interface	Converter based	10us-17ms @60Hz	Very High	>Most flexible, can handle AC/DC power >Real and reactive power flow can be controlled	>Response time depends on system dynamic performance >Additional circuit breaker may require and expensive	Yes	Significant	Provides the necessary adaptation functions to integrate all different microgrid components

Source: Adapted from HOSSAIN et al., (2014).

Table 6: Analysis of the various control techniques in AC and DC microgrids.

Comparison of AC and DC microgrids in the control strategies aspects			
Mode	Controller	Microgrid type	
		AC	DC
Grid-tie	Microgrid Central Controller (MGCC)	- Monitoring is based on gathering data inherited from low voltage AC networks, DG systems, and loads. - provides several control methods: prediction, security observation, power flow control, and requirement management. - Maintains synchronized operation with grid and conserves power exchange at or before the contract points.	- The key function of the MGCC is controlling the power demand and voltage variations against changed conditions and loads. - Facilitates scheduling, observing loads, and Demand Side Management (DSM)
	DG Controllers (DGCs)	- Monitors and controls each DG unit in order to manage the load demand in both grid-tied and islanded modes, and controls the transitions through modes with the help of MGCC.	- assures transfer of all generated power by the DG to utility grid, and then can return to islanded mode safely when required.
Islanded	Microgrid Central Controller (MGCC)	- controls the power flow of DG (active and reactive), and stabilizes voltage and frequency, prevents interruptions by developing strategies and using management with ESS support. - Initializes local blackstart to maintain reliability of power supply and sustainability of service. - interconnects the microgrid to grid-tied mode when the utility grid is stabilized after a probable fault	- controls and stabilizes the power flow and load voltage when an error or change occurs in the load profile and distribution sections - picks up the generated voltage in grid-tied or islanded modes owing to MGCC features
	DG Controllers (DGCs)	- checks all DG units independently in order to assure that the generated voltage has been transferred to the load in islanded mode, and tracks the utility grid to operate in synchronized mode due to MGC features	- assists load sharing for each DG units in the islanded and grid-tied modes

Source: Adapted from HOSSAIN et al., (2014).

2.4 THE SMART MICROGRID

In the descriptions of smart microgrid in the literature, the smart grid with its features and technologies of the smart grid are always defined, because of their interconnection as described here.

The International Energy Agency, IEA (2011) has defined the smart grid as an upgraded electricity network which utilizes digital and other advanced technologies for monitoring and managing purposes of the electrical energy transport from the production source to the customers, to meet their demands.

There is a very close connection between the smart grid and the microgrid, based on the state of the art of technology of micro grids. Microgrids are interconnected with the smart grids; considered to be the basis or basic components of the “macro” smart grid, allowing the implementation of the smart grid moderately/step by step, and introducing the development of interconnected distributed generation without doing harm to the main power system and offer new commercial agreements interest of the supplier/distributor and its clients. The microgrid and the smart grid are based on the same concepts to improve the interconnectivity of all components such as distributed generators with the focus on management and control, reliable energy, environmental issues and economy (de CASTRO, 2015).

The growth and evolution of the smart grid appear in the development of the interconnection of basic structures containing joint electrical energy generators and consumers suited in one limited area, to create a secure network unit named ´´intelligent (smart) micro grid´´. The smart micro grid network units used for smart grid developments make operating the network more accessible, because of the small scale power that has to be generated, transported and distributed (FARHANGI, 2010).

A main objective for smart microgrid systems is to accomplish promising new solutions by interconnecting smart microgrids in parallel with the utility distribution system and transitioning seamlessly to an autonomous power system complete with its controls, protection, and operating algorithms. It is expected that smart microgrids will be fielded in a wide variety of electrical environments ranging from substations to building-integrated systems, (BOWER & REILLY, 2014).

In Figure 7 is visualized a topology of an intelligent (smart) micro grid presented with a couple of possible distribution generators, advanced technologies and load profiles.

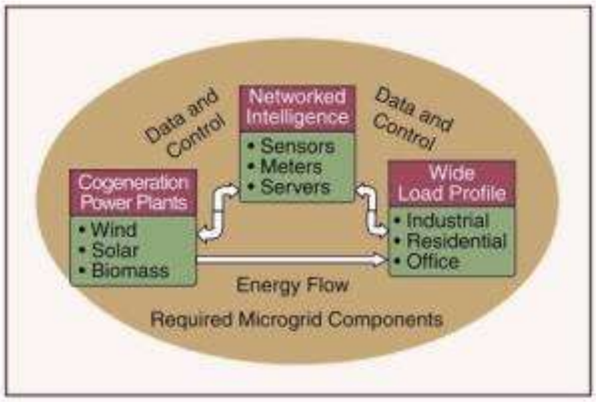


Figure 7: Topology of smart micro grid. Source: Adapted from Farhangi, (2010).

Since the concept of the Smart Grid had been introduced in 2001 by the U.S. Electric Power Research Institute, its popularity has kept increasing. The smart grid has been a driven factor in the battle to lower the carbon emissions and meet the exponential growing electricity demand. There is not one exact definition for the smart grid. The smart grid is defined in different ways across the countries, institutions and many researchers. What is well known among the many concepts of the smart grid, is that it´s mainly applied in the distribution network of the electricity grid, because that is the place where the most challenges of the existing electricity grid are. In the next part there will be mentioned a few of the many accepted definitions by researchers of the smart grid.

According to the Smart Grid 2013 Global Impact Report (2013), one of the accepted definitions of the smart grid is as follows:

> “The modernization of electricity networks through the application of innovative and intelligent products, services and technologies, in order to provide greater

> monitoring, automation, control, co-ordination and inclusion of the transmission, distribution, generation (including distributed generation) and the demand side, for the purpose of increased energy and cost efficiency, sustainability, energy security as well as the benefit and empowerment of customers and society (LEWIS, 2013).’’

The US Department of Energy, DOE (2009), defines the Smart Grid as follows:

> ´´An automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level´´.

The smart grid can be treated as a state-of the art electric power network framework for different matters such as advanced communication, sensing and metering systems, advanced energy information systems based on demand optimality aspects, advanced control systems and elevated efficiency (GÜNGOR et al., 2011).

The smart grid concept is described by Farhangi (2010), as the conjunction of the power system engineering with the ICT (information and communication technology). These are the basics of the smart technologies that are being applied to the current and future electricity networks.

If considered the many used concepts of the smart grid, it is definitely clear that they all have in common that the smart grid is an electricity grid which is a transformed electrical grid with new advanced technologies integrated with two-way communication technology to automate, control and manage all the units in the existing grid, especially the distribution of the electricity to the customers in the distribution network.

The following Figure 8 represents the scope of the smart grid concerns that covers all the aspects of the smart grid concept, as described earlier.

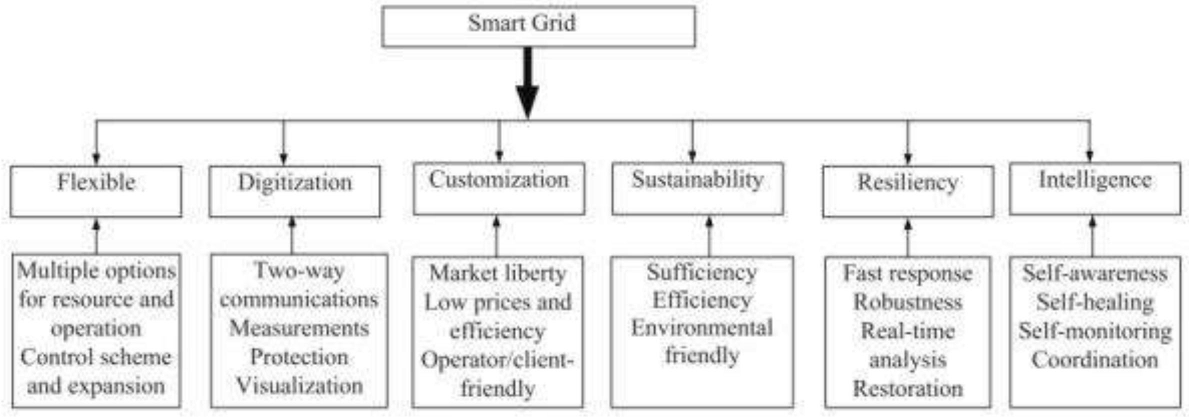


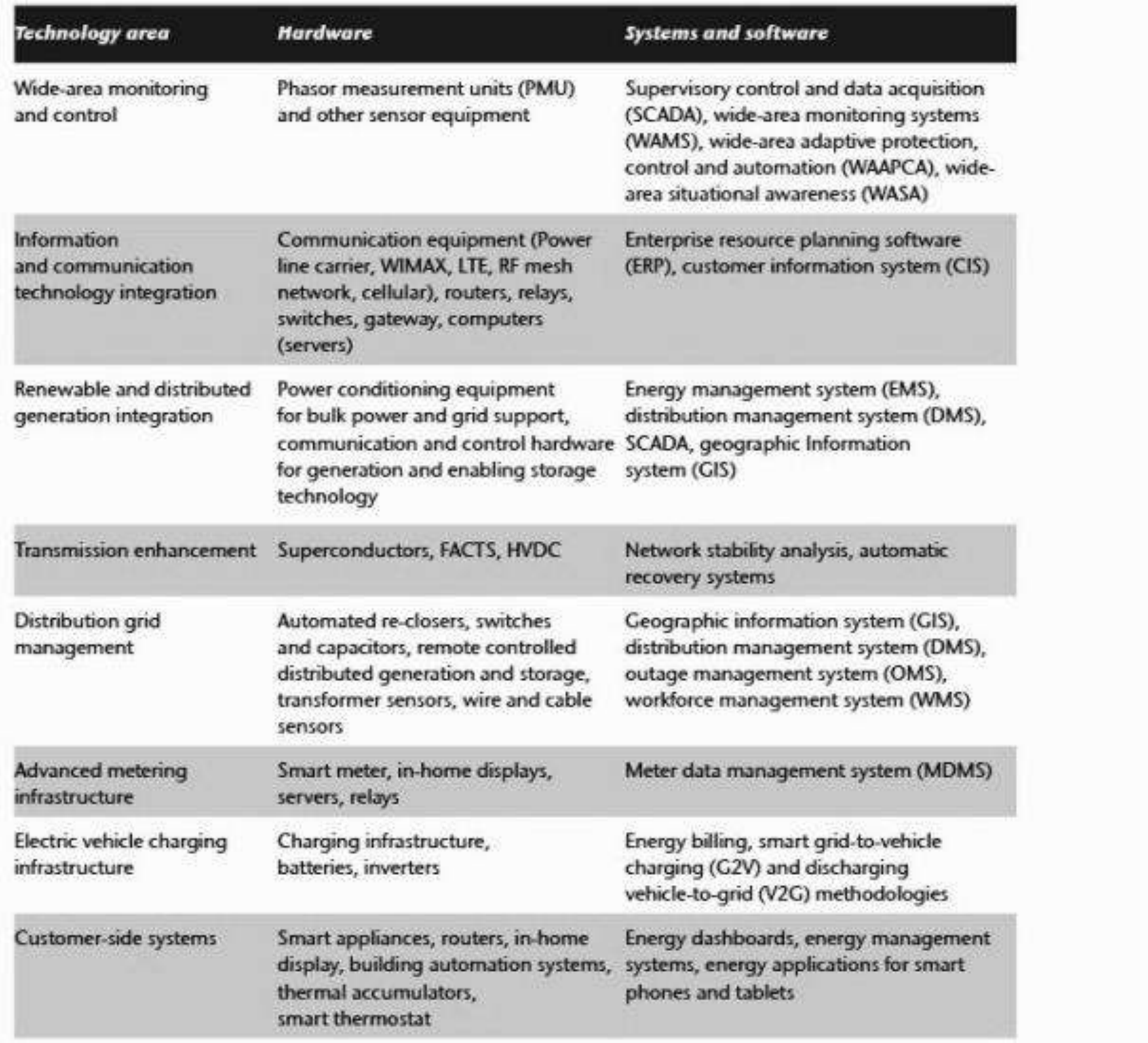
Figure 8: The main characteristics of a smart grid. Source: Rana & Li, (2015).

The smart grids are seen as modern grids that introduce state of the art technology into the existing electricity grid to integrate the electricity grid with information technology to get a better functioning, secure, reliable electricity network. The smart grids are also described as one of the important components for the sustainable energy future and there are many innovations in technology occurring based on ICT, electric Vehicles (EV), energy storage (batteries), wind solar and other distributed renewable energy sources and microgrids (MAH et. al., 2014).

With the focus on the challenges of the existing conventional electricity grid, we can consider the need for smart grids and thereby enhanced the need for smart microgrids, with their smart technologies such as advanced communication, automation, management and auto-repair technologies as a modern electrical grid (BUCHHOLZ & STYCZYNSKI, 2014).

In Table 7, the smart grid technologies areas are presented with their different hardware and systems and software. The smart grid technology landscape, as mentioned by the IEA (2011), the wide field of software, hardware, application and communication technologies.

Table 7: Smart grid technologies.



Technology area	*Hardware*	*Systems and software*
Wide-area monitoring and control	Phasor measurement units (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), wide-area monitoring systems (WAMS), wide-area adaptive protection, control and automation (WAAPCA), wide-area situational awareness (WASA)
Information and communication technology integration	Communication equipment (Power line carrier, WIMAX, LTE, RF mesh network, cellular), routers, relays, switches, gateway, computers (servers)	Enterprise resource planning software (ERP), customer information system (CIS)
Renewable and distributed generation integration	Power conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology	Energy management system (EMS), distribution management system (DMS), SCADA, geographic Information system (GIS)
Transmission enhancement	Superconductors, FACTS, HVDC	Network stability analysis, automatic recovery systems
Distribution grid management	Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable sensors	Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS)
Advanced metering infrastructure	Smart meter, in-home displays, servers, relays	Meter data management system (MDMS)
Electric vehicle charging infrastructure	Charging infrastructure, batteries, inverters	Energy billing, smart grid-to-vehicle charging (G2V) and discharging vehicle-to-grid (V2G) methodologies
Customer-side systems	Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tablets

Source: Adapted from IEA, (2011).

2.5 EXAMPLES OF (SMART) MICROGRIDS

As mentioned before, there are different types of microgrids. Of these microgrids the largest group of the microgrid type is the Institutional/Campus microgrid. Many of the Institutional/Campus microgrids are being employed for research matters and function as test-beds. As reported by many researchers of different institutions such as the IEA (The International Energy Agency), DOE (The U.S. Department of Energy), CERTS (The Consortium for Electric Reliability Technology Solutions), Lawrence Berkeley National Laboratories, and SANDIA National Laboratories, there are different microgrid experiments done to develop and keep the microgrids improving. Therefore research is done on the field of different strategies and technologies. These experiments or tests have different focuses for various reasons, such as commercial reasons or strictly R&D (Research & Development) goals (TURNER et al., 2015; LASSETER, 2010; MARNAY & BAILEY, n.d.; HUERTTA et al., 2014; SMITH, 2011; DOE, 2011; BOWER & REILLY, 2014; WHITAKER et al., 2008; GREACEN et al., 2013).

According to the summary report of the National Institute of Standards and Technology (NIST) in 2014, test-beds play an important role in smart grid, because they are essentially platforms for the rigorous and replicable testing of theories, new technologies, computational tools, and systems. The test-bed provides a development environment without the potential hazards or consequences present when testing in a live production environment. Test-beds in general can be used to demonstrate new components or entire systems, and can include software and hardware/physical equipment as well as networking components. Test-beds are especially important for evaluating performance and identifying any potentially adverse behaviors of interacting cyber-physical systems – before technologies are deployed in the smart grid. Smart grid test-beds can demonstrate “hardware-in-the-loop” and integrated cyber capabilities by combining real, simulated and emulated components or systems, creating an effective simulation of complex cyber-physical interactions in the power system (BOWER & REILLY, 2014).

There are many examples of microgrids as well as microgrid test-beds around the world (as presented in Table 8. The peak power of the microgrid can range from a few kilowatts to megawatts. There are different aspects and objectives for planning and establishing a microgrid test-bed, which are similar to a micro grid laboratory platform. Some have energy storing capacity and others not. It is also mentioned that the purpose of these test-bed plays a role in preserving the extra generated energy or not and frequently the energy storing is left out due to the expenses, but on the long run you can benefit more from it. These microgrids are presented in Table 8 with their significant specifications such as distributed generation sources, total capacity, location.

Table 8: Several smart microgrids around the world.

Microgrid Name	**Place/Country**	**Microgrid type**	**DGs Renewable**	**DGs Non-renewable**	**Capacity**	**Storage**
CERTS	Ohio	Residential; AC testbed	No	Gas		Battery
Fort Carson	U.S. base Colorado Spring	Military; Grid-tied	PV; Biomass; Thermal-Solar; Wind	Diesel	4MW	--
NYU	New York	Campus; Grid-tied	CHP	Gas	13,4MW	
BCIT	Burbnaby	Campus	PV; Thermal; Wind	No	555kW	Battery
NEDO	Japan Kyoto	Grid-tied testbed	PV; Wind	Gas	---	Battery
Osaka Plant	Japan Osaka	Campus; AC	FC-CHP	---	300kW	Battery
NTUA	Athens	Campus; Grid-tied	PV; Wind	Diesel	2,21kW	Battery
Kythnos	Greece Gsidouro	Remote/´´Off-Grid´´; LV	PV	Diesel	15kW	Battery
Subax	China	Residential/Community; Remote/´´Off-Grid´´	PV; Wind	Gas; Diesel	50kW	Battery
Continuon's MV/LV Holland plant	The Netherlands	Utility; AC	PV	---	315kW	Battery
CSIRO Energy Center	Australia Newcastle	Utility; AC	PV; Wind	Gas	500kW	Battery

Source: Elaborated by the author.

Several smart microgrids around the world

Of the several (smart) microgrids around the world as presented in Table 8, a few are further described in the next part to clarify their purpose of establishment.

North America:

In North America there are many microgrid projects done and still going on. The most well-known U.S. microgrids are the Consortium of Electric Reliability Technology Solutions

(CERTS). The CERTS is a partnership between Northern Power Systems, S&C Electric Co, TECOGEN, AEP, Sandia National Laboratories and the University of Wisconsin. Their microgrids project includes various DGs and a thyristor based switch for grid disconnection in the off-grid mode. Their main goal was to search for a simple solution for operating grid-connected micro generation. The CERTS is responsible for the development and implementation of the microgrid concepts which reduces the microgrid field engineering tasks. These concepts are: a strategy for automatic and smooth transformation between island mode and grid connected mode, a microgrid protection process independent of high fault currents and a microgrid control arrangement for voltage and frequency stability with absent communication system (BARNES et al., 2007; HATZIARGYRIOU et al., 2007).

Fort Carson microgrid:

This is a military microgrid on a U.S. base in Colorado Springs of the SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security) program. This extended base enhances an area of 550km^2 and 14,000 habitants. The goal of this base is to become net zero facility, which means utility independent of the energy utility grid. A requirement of the microgrid is to perform during energy interruptions in island-mode to keep a part of the base operating (BOWER & REILLY, 2014)

New York University (NYU) microgrid:

This campus/institutional microgrid of the New York University (NYU), one of the largest universities in the United States, has been participating in the power producing sector since the 1960s and enhanced an extended oil-fired cogeneration plant in 1980. With the focus on microgrid they transformed to an advanced natural-gas combined heat and power (CHP) station at the end of their former (oil-fired) stations life-cycle for increased reliability and better managing of their energy expenses. The distribution area of electrical energy of this pant involves 22 buildings and the heat distribution area involves 37 building spread over the campus. This campus/institutional microgrid, NYU, is grid-connected to the Con Edison distribution grid and also has the capacity for functioning in island-mode, which had a favorable trial period during Hurricane Sandy (HAYDEN, 2013).

British Columbia Institute of Technology microgrid:

This Campus/Institutional microgrid is a testbed at BC The British Columbia Institute of Technology (BCIT) main campus in Burbnaby. The focus of the design and small size microgrid development is to introduce it as testbed to the utility industry and researchers for matters based on the development of microgrid technologies for North American. It consists of command and control unit and campus-wide communication network, (HOSSAIN et al. 2014).

Japan:

Japan is recognized as the country with the most microgrid implementation projects around the world. They are dedicated to introducing more RE systems into their distribution system and this could bring harm to their utility power system. These RE systems are usually wind and PV systems of an irregular nature. To solve these challenges the microgrids are introduced of which most projects are funded by the NEDO, New energy and Industrial Technology Development Organization, and started around 2005. Examples are the Kyoto eco-energy microgrid testbed which is connected to the utility grid trough a substation. This microgrid enhances gas engines, a battery bank, two PV systems, a wind turbine, remote monitoring and control system and communication systems (HATZIARGYRIOU et al., 2007).

European Union:

Reduction of carbon emissions by 2020 is high on the agenda of the European member states since they have one of the highest levels of global warming and climate change alertness which has resulted in the promotion of increased utility of renewable energies and reduction of energy demand by increasing the energy efficiency. The “Microgrids project”, was the first EU funded microgrid project managed by the National Technical University of Athens (NTUA). This project was established with the focus on the dynamics of DGs in microgrids and the develop methods for various matters such as security, control algorithms and definition of DG interface response and advanced (smart) concerns (HATZIARGYRIOU et al., 2007).

Other examples of microgrids are a pilot project in Greece on the Kythnos Island, ISET microgrid in Germany with the focus on an extensive study on control applications, the microgrid at Seville on the university of Seville Spain that is based on PV arrays, Fuel cells and battery banks (lead acid) for storage. Their communication and control system is based on SCADA and PLC (Programmable Logic Control). There are also smaller scale microgrids projects of the EU such as the Continuon Holiday Camp Microgrid in the Netherlands (USTUN et al., 2011; HATZIARGYRIOU et al., 2007).

2.5.1 SMART MICROGRIDS IN BRAZIL

Many Brazilian electric utilities began studying Smart Grid in 2010, to develop a plan to address their investments in new infrastructure and Research and Development (R&D) projects proceeding to the modernization of the Brazilian electric system. There were a few motivating aspects collected for the implementation of the smart grid, such as: increase of the operational efficiency; expansion and automation of the electric power system with standardized smart technologies; reduction of non-technical losses; improvement of the system reliability and power quality, especially for industries and high-tech based companies (PICA et al., 2011).

There has been an association established by the Ministry of Minas and Energy (MME) between the EPE (Empresa de Pesquisa Energéticas), the CEPEL (Centro de Pesquisas de Energia Elétrica), ANEEL (Agência Nacional de Energia Elétrica and the ONS (Operador Nacional do Sistema Elétrico). This association will have their focus on public political matters for implementing smart grids and management studies to control the introduction of new elements in the electric grid system such as microgrids, (de CASTRO, 2015).

The main challenges concerning the introduction of smart grid in the energy sector of Brazil are mainly the remote areas like the rural areas and the Amazon; illegal connected energy loads, the size of the Brazil energy matrix, reliability standards and legislatives of the energy sector. The smart grid in Brazil is mainly achieved through the enhancement of smart metering by distribution companies to expand the efficiency in operation with remote meter data transmission and reduction of the energy commercial losses (PICA et al., 2011).

Examples of smart grid enhancing smart microgrid concerns in Brazil, implemented by several companies, research centers and universities are (FALCÃO, 2010):

- ONS (Operador Nacional do Sistema Elétrico) Implementation of PMUs (Phasor Measurement Units) project: studies for the installation of PMUs units at strategic points of the national interconnected system with the objective, among others, to improve the disturbance capacity and state estimation; and monitoring the electrical system for connecting electrical islands and closing loop and oscillations monitoring;
- UFSC (Universidade Federal de Santa Catarina) MEDFASEE Project: is smart microgrid project based on synchronized phasor measurement system consisting of units located in several Brazilian university campuses and connected to the low voltage network, able to monitor the functioning of the Brazilian electrical system;
- Measurement Systems Automated Deployment projects by Light, Wide, Eletropaulo and Cemig: several electricity distribution companies in the country have been executing the implementation of centralized systems of electronic measurement.
- CEPEL (Centro de Pesquisas de Energia Elétrica) Automatic Measurement project: development of centralized metering system and non-invasive system appliance monitoring;

- COPPE / UFRJ (Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia/ Universidade Federal de Rio de Janeiro) Microgrid projects: is campus smart microgrid that involves the implementation of an experimental microgrid, consisting of various alternative sources of small size, with the objective to study control schemes, automated metering and protection; PMU Applications in System Security: Online detection of voltage collapse proximity.

2.6 MODULAR DESIGN APPROACH FOR THE SMGP

The perception of modularity has gained interest of engineers, management researchers and corporate planners in various utilities in the last decennia. Modularization of a product or process is described as the separation of components which are then committed to modules conform a precise arrangement or method.

Modularization has three objectives from an engineering view:

1. To allow simultaneous activity.
2. To control complexity.
3. To adapt concerns to come.

Modularity adapts concerns because the specific components of a modular design may be adjusted or alternated suddenly, but has to be according to the design guidelines (BALDWIN & CLARK, 2004).

2.6.1 THE MODULAR DESIGN METHOD

Eggen (2003 apud FLEIG, 2008) defines the concept of modularity as a method used by companies as an alternative to their product range at the same time it facilitates the traditional mass production that turns into mass customization. In the opinion of this author, there is no guide to determine the best modularity method to be followed by a company. Modularity is a tool to break the structure of the product in small but manageable units, and thus make mass customization possible. A module is structurally independent building block, which is part of a large system with well defined interfaces. The module is connected to the rest of the system in a way that development can occur independently.

According to Jose and Tollenaere (2004), in design the evolvement of modules of components is a manner to establish a great number of requested products. Standardization and modularity are important tools for the development of product families, because it allows the creation of a variety of products using the same modules called platforms. In modular design the application of modules is a specific method adjusted to the design. Modularization is defined as a strategy to systematize complex designs and process operations effective by breaking up complex systems into smaller blocks. Hereby the designer can be admitted to work with joint collections of components to evolve and produce a great number of products (JOSE & TOLLENAERE, 2005). In the engineering literature several definitions for the terminology involved with modular design are found and presented in the Table 9.

As defined by Clark and Baldwin (2004), the compatibility between modules is guaranteed by "design guidelines" that control the architecture, the interfaces and the patterned test of the system. The process of modularizing a system includes the three functions:

- Defining its architecture: means the existence of the modules, what they are
- Defining its interfaces: the way the modules communicate or connect
- Defining tests: to make sure that the modules will interact together and each will be functioning great

Table 9: Definitions for ´´modularization´´ from the engineering literature.

Author	Definition
Galsworth, 1994	A module is a group of standard and interchangeable components.
Wilhelm, 1997	A module is a complex group that allocates a function to the product and which could be changed and replaced in a loose way and be produced independently.
Baldwin and Clark, 1997	A modular system is made of independent units which can be easily assembled and which behave in a certain way in a whole system.
Huang and Kusiak, 1998	The term modularity is used for the expression of common and independent parts for the creation of a variety of products.

Source: Adapted from Jose and Tollenaere, (2004).

As mentioned earlier by Baldwin and Clark (2004), the modularity in the design of a complex system permits modules to undergo transformations in the future, without undermining the purpose of the complete system. Hereby is pointed out that the modular design of a complex system is permissive to uncertainty and accepts experimentation in the modules.

The connection between people and products is defined by the way they design, produce and use them. Therefore modularity comes down to three basic types:

1. modularity-in-design: In a complex system the separation of its components of use or the functionality of production in independent modules, does not indicate that the

design of the system is modular. It is only modular-in-design if the process of designing it can be divided and shared over independent modules, which are related to design guidelines, not by continuous agreements between the designers.

2. modularity-in-production: Just like modular-in use systems, this type depends on designs that are tightly coupled and centrally controlled. It is used for many years by industries like for example automobile industries. The production of different parts of the automobile is done in various sites and brought together to assemble the final product. This is possible due to their precise guidelines for the way the different parts must be connected together to assemble a specific vehicle and for the utilities that provide the parts to follow the engineering specifications such as dimensions, tolerances, functionality etc.
3. modularity-in-use: Is a system of goods in which customers can combine different elements together to have a desired finish. For example, customers frequently purchase things like bed frames, covers, mattresses, linens of various manufacturers and distributors, which all adapt together because they are made in common sizes. Modularity-in-use accommodates customization of the system to please the customer.

Concluded is that modularity-in-design is less assumed and has the most appealing economic results in comparison with other modularity types. The reason lies in the fact that new designs are essentially options with associated economic option value. Modularity-in-design accumulates the alternatives built in a complex system. Increase of the total economic value of the system and transforms the manners how the system can develop are both additional results, (BALDWIN And CLARK, 2004).

Ulrich and Eppinger (2012) described the product architecture of modular design as the event where the physical components are related to functional elements to form different products. These two dimensions in the architecture are defined as follows:

1. The functional one, which is the selection of activities and alterations that supplies to the general functionality of the product.
2. The physical one, which indicates to the selection of physical components and assemblies that facilitates a function.

The architecture could be recognized as an arrangement between components of the product and the assignment of each component. Product architecture design is about the agreement to consider one or multiple functions on each module. The architecture is outlined between the concept development phase and the design of system levels (assembly hierarchies), as presented in Figure 9, (ULRICH & EPPINGER, 2012, p. 223).

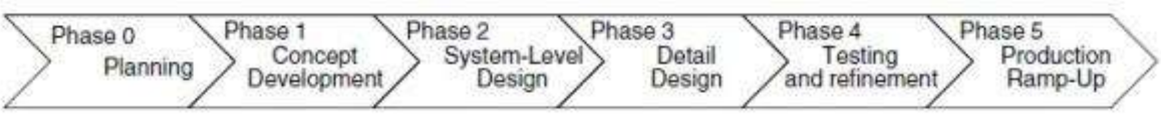


Figure 9: The product/system development process by Ulrich and Eppinger (2012). Source: adapted from Ulrich and Eppinger, (2012).

The Table 10 presents the main modular design methodologies found in the literature. These methodologies are proposed by different authors and give a clear understanding of the different phases the design procedure will go through when this method shall be used in the modular design.

Table 10: Modular Design Methodologies.

Methodology	Proposed by (Author)	Phases	Approach
Heuristic method	Stone et al., 1998	Phase 1 - Identify the customer needs Phase 2 - Generate a functional model Phase 3 - Identify the product architecture Phase 4 - Generate the module concepts Phase 5 - Incorporate design	Identify the modules from functional models. The decisions are based on knowledge of engineers.
Modular Function Deployment (MFD)	Erixon, 1998	Phase 1 - Define the customer requirements Phase 2 - Select technical solutions Phase 3 - Generate modular concept Phase 4 - Analyze modular concept Phase 5 - Optimize the modules	Engineers provide strategic information to take decisions based on previous designs.
Combined method	Eggen, 2003	Phase 1 - Identify the customer needs Phase 2 - Transform the customer needs into specifications of the design Phase 3 - Functional decomposition of the product Phase 4 - Create a model in which modules can be identified Phase 5 - Identify the product architecture Phase 6 - Generate the module concepts Phase 7 - Evaluation of the concepts	Combines the heuristic method with the Modular Function Deployment (MFD) for identifying a modular design structure.
Design of modular systems	Maribondo, 2002	Phase 1 - Informational design of modular system Phase 2 - Conceptual design of modular system Phase 3 – Preliminary design of modular system Phase 4 – Detail design of modular system	It presents a roadmap to be followed from collecting preliminary information about the problem of the design up to the detail design of the modular system.

Source: Reproduced from Fleig, (2008).

To describe the product architecture as mentioned in the phases of methods of the modular design (Table 10), two types of product architectures are identified in the modular design concept from different authors in the literature:

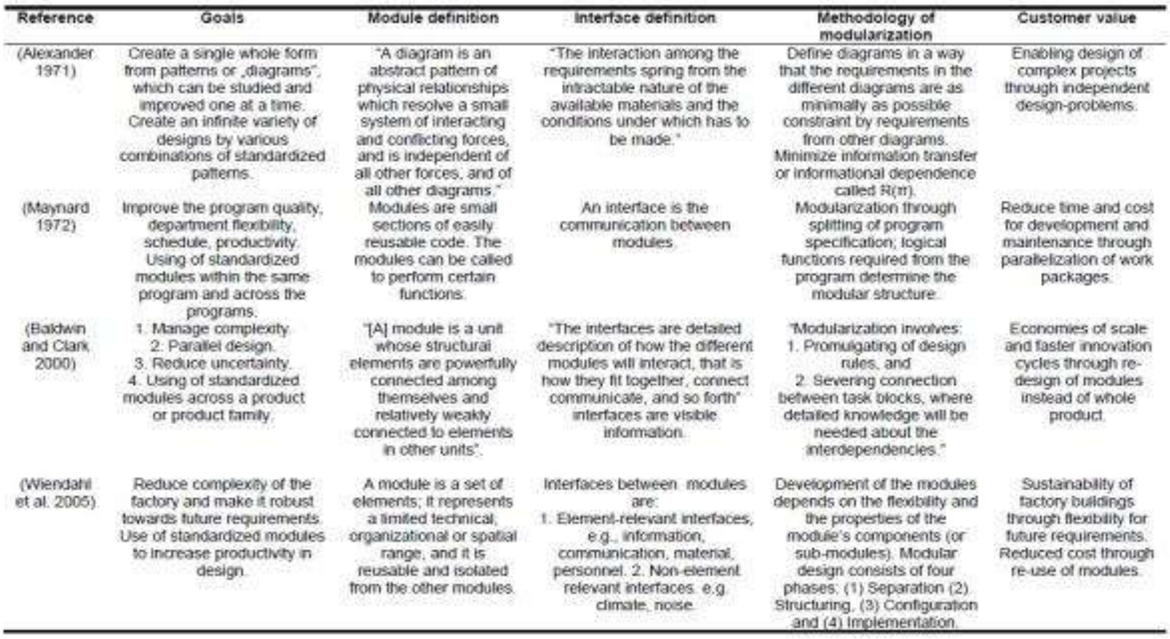
1. The modular architecture aims to establish the minimum inter-module correlations between modules and maximum intra-module correlations in every module. For the accomplishment of these two goals, the modular design methods are separated into component- and function-based means (GU and SOSALE, 1999 apud LIU et al.,

2016)). The component-based method is direct for practical outcomes, but will result in extended activities and may prevent component sharing, because the secondary functions of a component are ignored when designers only look for cooperation between components. The function-based approach undertakes a bundling process upon a function module and thus determines the functions that each module should embody.

2. Integral design (ULRICH and EPPINGER, 2012 apud JOSE and TOLLENAERE, 2004): it is a steady architecture focused on an improved product. It is the classical product design where changes to one component cannot be made without interfering with others. Its design includes complex relationships (not one to one) between components and functions, and complex interfaces connecting components.

A review of the modular method from the view of different authors is presented in the Table 11. Hereby is described the basics of their modular method which are frequently build up in stages as presented in the earlier Table 12 (MOHAMAD et al., 2013).

Table 11: Review of Modular Design method from different.



Reference	Goals	Module definition	Interface definition	Methodology of modularization	Customer value
(Alexander 1971)	Create a single whole form from patterns or „diagrams", which can be studied and improved one at a time. Create an infinite variety of designs by various combinations of standardized patterns.	"A diagram is an abstract pattern of physical relationships which resolve a small system of interacting and conflicting forces, and is independent of all other forces, and of all other diagrams."	"The interaction among the requirements spring from the intractable nature of the available materials and the conditions under which has to be made."	Define diagrams in a way that the requirements in the different diagrams are as minimally as possible constraint by requirements from other diagrams. Minimize information transfer or informational dependence called R(π).	Enabling design of complex projects through independent design-problems.
(Maynard 1972)	Improve the program quality, department flexibility, schedule, productivity. Using of standardized modules within the same program and across the programs.	Modules are small sections of easily reusable code. The modules can be called to perform certain functions.	An interface is the communication between modules.	Modularization through splitting of program specification; logical functions required from the program determine the modular structure.	Reduce time and cost for development and maintenance through parallelization of work packages.
(Baldwin and Clark 2000)	1. Manage complexity. 2. Parallel design. 3. Reduce uncertainty. 4. Using of standardized modules across a product or product family.	"[A] module is a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units".	"The interfaces are detailed description of how the different modules will interact, that is how they fit together, connect communicate, and so forth" interfaces are visible information.	"Modularization involves: 1. Promulgating of design rules, and 2. Severing connection between task blocks, where detailed knowledge will be needed about the interdependencies."	Economies of scale and faster innovation cycles through re-design of modules instead of whole product.
(Wiendahl et al. 2005)	Reduce complexity of the factory and make it robust towards future requirements. Use of standardized modules to increase productivity in design.	A module is a set of elements; it represents a limited technical, organizational or spatial range, and it is reusable and isolated from the other modules.	Interfaces between modules are: 1. Element-relevant interfaces, e.g., information, communication, material, personnel. 2. Non-element relevant interfaces. e.g. climate, noise.	Development of the modules depends on the flexibility and the properties of the module's components (or sub-modules). Modular design consists of four phases: (1) Separation (2) Structuring, (3) Configuration and (4) Implementation.	Sustainability of factory buildings through flexibility for future requirements. Reduced cost through re-use of modules.

Source: Adapted from Mohamad et al., (2013).

These authors also describe their methods objectives, client value and concepts for a module and an interface. The stages allow the designer to focus on the objectives, keep track of the progress and complete each stage hierarchically before going to the next step to get closer to the final design.

From all the presented modular design methods in this part, one thing is evident for the modular design structure and that is the fact that a modular design structure is based on three typical aspects:

- Design rules, which are familiar and accepted by groups in charge of the distinctive modules
- Hidden modules according to the design rules, but are separate from each other as work is developing.
- Systems integration and testing of modules, is where hidden modules are constructed into a system and any left small difficulty of variance are cleared up (BALDWIN and CLARK, 2004).

2.6.2 PROPOSED MODULAR DESIGN METHOD FOR THE SMGP SYSTEM

The process of system design is the focus of systematic procedures, which are embedded in a broader process, the process of system/product development. From the most models in the literature as described earlier, it is clear that there is standardization in their structures (Tables 10 and 11). As seen earlier, the methods are organized in different phases, for example Maribondo (2000) for modular systems, which is composed of four steps: Informational design, Conceptual design, Preliminary design and Detail design, as shown in Table 10. The four phases will be described in more detail before presenting a roadmap of the proposed method for the modular design of the SMGP in Figure 10.

The four phases described are (MARIBONDO, 2000 apud DOS SANTOS & SANCHES, 2008):

1. Informational Design - This stage defines the starting point of the design and aims at defining the problem that indicated the need for development of a system. Hereby clarifying the task by detailed analysis of the design problem and to search all the information necessary for the full understanding of the problem. The model at the end of this step is the specification of the design.
2. Conceptual Design - This stage is considered the most important phase in a design process, because the decisions taken at this stage influence the results of the following phase. The conceptual design is the stage that generates a design of a product regarding to the identification of a need, to ensure to meet the need. This conception is subject to resource constraints and design constraints. The product model obtained at the end of this phase is to design the product, which is the key solution that plays a global role.

3. Preliminary design - This is the development phase of the design process. According to the technical and economic criteria and consideration of additional information to the point where production can be conducted by the detail design following here after. In this phase the model passes the design for optimized layout of the product.
4. Detail design - In this phase all product elements must be understood and their provisions, forms, dimensions and tolerances, material specifications, technical feasibility, economic manufacturing processes and required machinery should be established. The model product optimized layout for the detailed layout of the product as well.

A systems-level perspective drives the selection of technology platforms and individual components, this is also the case for the proposed SMGP design based on their functional and performance attributes in this work. To propose a method for the SMGP design, a roadmap was made throughout this work.

In this work the modular system design for the SMGP will be done up to the stage of preliminary design and the following general roadmap for the design is presented and further on this paragraph the detailed roadmap used for the informational design of modular system for this work is presented with Figure 10.

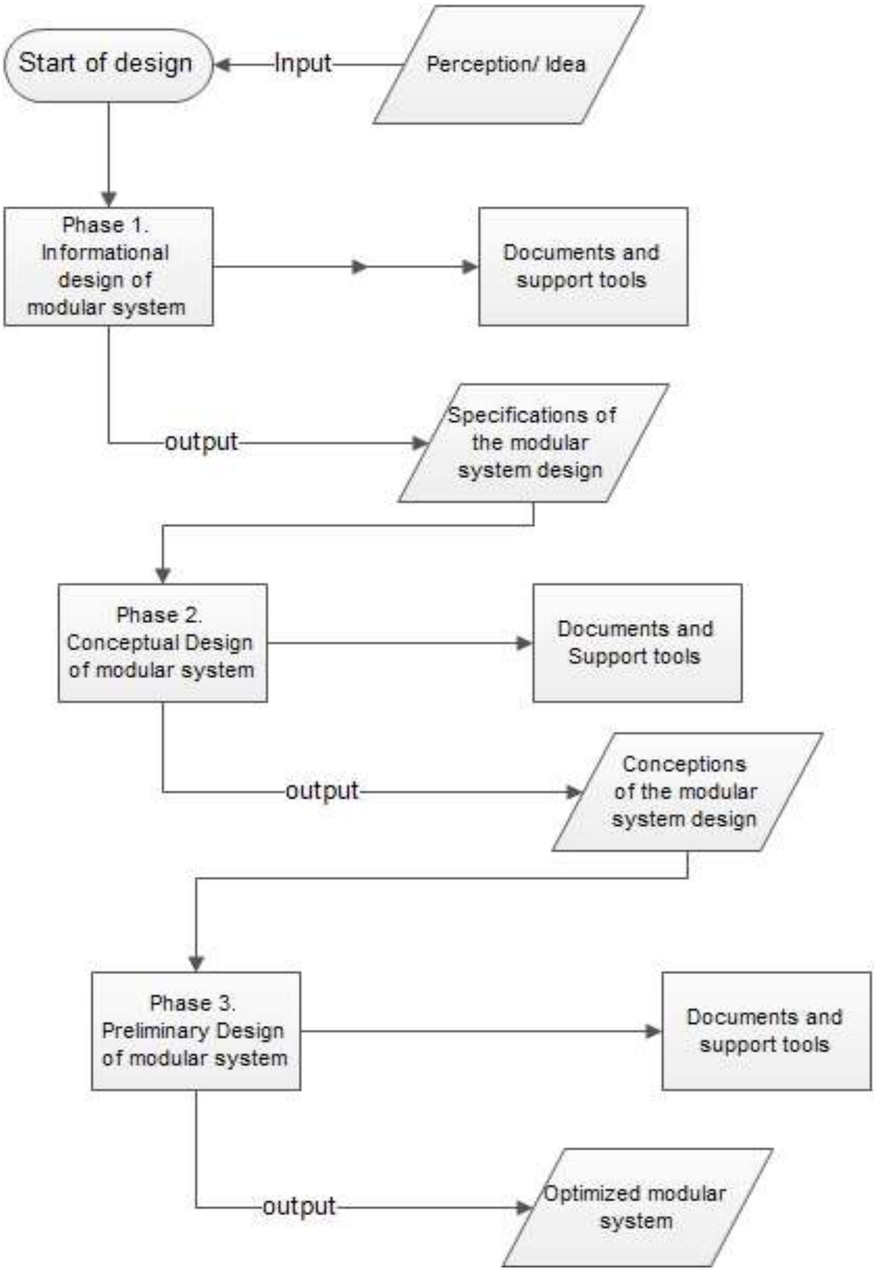


Figure 10: Flowchart of the followed roadmap for the modular system design of SMGP. Source: Elaborated by the author.

2.7 FINAL CONSIDERATIONS

The state of the art concerning the energy generation in general and the distributed generation, microgrid, smart grid and smart microgrid have been enlightened in this chapter. The aim was to describe the smart microgrid context which has a narrow relationship with the smart grid, because they form the basis for the further development of the smart grid in the energy distribution section of the overall energy generation context. The smart microgrid its objectives are to implement the communication and information technology features in the small scale grids with the integrated renewable energy or distributed generation (DG) resources such as wind, solar, biomass and micro or small hydro. As presented through examples, these microgrids do not only enhance renewable energy generators but also non-renewable energy generators such as diesel or gas. A few of the microgrids enclose energy storage units such as batteries or flywheels depending on their purpose. This research work will be about a campus or institutional microgrid. In this context the modular design method is introduced in this chapter to enlighten the modular approach for the SMGP to be developed.

Several authors have been mentioned in this chapter with different views of the modular design method in stages. These authors have all described their methods objectives, client value and concepts for a module and an interface. The stages allow the designer to focus on the objectives, keep track of the progress and complete each stage hierarchically before going to the next step to get closer to the final design. In modular design the application of modules is a specific method adjusted to the design. Modularization is defined as a strategy to systematize complex designs and process operations effective by breaking up complex systems into smaller blocks. The next chapter will focus on the first stage in the conceptual phase of the modular design method.

CHAPTER 3. INFORMATIONAL DESIGN OF MODULAR SYSTEM

In this chapter we shall approach the SMGP as a system on which we can apply a modular design method. According to Strahl (2015), a microgrid is a platform for coordinating various, potentially distinct DERs (Distributed Energy Resources) into a single load - or generation - shape that can intelligently interact with the modern electricity grid. Microgrids have the potential to be the most adaptable, customizable and sophisticated of all DERs by aggregating load and generation to provide any number of services to the utility grid (STRAHL, 2015). The need for a smart microgrid laboratory on an engineering campus is very realistic in this modern world, where almost every electronic device has embedded smart features such as mobile phones and many vehicles. In the engineering field, the power electronic devices, communication systems, control and management systems are known as the fundamental tools of smart systems. As explained in chapter 1, it is very important to gain the experience in this field in no easier way than during study on a campus SMGP, where one can experience a living- laboratory environment with the smart microgrid which will be generating energy in real-time and provide real-time data for experiments, training and research. With the modular approach, this SMGP can be designed using the fundamentals of this design method, which are appropriate for this system, since the smart microgrid laboratory already consist of various elements which can be categorized in module functions. Another reason for this design method is that this final design can be gradually implemented if not capable of financing and constructing the complete system on the campus at once. This chapter presents the problem definition of the research, which marks the start of the informational phase of the modular design for the smart microgrid laboratory platform for a university campus and aims to describe the fundamentals of modular design by a review of the modular design methods, which will provide the information for developing the proposed modular design method for the smart MG laboratory platform here presented.

3.1 THE PROBLEM DEFINITION

The need for a smart microgrid laboratory on a university campus with engineering programs is very high. In this work, the university campus Gama of the University of Brasília (UnB) is chosen as an example for the development of the SMGP for a university campus. The electrical energy consume has been followed for almost 2 years for analysis of the energy profile. The monthly accounts of year 2014 and 2015 and additional information has been used to make tables and graphics for further analysis. Also an experimental energy monitoring system has been installed at campus Gama, with a Supervisory Control And Data Acquisition system, “Scada.Br”, on a computer in the electro-laboratory of Campus Gama with a connection to the two electrical energy distribution multi-meters in building UEA, the SENTRON PAC 3100, since the month May of year 2015. With this connection established, the data of the daily consumption, active and reactive power levels, voltage levels of each phase, currents etc. can be followed and reports can be made and stored on the computer in the electro-lab for later use along this project and for other students of campus Gama to monitor real-time data. To start with the history of the electrical energy consume and demand of the campus, there has been made a collection of all the data necessary to understand all the details on an energy invoice, starting with the electrical energy structure of Brazil and the characteristics of the applied tariff structures.

3.1.1 THE CAMPUS GAMA

The University of Brasilia started the construction of a new campus at Gama in year 2008. Campus Gama started in 2008, mainly with the objective to accommodate the undergraduate courses in the field of engineering with five qualifications: automotive; electronics; energy; aerospace and software. Besides these five undergraduate courses, there are also four graduate courses offered: Clinical Engineering, Modeling of Complex Systems (distance), Biomedical Engineering and Engineering Materials Integrity. Actually the campus attends over 1200 students, 120 lecturers and over 100 employees for technical and administrative support. The number of students is expected to grow to a total amount of 2,800 students when the campus is fully implemented.

The Campus has an area of 335,020.95 square meter of Greenland. The planned construction consist 24 buildings with a constructional area of 122,925 square meters of which 3 buildings are already established with a total constructed area of 11,264 square meters. The construction of the campus is planned to be deployed in stages, to be carried out according to the growth on the Campus and to conserve the natural green environment for a green infrastructure.

In Figure 11 is presented the planned infrastructure of the Campus Gama besides the actual infrastructure of the campus. The actual construction of the campus Gama represents three main buildings, a multisport field, and a few additional containers which are functioning as small laboratory environments and study areas. The three main buildings as shown in the next figure on the right are:

- The UED (Education and Teaching Unit): Is the main building of the campus containing classrooms, laboratories, professor offices and the secretary office with an area of 6.000m².
- The UAC (Academic Unit): with an area of 4.200m² containing classrooms, a library etc.
- The MESP (Services Module and Sporting Equipment): currently this construction contains a copy and printing facility, the campus restaurant, and other student facilities including the multisport field.

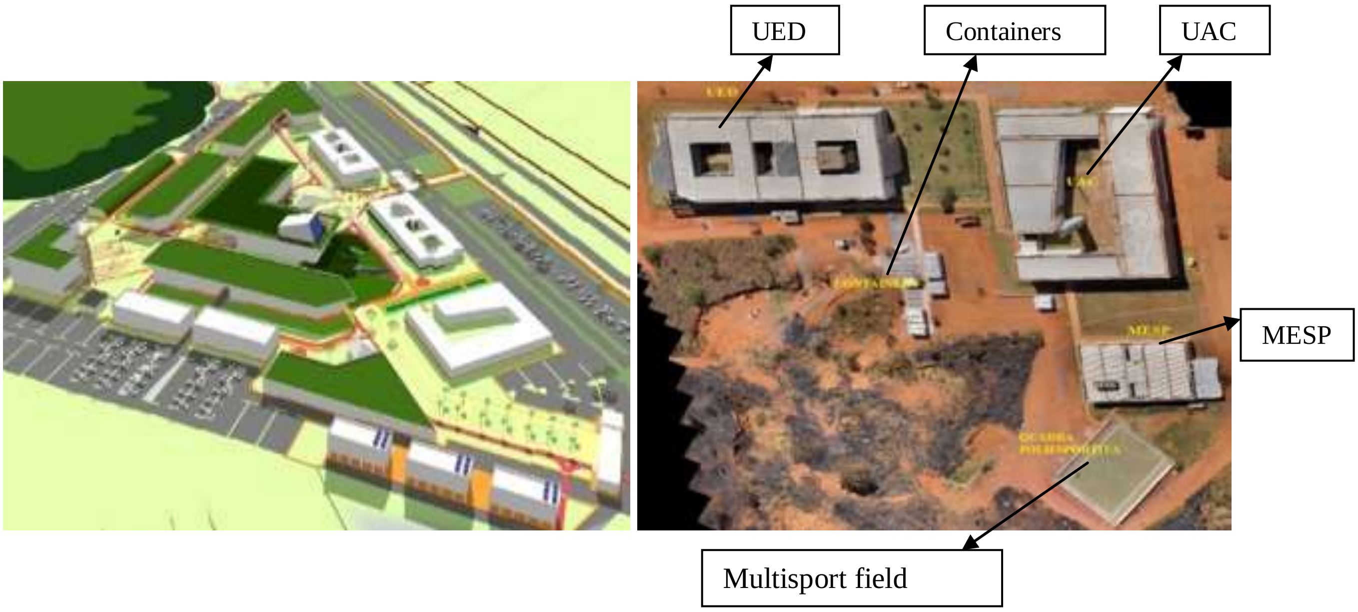


Figure 11: Campus Gama as projected on the left and on the right is the current state presented. Source: Adapted from (FUB, n.d.) & Google earth.

The construction of the campus is planned to be deployed in stages, which will be carried out related to the growth on the campus. One of the main objective of this planning is to conserve the natural green environment for a green infrastructure (FUB, n.d.). Another objective of the campus is to integrate renewable energy generation in their infrastructure to generate green energy and maintain an energy support system. In Figure 12 is presented the energy schematic diagram of the campus Gama.

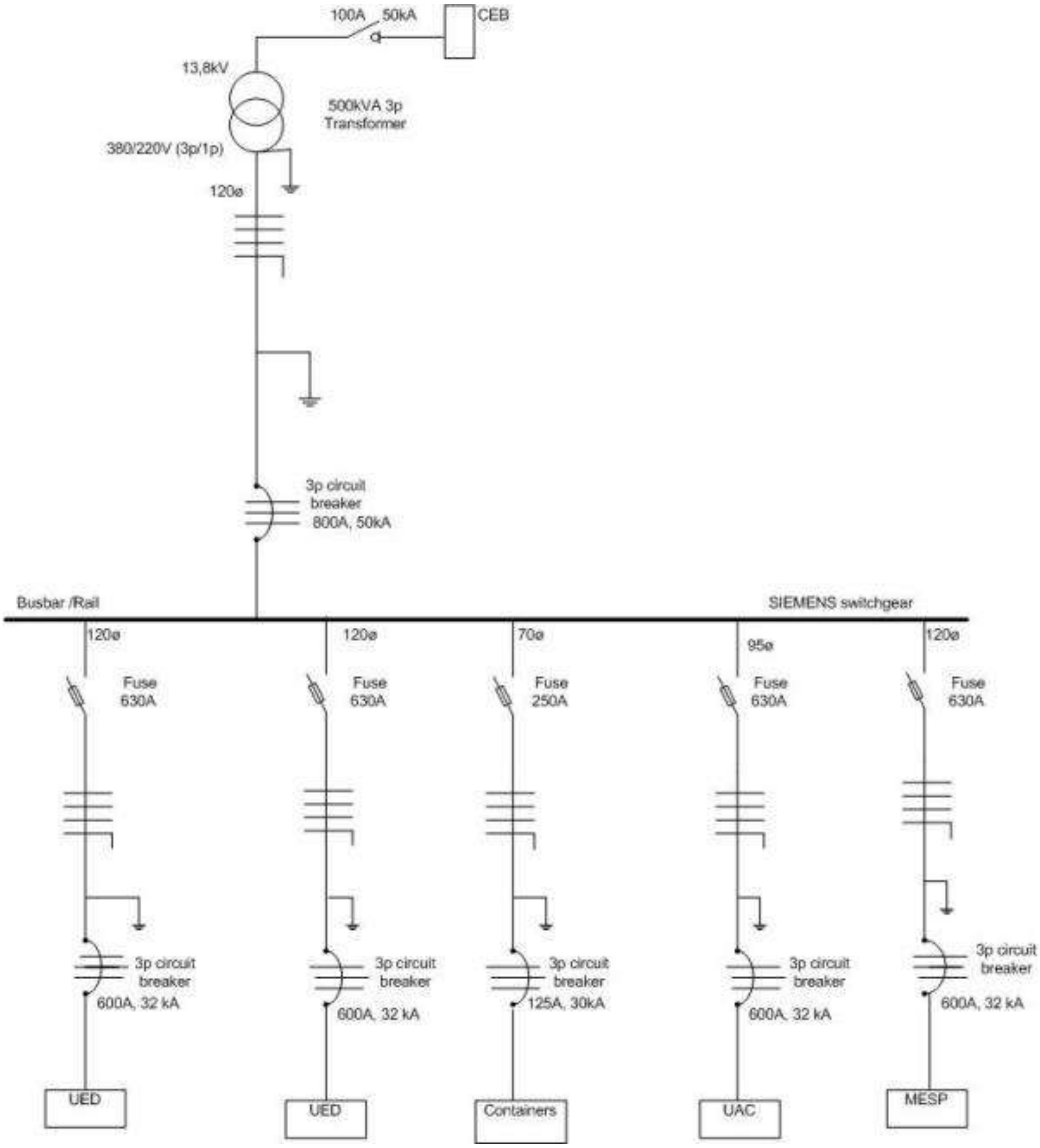


Figure 12: Electric schematic diagram of campus. Source: Elaborated by author.

As presented in Figure 12, the three main buildings are connected to the local utility grid of 380/220V Low voltage, secondary side of the 3phase transformer of 500kV. The building UED has two Siemens switch breaker panel installations on which the SENTRON PAC 3100 multi-,meters are installed, that´s why you have the UED block two times present in the figure. The new construction in Figure 12, is the part of the containers, which was connected to the local utility grid in 2015, during this research work and is presented in Figure 13 with the main breaker panel of the containers and the distribution lines to each container with its circuit breakers and specifics.

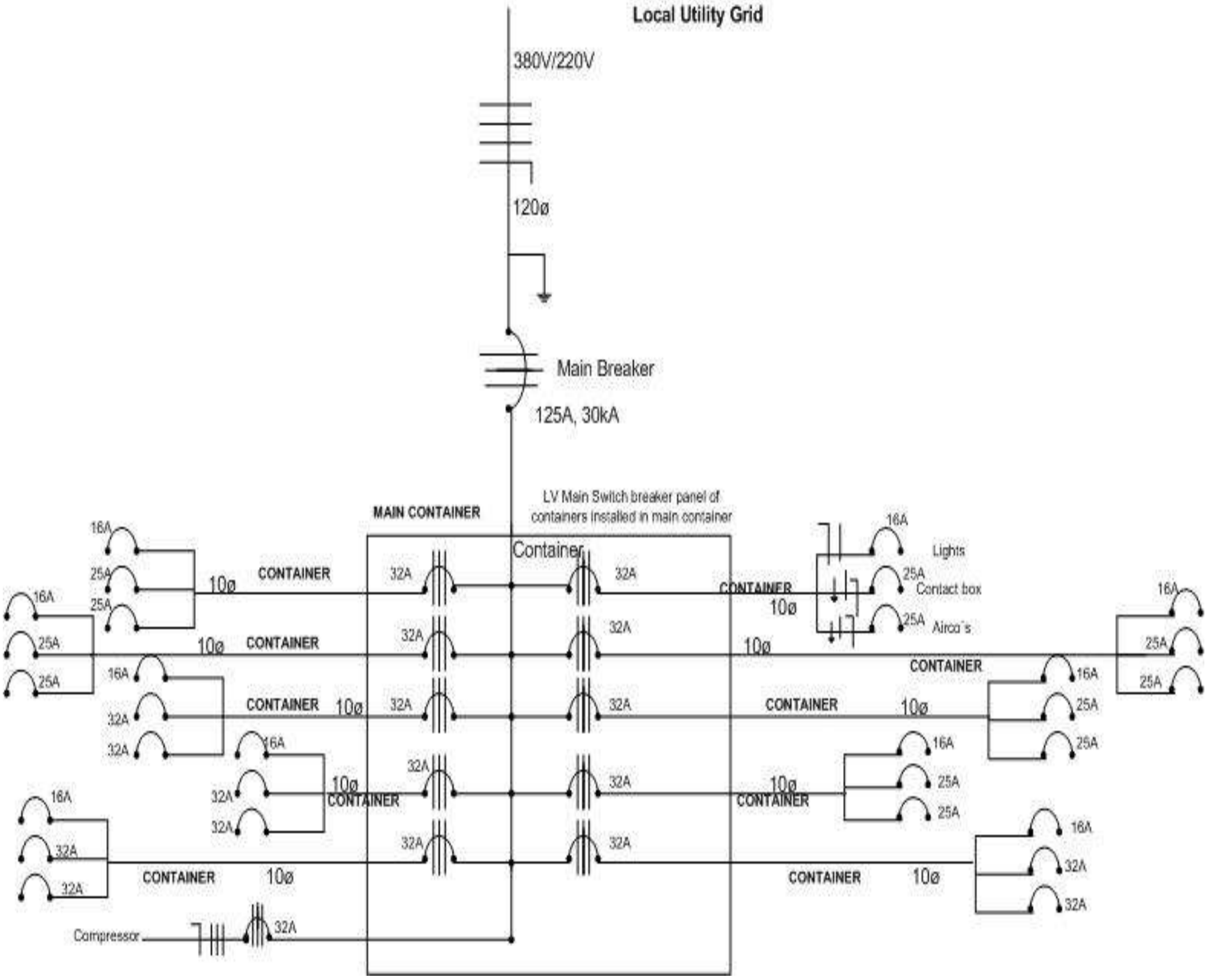


Figure 13: Electrical diagram of campus expansion with containers. Source: Elaborated by the Author.

3.1.2 THE TARIFF STRUCTURE AND ANALYSIS OF CAMPUS GAMA

The tariff structure is defined by ANEEL as:

> “A set of applicable tariffs for electricity consumption components and/or power demand, acording to the mode of supply”.

Brazil has different type of tariffs for different seasons of the year as well, besides the well-known peak-hour tariffs in most countries. The tariff is further defined as a definite cost of providing a service for a given entity. In the relationship between utilities and consumers the tariff represents the price of electrical energy consume and the demand of the consumers, which has been monitored by a metering system.

In the tariff structure we have the consumers divided in groups A and B and also classes and subclasses. Both the value of tariffs and the collection of rules among consumers in groups A and B are different in the electrical energy sector, (DE BARROS et al., 2011). Here follows a list of the main aspects of the consumers of groups A and B, (ANEEL, 2008):

Group A is defined as a collection of the consumer entities with a voltage supply of not less than 2.3kV (high voltage) or connected to underground distribution system in secondary voltage (values under 2.3kV), identified by a binomial tariff rate and subdivided into the following subgroups?

subgroup A1: a voltage supply not less than 230kV;
subgroup A2: a voltage supply of 88kv to 138kV;
subgroup A3: a voltage supply of 69kV;
subgroup A3a: a voltage supply of 30kV to 44kV;
subgroup A4: a voltage supply of 2.3kv to 25kV;
subgroup As: a voltage supply less than 2.3kV from underground distribution systems.

Group B is defined as a collection of the consumer entities with a voltage supply of beneath 2.3kV (low voltage), identified by a monomial tariff rate and subdivided into the following subgroups:

subgroup B1: residential/households
subgroup B2: provincial/rural
subgroup B3: other classes
subgroup B4: public lightning

The contract of the electrical energy provider CEB distribution S.A. and the Foundation University of Brasilia- Faculty of GAMA (FGA), represents the following specifications:

- Classificatio: P. Public
- Connection: 3-Phase
- Nominal Voltage between phases: 13.8kV
- Frequency: 60Hz
- Subgroup: A4
- Tariff Mode: High Voltage, Bleu Rate-Seasonal Hour
- Contracted Demand at Peak Hour: 600 kW
- Contracted Demand at Off-Peak Hour: 350 kW

As seen from the specifications of the campus Gama electrical energy contract tariff mode of the campus is High Voltage, Bleu Rate-Seasonal Hour. This tariff structure is further enlightened in the next part.

The tariff aspects of campus Gama based on the price structure appropriate for customers in the Bleu Rate-Seasonal hour tariff mode are as follows (DE BARROS et al., 2011):

- For Active Electrical Energy Consume (kWh);
- Peak Hour price in Dry Period (PS);
- Off-Peak Hour price Dry Period (FS);
- Peak Hour price in Wet Period (PU);
- Off-Peak Hour price Wet Period (FU);
- For Active Power Demand (kW).

Hereby the tariff options are based on the tariff structure for each type of customer according to the groups and classes and are defined as follows**:**

- Rate structure: defined as the set of rates applied to metered usage and/or contracted demand according to the mode of supply.
- Time-of-use rate structure:
  - Blue Rate: different electricity usage rates according to daily and yearly time of use and different rates for contracted demand according to daily time of use.
  - Peak Hours (P): period defined by the utility company, comprising 3 (three)daily consecutive hours, except for Saturdays, Sundays and some holidays.
- Off-peak Hours (F or FP): period comprising the number of consecutive daily hours outside those defined as peak hours.
- Wet Period (U): period comprising 5 (five) consecutive months, including the power supply measured from December of one year to April of the next year.
- Dry Period (S): period comprising 7 (seven) consecutive months, including the power supply measured from May to November.

Analysis of the campus Gama consume and demand structure

The data collected for the analysis of consume and demand was obtained from the recent electrical energy bills collected from the two years 2014 and 2015 and presented in Table 12.

Table 12: Consume, Demand and Tariffs of campus Gama.

Year	2014	2015
Demand (kW)		
Peak hour Demand (kW)	600	600
Off-Peak hour Demand (kW)	350	350
Consume (kWh)		
Average Peak hour Consume (kWh)	3514,17	3961,58
Average Off-Peak hour Consume (kWh)	32.674	35.541,25
Consume Tariff (R$/kWh)		
Avg.Tariff (R$/kWh) Peak hour consume	0,37	0,61739493
Avg.Tariff (R$/kWh) Off-Peak hour consume	0,24	0,439338
Consume Value (R$)		
Total Value (R$) Peak-hour consume	13.575,36	32.179,98
Total Value (R$) Off-Peak-hour consume	94.582,86	193.691,1
Demand Tariff (R$/kW)		
Avg.Tariff (R$/kW) Peak hour demand	20	22
Avg.Tariff (R$/kW) Off-Peak hour demand	6	7
Demand Value (R$)		
Total Value (R$) Peak-hour Demand	129.346,82	151.102,29
Total Value (R$) Off-Peak-hour Demand	24.052,24	28.290,17

From the collected energy consume data of the campus Gama is presented a graphic containing the consume profile over year 2014 and 2015 and presented in Figure 14 and Figure 15.

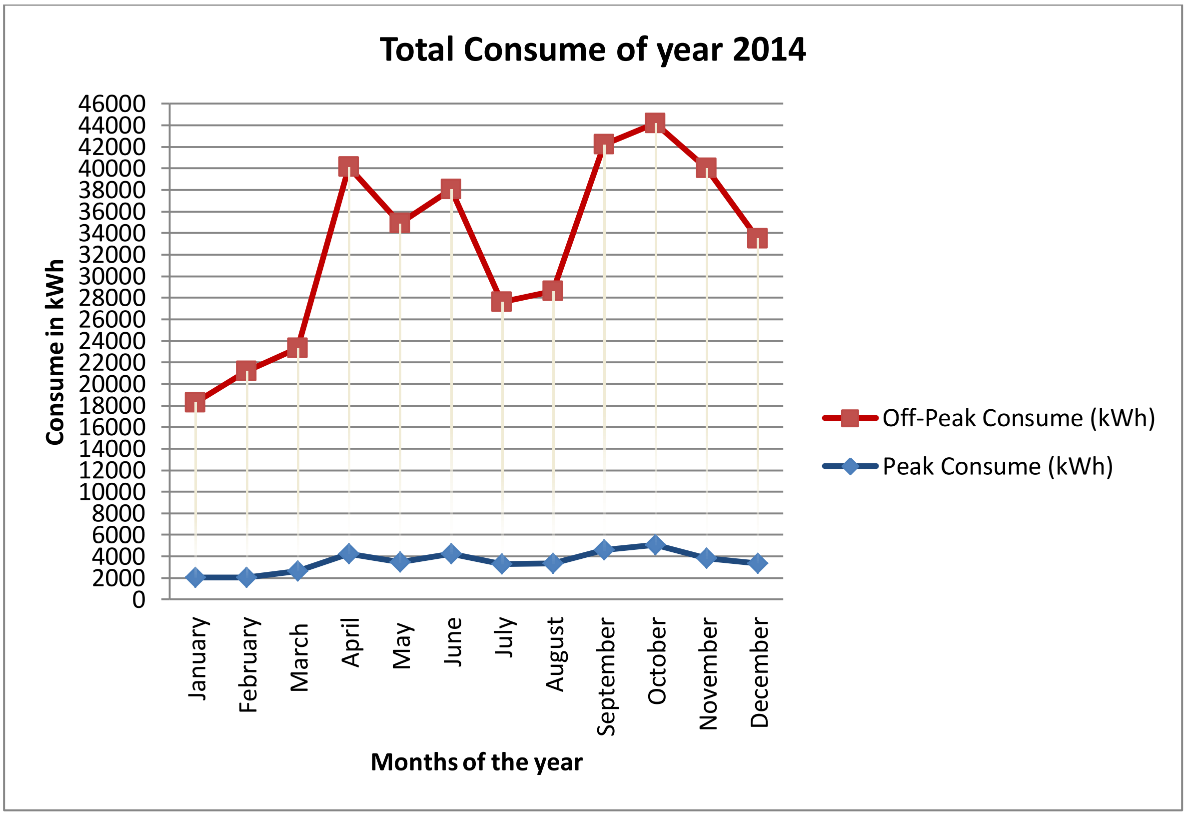


Figure 14: Consume of campus Gama in year 2014. Source: Elaborated by the Author.

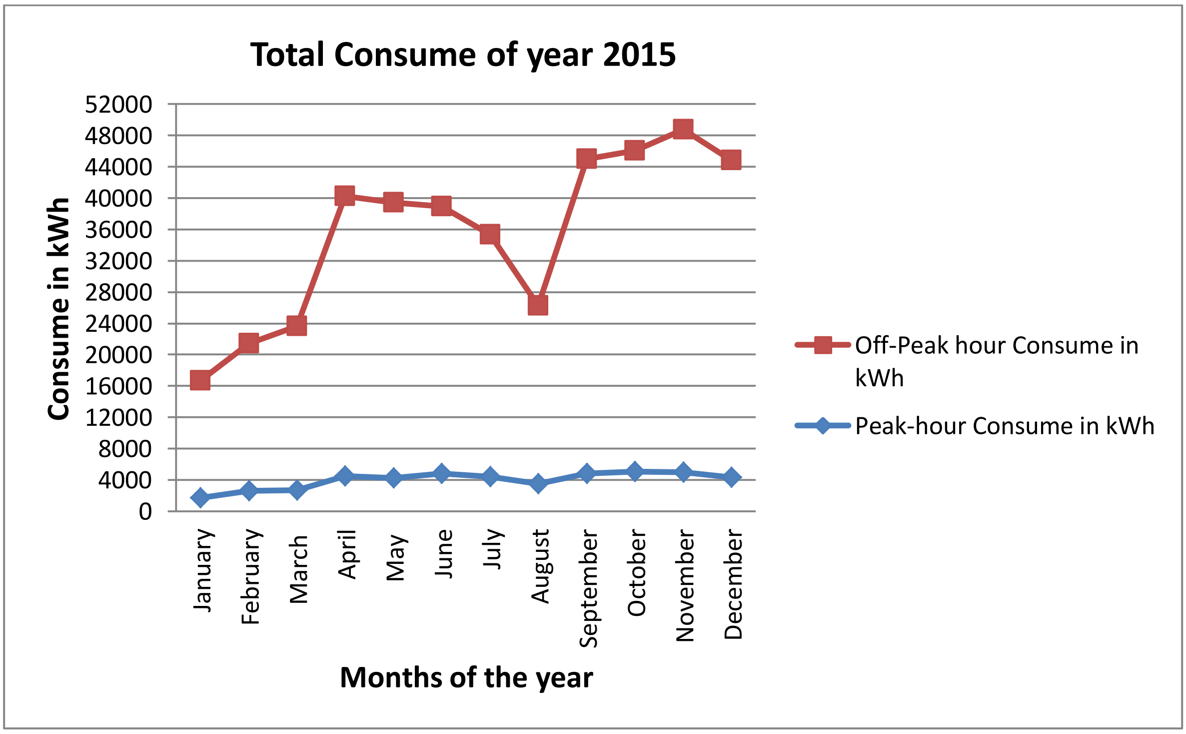


Figure 15: Consume of campus Gama in year 2015. Source: Elaborated by the Author.

3.1.3 IMPLEMENTED ENERGY MONITORING INFRASTRUCTURE

In the building UED (Unidade de Ensino e Docência) of the campus Gama, two energy distribution meters present of the SENTRON PAC 3100 are present. These energy distribution multi-meters are measuring all the parameters of the electrical energy that´s being distributed to the building loads. With the perception to monitor and control with real-time data on the campus in mind, the implementation of a prototype monitoring unit got established. The SENTRON PAC 3100 meters are excellent for implementing a real-time data monitoring unit, since they enhance the MODBUS communication protocol and data can be transferred over communication lines to a computer with a EMS (energy Management System) or Data Acquisition system. In this prototype or experimental monitoring unit setup is installed and programmed the Supervisory Control And Data Acquisition type SCADA.Br software to communicate with the two SENTRON PAC 3100 meters to display the various measured distributed electrical energy parameters.

The main components of the real-time monitoring system are:

A. the two SENTRON PAC 3100 multi-meters
B. the SCADA.Br software;
C. the RS485/RS232 Converter

A. THE SENTRON PAC 3100 CHARACTERISTICS

The SENTRON PAC 3100 is a multi-meter of producer SIEMENS that measures more than thirty (30) low voltage electrical energy metric units in the energy distribution system and enables visible analogical presentation of these measurements. This multi-meter is for alternating current (AC) measurements and is not adequate for DC measurements. Other characteristics of this meter are the ability to measure single, two and three–phase currents and to operate in networks with three or four conductors (wires or cables). This multi-meter can be connected with maximum voltage value of U nominal equal to 480V UL-L (SIEMENS, 2009).

Trough current transformers x / 5 A, higher voltage values can be measured.

As presented in Figure 16, the LCD display presents clear readable values through the large scale of the data on the display. The SENTRON PAC 3100 further consist of four buttons with clear indications through which the user can collect from a menu with multi-language text which data he wants to display and it also has a access code of 4 characters installed for protection against non-authorized users.

For the communication with other devices, the SENTRON PAC 3100 multi-meter uses an RS485 interface integrated Modbus RTU. For the communication network the SENTRON PAC 3100 has two (2) digital inputs for its own power supply for status monitoring and two digital outputs for programmable outputs as pulse outputs for active or reactive energy pulses or as switching outputs for remote control via the interface RS 485 (SIEMENS, 2009).

Figure 16: The SENTRON PAC 3100 multi-meter. Source: Adapted from SIEMENS, (2009).

For current measurements, the SENTRON PAC 3100 utilizes connections with 5 A standard current transformers. All current measuring inputs support continuous load of 10 A (max. 300 V) and allows overloading impulses for currents up to 100 A for a duration of 1 s.

For voltage measurements, the SENTRON PAC 3100 allows direct measurement on the system or utilizes voltage transformers. At the device input, voltage inputs can directly be measured through protection impedances. To measure higher voltages than the permissible rated input voltages, external voltage transformers are used. This multi-meter device is designed for input voltages measurement up to 277 V to the neutral conductor and 480 V to the driver conductors (SIEMENS, 2009).

B. THE SCADA Br. CHARACTERISTICS

The Supervisory Control And Data Acquisition software, SCADA Br., is a monitoring software with Open Source license (free software) capable of performing communication and control activities between devices. This software serves as interface between the operator and processes of various types of devices, such as industrial machines, automatic controllers and sensors of all kinds (SCADA Br., 2010).

The SCADA Br. software uses Modbus data source to acquire data from any Modbus equipment and is accessible through two mModbus types:

- Modbus IP: a network I / P, that may be on a local network or intranet, or anywhere on the Internet;
- Modbus Serial: as a local area network accessible via Modbus RS232 or RS485.

SCADA Br. systems are built from simple sensing and automation applications, to complicated famous control panels in electrical energy generation companies and electrical distribution stations, central traffic control and so on. A typical SCADA must provide drivers with communications equipment, a system for continuous data registration or data logger, and a graphical interface for the user, known as "HMI" or Human-Machine Interface. In the HMI graphics are available such as buttons, icons and displays, representing the actual process. It is monitored or controlled. Among some of the most used functions in SCADA systems are:

- Graphic generation and reports with history data of processes;
- Use scripting languages to develop automation logics or logarithms.
- Detection alarms and event record in automated systems;
- Process control including remote sensing parameters and set-points, drive and equipment Command (ScadaBR, 2010).

The ScadaBR is a Java-based application platform or PCs running on Windows, Linux and other operating systems and can run software from an application server (Apache Tomcat is the default choice). When you run the application, it can be accessed from a web browser, preferably Firefox or Chrome. The main interface of SCADA Br. is not difficult to use and already offers visualization of variables, graphs, statistics, configuration of protocols, alarms, building type HMI screens and has a range of configuration options. After configuring the communication protocols with the equipment and variables sets of inputs and outputs, or tags in an automated application, you can assemble web user interfaces using the browser itself. It is also possible to create custom applications in any modern programming language, from the available source code or its API web-services. The control mechanism access is the master-slave or client-server (ScadaBR, 2010).

A. THE RS485/ RS232 CONVERTER CHARACTERISTICS

As the name already indicates, this device is an adapter type that converts RS485 signals to RS232 signals. This small compact device (Figure 17) is used mainly to permit the communication between devices with Modbus serial RS485 and a computer that has a serial port connection based on RS232.

This device is a small compact device that does not requires any power supply. It connects through pinouts with the ports on the PC to convert RS-485 signals to RS-232 signal. The pinouts on the converter are called female DB9 and are standard to all PC serial COM Ports (RMS Technologies, 2009).

Figure 17: RS485/RS232 Converter. Source: Photograph by the Author

THE IMPLEMENTED ENERGY MONITORING SYSTEM

The energy monitoring system is presented in Figure 18 and as mentioned before, the four main components: the two SENTRON PAC multi-meters, the RS485/232 converter and the SCADA Br. software make up the basic structure of the implemented electrical energy monitoring system that has been implemented to make it possible to analyze real-time data in the scope of this research work. In the electricity laboratory on the campus Gama of building UED the SCADA Br. was installed on a server using a network of RS485 communication cable between the SENTRON PAC 3100 multi-meters in the building and the server. The physical installation of the SENTRON PAC 3100 multi-meters had already taken place during the construction of UED building. The configuration of the multi-meters and the parameter units of the Modbus protocol in SCADA Br. were also carried out during the implementation of this monitoring infrastructure.

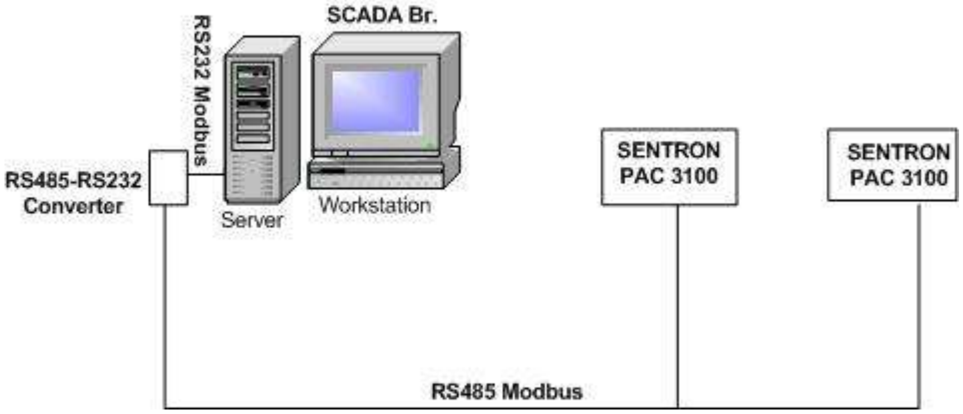
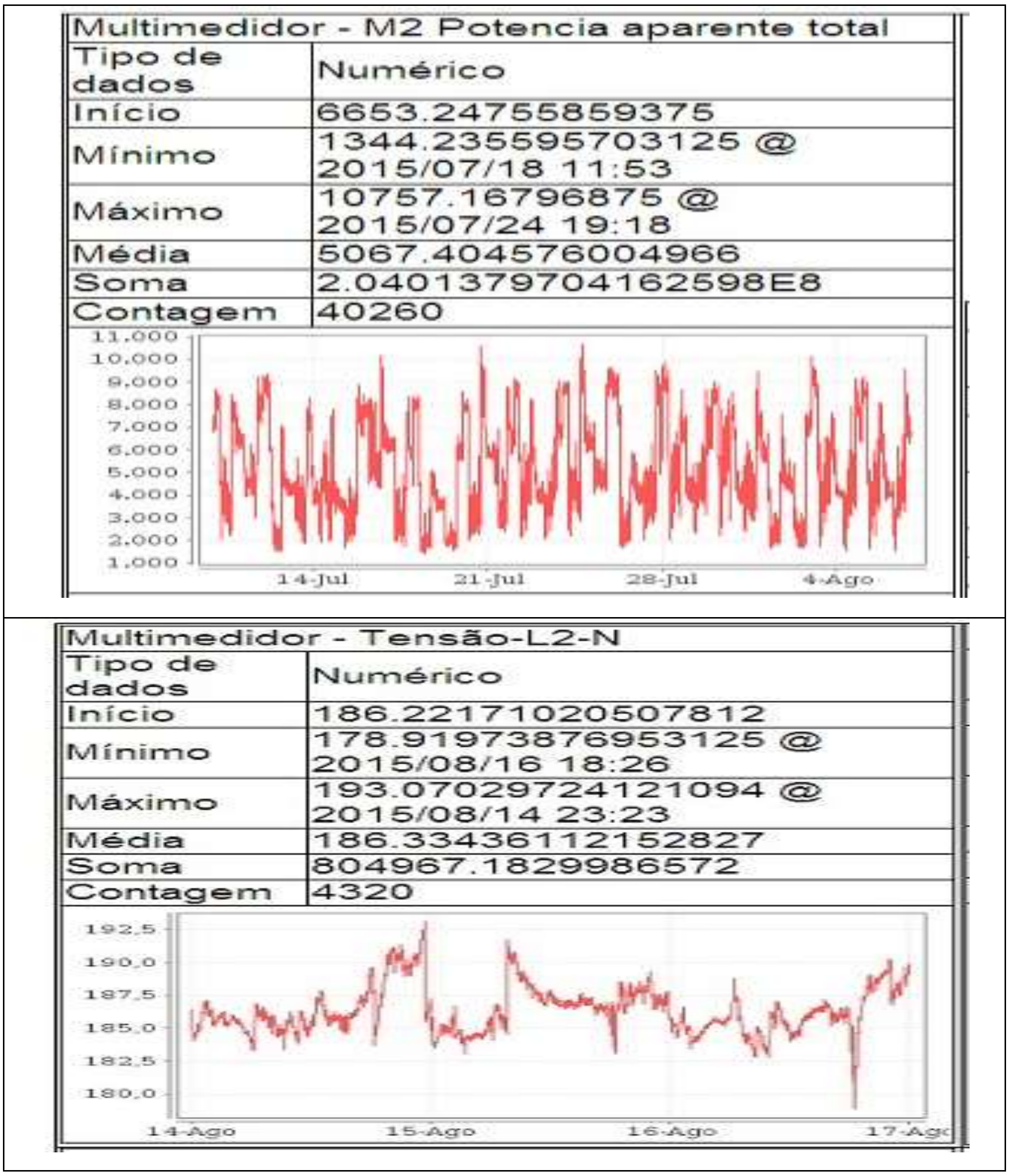


Figure 18: Diagram of monitoring system of campus Gama. Source: Elaborated by the Author.

The communication protocol used between the SENTRON PAC 3100 meter and SCADA-BR is the MODBUS RTU (Remote Terminal Unit). This protocol specifies the type of master-slave communication, where the slave does not start communication while it is not required. The acronym RTU implies transmission and is encoded in a binary format mode.

The SENTRON PAC 3100 was connected with the server (computer) in the laboratory through a data communication cable of approximately 15 meters, which was applied to the RS485-RS232 converter with the server. To communicate with the multi- meter the communication standard Modbus was used, to provide accurate reading of the data across the platform, which allowed the observation and analysis of meter data and allows tracing a pattern of consumption in the UED building as presented in Figure 18.

In Figure 19 is presented a typical power data profile on the SCADA Br. system of report over a few days from July to August of one of the SENTRON PAC multi-meters. The apparent power rate value is measured in kW (kilowatts) and the voltage in V (volts) in Figure 19.



Multimedidor - M2 Potencia aparente total	
Tipo de dados	Numérico
Início	6653.24755859375
Mínimo	1344.235595703125 @ 2015/07/18 11:53
Máximo	10757.16796875 @ 2015/07/24 19:18
Média	5067.404576004966
Soma	2.0401379704162598E8
Contagem	40260

Multimedidor - Tensão-L2-N	
Tipo de dados	Numérico
Início	186.22171020507812
Mínimo	178.91973876953125 @ 2015/08/16 18:26
Máximo	193.07029724121094 @ 2015/08/14 23:23
Média	186.33436112152827
Soma	804967.1829986572
Contagem	4320

Figure 19: Typical power profile of part of UED building. Source: SCADA Br.

3.2 INFORMATIONAL DESIGN OF MODULAR SYSTEM

The informational design modular system corresponds to a design roadmap to help the designer to clarify the problem presented by the design, in order to support him in the decision-making process to two aspects namely: define the design problem to study and establish specifications for the development of the design. The term "informational design" was established with the need to standardize the stages of design process, as to put them all in the design level. In other words, until well recently the informational design was called "definition of design problem" (MARIBONDO et al., 2002).

The development of the design process is carried out in three abstractions levels, namely: phases, stages and tasks, which are intended to show to the designer to do to get out of an internship of more complex information into a less complex. The final level of abstraction corresponds to the tasks. At this stage there are the tools and supporting documents applied to help the designer to collect and store information as a basis for decisions in the design process (GIACOMINI, 2004, p. 64-72).

This informational design phase of the design stage is shown in Table 13. Hereby are presented: the tasks of each step and the support tools or documents used along the process of the design. The input and output in each stage is of importance to be able to follow the procedure and understand the correlation between these stages in the design process.

Table 13: The roadmap followed for the informational design stage of the modular system.

Phase 1	Informational design of modular system		Input	Output	Documents and support tools
Stage 1.1	Search for information about the design theme		Collected information to contextualize the problem	Clarification of the problem	Life cycle of the system/product
	Task 1.1.1	Establish the life cycle of the system/product			
	Task 1.1.2	Search for technical information to clarify the problem of the design.			
Stage 1.2	Identify the necessities and requirements of the clients of the modular system		Purpose and goals to be achieved with development of the design	List of necessities of the clients	Life cycle of the system/product
	Task 1.2.1	Identify the clients and users of the design during the life cycle of the system			
	Task 1.2.2	Identify the necessities of these clients and users			
Stage 1.3	Establish the requirements of the clients of the modular system				
	Task 1.3.1	Transform the language of the clients into suitable conext for the design	Needs of the clients of the modular system	List of requirements of the clients of the modular system	Transformation method of the necessities in requirements of the clients of the modular system
Stage 1.4	Establish the requirements of the design of the modular system		Requirements of the clients	Requirements of the design	Mudge diagram and transformation of clients requirements into design requirements
	Task 1.4.1	Review and valorize the customer requirements			
	Task 1.4.2	Establish technical terms to represent how to meet the requirements of the clients of the modular system			
Stage 1.5	Prioritize the design requirements of the modular system		Requirements of the design	Design requirements classified in level of importance	Matrix of Quality Function Deployment (QFD)
	Task 1.5.1	Apply the matrix of Quality Function Deployment (QFD)			
Stage 1.6	Establish the design specifications of the modular system		Design requirements classified in level of importance	design requirements specified to meet the modular system	Table of specifications of the design
	Task 1.6.1	Apply the design specifications table			

Source: Elaborated by the Author.

STAGE 1.1 Search for information about the design theme

In the paragraph earlier, the information is gathered about the design approach and in chapter two is given background information regarding to the smart microgrid concept and technologies, and examples of microgrid laboratories around the world.

TASK 1.1.1 Establish the life cycle of the system/product

According Maribondo (2000, apud GIACOMINI, 2004) , the product life cycle is a supporting document to the design process to register the needs of various clients involved in the development of a product or system. Through it, the stages are analyzed that are part of the product life cycle, aiming to map all the paths of materials and products resulting from each of them in order to identify inputs, pollutions and other information involved in origin, use and disposal of such products.

The product life-cycle phases of the SMGP system are presented in Figure 20.

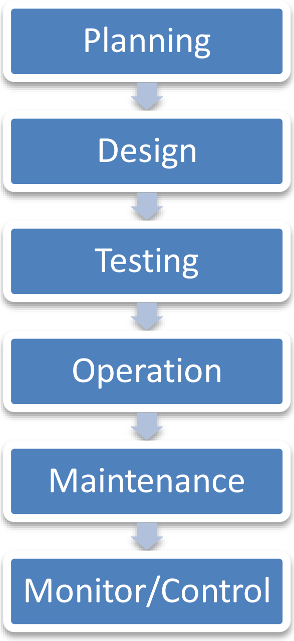


Figure 20: Product Life-cycle for the microgrid laboratory platform. Source: Elaborated by the Author.

The importance and objectives of the product life-cycle phases are explained as follows:

- Planning:

  This phase identifies all the work that has to be done, where the idea is further developed in as much detail as possible and the steps necessary to meet the objectives are planned. In this phase the perception of the product or system is further developed after the research is done and the documentation is gathered. The tasks and requirements are identified. A plan is created outlining the activities, tasks, dependencies, and timeframes.
- Design:

  Here the characteristics and details are further developed to design the proposed end product of the project, in this case the SMGP
- Testing:

  At this stage the design should be reviewed for quality and measured against the acceptance criteria with test done to simulate the outcomes to predict the overall functionality of the system. Here appropriate adjustments are made and recorded as variances from the original plan. In any design project, a project manager spends most of the time in this step. Throughout this step, project sponsors and other key stakeholders should be kept informed of the project's status according to the agreed-on frequency and format of communication. The plan should be updated and published on a regular basis.
- Operation:

  In this stage the design has already been updated , constructed, implemented and tested. The system is already available and ready to be operated.
- Maintenance

  In this stage the product service comes in to maintain the product functioning according to the product requirements.
- Monitor/Control

  Here the product in operation will be managed and controlled trough data communication and control platform.

TASK 1.1.2 Search for technical information to clarify the problem

The problem here is more of an issue that sparked the perception of this work. This problem /issue is the absence of an appropriate facility on the campus of Gama to integrate renewable energy generation in a laboratory environment based on smart microgrid system fundamentals such as distribution automation, distributed generation, smart metering, information technology and communication. This facility shall enable the students to gain experience in a living laboratory environment, since the system is generating energy and providing real-time data for experiments, research and training in the field of smart microgrid technologies such as supervision and control strategies of energy management. This problem is multi facetted, because the lack of this facility also prevents the student the hands-on experience as engineers in the field of smart technologies embedded in a microgrid scale, which is fundamental for their future as engineers in modern world, where there is a global challenge in the evolution of energy infrastructure based on efficiency, sustainability and reduced environmental impact.

Technical information on this field is provided in the literature and there is a selection of information regarded to microgrid technologies presented in chapter two of this work. Additional information regarded to the technical information to clarify the problem will be presented in the next part.

The modern developments show an increase in the interest of smart grids by producers and clients. There is a close relationship in the developments of smart grids and microgrids for efficient system functioning. The augmenting evolution of information and communication technology (ICT) systems brings the smart grids and microgrids into greater developments. Distributed Generation is embedded in smart and micro-grids and has the benefits of reducing environmental impacts and the liberation of electricity on the market. Hereby the smart grid involves technology efforts that provides economical and environmental benefits such as a job opportunities, decrease of carbon dioxide emission degree and development of workers.

A smart microgrid is defined as a modern platform based on the service-oriented architectures for integrating micro-grid modeling, monitoring and control. To construct smart microgrids for smart and flexible operation and grid control, there is an extend research required. An example of a research organization on the field of smart grids and microgrids is the Consortium for Electric Reliability Technology Solutions (CERTS) was constructed in the US for power system reliability of emerging technological, economic, regulatory-institutional, and environmental influences. One of their projects is an islanding detection on a laboratory sized power system in operation at the Tennessee Tech University of Cookeville, USA. Hereby the research is mainly based on intentionally and unintentionally islanding mode. The focus points for many smart grid related laboratories are communication, power systems control and interconnection between the distributed generation and centralized power grids. Also frequently used are Universal Monitoring, Protection, and Control Units (UMPCUs) which are similar to Intelligent Electronic Devices (IEDs) are installed at each component of a grid in order to collect informative data such as connectivity, device model, and measurements. The elaborated standards hereby are the ethernet infrastructure and IEC61850 which are employed to improve the response time of automation system in smart grid. IEC61850 is a protocol for communication networks and systems in substations standards with the objective to replace the conventional serial communication protocol. IEC61850 has the advantage of permitting more advanced protection capabilities via the use of direct exchange of data between devices over existing station bus (SHAMISHIRI et al., 2012).

Another example of the importance of test facilities for smart grid technologies is presented by Farhangi (2008) with a smart microgrid laboratory of the British Columbia Institute of Technology (BCIT). He calls it a “scaled-down version of the Intelligent Grid”. This intelligent microgrid has the objective to facilitate utility companies, technology providers and researchers to work together to develop and facilitate the commercialization of architectures, protocols, configurations and models of the developing intelligent grid with the motive of planning a “path from lab to field” for innovative and cost effective technologies and solutions for the development of North America’s smart grid. Here the smart microgrid is described as an RD&D (Research, Development and Demonstration) platform where current and future technologies in telecommunication, smart metering, cogeneration and intelligent devices are operated to develop and qualify a very powerful, cost-effective and scalable result, necessary to facilitate and attend the progress and the rush of the Smart Grid in a way. The main functionalities are categorized in three groups named the construction of an RD&D platform, operational analysis and qualification of grid activities, and development and qualification of intelligent agents, protocols and models (FARHANGI, 2008).

The smart microgrid of TERI Gram presents his key elements in a smart microgrid laboratory environment as:

- Integration of multiple DERs, ensuring maximum utilization of renewable energy sources
- Resource and load profiling, controlling, and forecasting
- Centralized control (Smart Hybrid Controller/Intelligent Dispatch Controller) for resource optimization and demand management
- Load prioritization
- Integrated, high-speed, FPGA-based digital communication on LabVIEW platform
- Real-time data acquisition and monitoring of thousands of electrical and physical signals
- Minimized outages and fast response to network disturbances through automatic connect/disconnect of system components (THAKUR & SAHOO, 2011)

Next is described a view about the importance of test facilities for smart grid technologies made by the NIST (2014). The main driver for the conception of the future smart grid is technology. As for many technologies, their individual performance is good, but when interconnected into a smart grid system various unpredictable events can develop. The development of a resilient, reliable, and safe smart grid therefore demands the potential to test system behavior and collaborate before practical operation in the energy delivery system. A reasonable test conditions can provide a solution. Smart grid tools and technologies enable bidirectional flows of energy and communication for a more efficient, reliable, and secure grid. Test-beds are necessary to provide the fast development and implementation of smart grid technologies, including development of new devices and software. Test-beds also provide smart grid measurement and characterization, which are important enablers of effective communication and interoperability of new smart grid equipment and the infrastructure that serves the grid. Testing also validates the interoperability of heterogeneous technologies for a particular purpose, and helps identify best configuration practices, increasing stakeholder confidence and enabling smart grid adoption (NIST, 2014).

In smart microgrids the optimization of resources and intelligent demand management uses state of the art digital technology and decentralized control makes the system efficient and modular. The main technologies for the smart microgrids are based on the integration of the components such as: renewable energy source, energy storage, (AC/DC and (DC/DC) converters/inverters, Intelligent
dispatch controllers and bi-directional digital controllers.

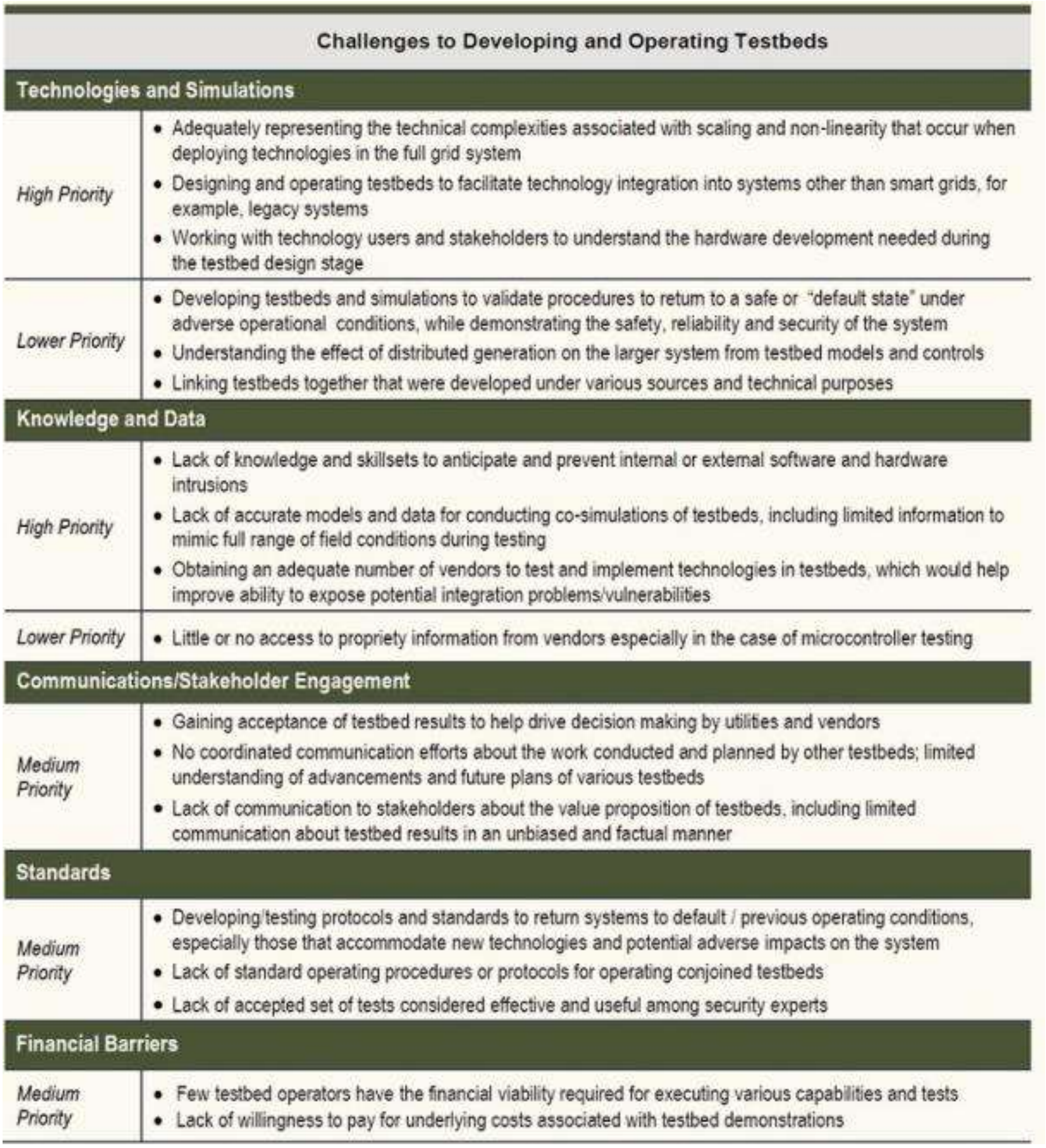
The main benefits of a smart microgrid could be:

- Fostering demand-side management and demand-side response
- Reducing power outages and increasing the reliability, efficiency, and safety of the grid
- Reducing the carbon footprint and minimizing fossil fuel consumption
- Providing better autonomy to customers to manage their electricity needs (THAKUR & SAHOO, 2011)

The development of testbed related to smart grid technologies, such as in this case of the proposed smart microgrid laboratory which will function as a real-time testbed, there are different aspects of great importance for the development of smart grid technologies. These aspects are mainly stakeholder engagement, hardware, sensors and control, grid integration, reliability and stability, and information sharing/communications. Next is presented in Table 14, the challenges of developing a testbed based on smart grid technologies (NIST, 2014)

The implementation of the proposed SMGP will have several benefits and will be of great importance as mentioned before in the development of smart grid related technology. As indicated in chapter two, these smart grid technologies are used in microgrids to be able to do test and analyze their performance in a small scale grid.

Table 14: Challenges to developing and operating testbeds related to smartgrid technologies.



	Challenges to Developing and Operating Testbeds
Technologies and Simulations	
High Priority	• Adequately representing the technical complexities associated with scaling and non-linearity that occur when deploying technologies in the full grid system • Designing and operating testbeds to facilitate technology integration into systems other than smart grids, for example, legacy systems • Working with technology users and stakeholders to understand the hardware development needed during the testbed design stage
Lower Priority	• Developing testbeds and simulations to validate procedures to return to a safe or "default state" under adverse operational conditions, while demonstrating the safety, reliability and security of the system • Understanding the effect of distributed generation on the larger system from testbed models and controls • Linking testbeds together that were developed under various sources and technical purposes
Knowledge and Data	
High Priority	• Lack of knowledge and skillsets to anticipate and prevent internal or external software and hardware intrusions • Lack of accurate models and data for conducting co-simulations of testbeds, including limited information to mimic full range of field conditions during testing • Obtaining an adequate number of vendors to test and implement technologies in testbeds, which would help improve ability to expose potential integration problems/vulnerabilities
Lower Priority	• Little or no access to propriety information from vendors especially in the case of microcontroller testing
Communications/Stakeholder Engagement	
Medium Priority	• Gaining acceptance of testbed results to help drive decision making by utilities and vendors • No coordinated communication efforts about the work conducted and planned by other testbeds; limited understanding of advancements and future plans of various testbeds • Lack of communication to stakeholders about the value proposition of testbeds, including limited communication about testbed results in an unbiased and factual manner
Standards	
Medium Priority	• Developing/testing protocols and standards to return systems to default / previous operating conditions, especially those that accommodate new technologies and potential adverse impacts on the system • Lack of standard operating procedures or protocols for operating conjoined testbeds • Lack of accepted set of tests considered effective and useful among security experts
Financial Barriers	
Medium Priority	• Few testbed operators have the financial viability required for executing various capabilities and tests • Lack of willingness to pay for underlying costs associated with testbed demonstrations

Source: Adapted from NIST, (2014).

To clarify the issue related to the SMGP, it is necessary to know the benefits, why it is of importance, what the objectives and benefits are for the campus of Gama and of what use the design will be. With the given explanations from technical information in the literature is proposed to clarify the issues related to smart microgrid laboratories, with examples, justifications of the need to develop test beds and the challenges.

This SMGP will facilitate the education, development and research in the field of both smart and microgrid technologies, causing the education level with the available knowledge and experience to increase on the campus Gama.

In this understanding the research will focus mainly on the following topics:

- Analyzing demand response in consigning intermittency in renewable generation;
- Assessment of impacts of inclusion of alternative sources to the electricity grid;
- Controlling the integrated use of energy storage, distributed energy resources and loads, to ensure the stability of grid (controls, communication, security, etc.)
- Voltage and current analyses
- Effects and behaviors during on-grid and island mode operation
- Analysis of the effects of harmonics and inter-harmonics of induction motor and other common charges in the electric power system;
- Monitoring and diagnostics of smart grid equipment.

STAGE 1.2 Identify the necessities and requirements of the clients of the modular system

In this stage the main purpose is to create a list of necessities and requirements of the clients which will be related to the life cycle stages of the modular system to analyze the relevancy of the necessities. Not all the needs that the clients have such as, wanting the system to do that and that, will be used, because some are overlapping each other and others will be transformed in technical language to fit eventually in the design process that start here with the system life cycle.

Task 1.2.1 Identify the clients and users of the design during the life cycle of the system

For this task is assigned in this work the analysis of the stakeholders approach to identify the clients and users. In the scope of this work is better to identify stakeholders, because they give a brighter perspective to the term of clients here, because this system is not something you can purchase in a store and consume. To start the informational step procedure of the SMGP design, the stakeholders should be listed, because every project has an effect on people and organizations and is influenced by them too. A stakeholder could be defined as those (a person, organization or institution) who has a personal concern, share or interest in the success of the project from the initial phase of the project. A key success factor of a project is the identification of these stakeholders at the initial phase of a project (Watt, 2014). To define the customers, the stakeholders should be analyzed according to their involvement (intern or extern stakeholder), their influence capacity and level of interest in the project. The stakeholders can be related to the early stages of development as supply chain partners, such as: assembler, equipment and tools supplier, supplier of commodities, material supplier, technology supplier and service provider. The forms of relationship hereby are as follows: risk partnership, technology partnership, strategic partnership, co-development partnership production contracted long and short-term.

Stakeholder analysis involves the following steps:

- **Identification of all stakeholders involved**
  - stakeholders which may be affected by the problem or the project are identified
- **Categorization of the stakeholders**
  - all relevant stakeholders are categorized according to criteria relevant for the specific project (active, beneficiaries, affected, supporters, opponents)
- **Detailed analysis of selected stakeholders**
  - more detailed analysis of selected stakeholders (characteristics, relations, interest, power)

Identification of stakeholders

For the reasons as mentioned earlier, the stakeholders for this microgrid laboratory platform have been identified as follows:

- educational institutions(such as universities)
- platform construction team
- research organizations
- electrical energy distribution companies
- solar panel suppliers
- solar energy components suppliers (inverters, solar panels etc.)
- microgrid operators
- microgrid construction contractors
- intelligent metering system developers and suppliers
- utility grid operators
- power management (EMS) and control systems suppliers
- governmental energy legislators
- project finance sponsor

- project manager
- metering service providers

Categorization of stakeholders

The stakeholders are categorized in the following groups:

- Key stakeholder: Those who can significantly influence or are important to the success of an activity
- Primary stakeholder:

  Those individuals and groups who are ultimately affected by an activity, either as beneficiaries (positively impacted) or those adversely impacted
- Secondary stakeholder:

  All other individuals or institutions with a stake, interest or intermediary role in the activity.

  The categorization of the stakeholders is presented in Figure 21 by a diagram.

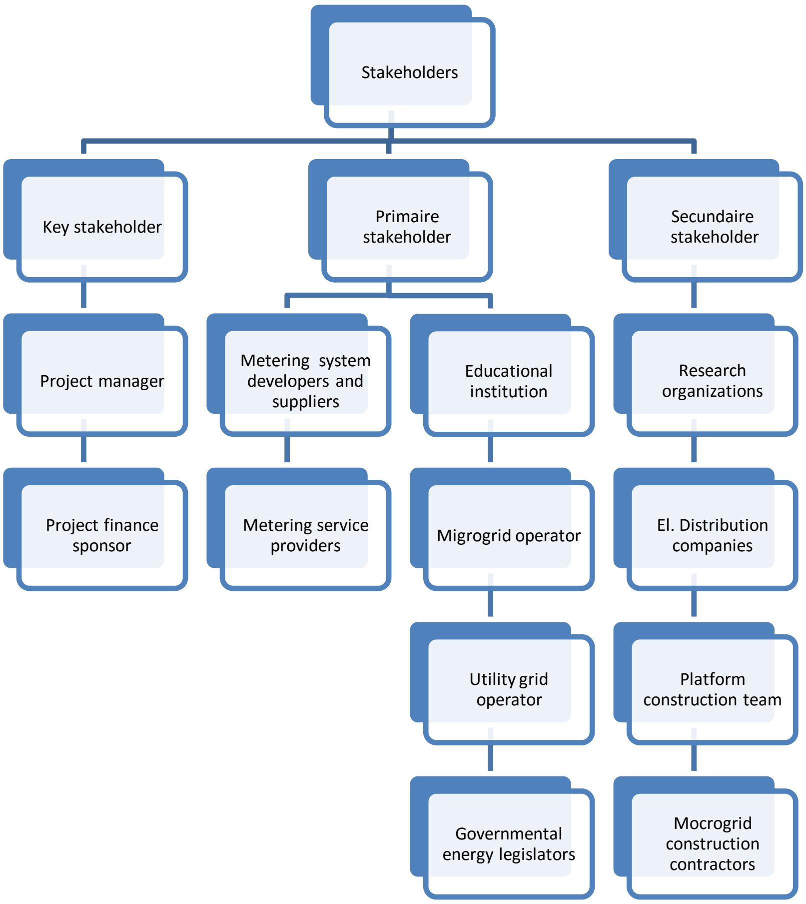


Figure 21: Stakeholder structural organization. Elaborated by the Author.

Detailed analysis of selected stakeholders

In Table 15 is defined the basic characteristics, interests and how the stakeholders are affected by the problem of the project. Capacity and motivation to bring out changes (why should the stakeholder be interested on bring about changes? What can they do to about it?). Further on is listed the possible actions to address stakeholder interests. There we take a look at, in a realistic way, what the project does to address stakeholder interests. Here is analyzed what can be done to influence stakeholders.

Table 15: Stakeholder analysis.

Stakeholder	**Impact** *How much does the project impact them? (Low, Medium, High)*	**Influence** *How much influence do they have over the project? (Low, Medium, High)*	**What is important to the stakeholder?**	**How could the stakeholder contribute to the project?**	**How could the stakeholder block the project?**	**Strategy for engaging the stakeholder**
Project manager	High	High	Maintaining good project progression	Agree with members to implement the project	Going on strike	Weekly round-table discussions
Project financier	High	Medium	That the available budget is spend properly	Communicate with project manager to get feedback	Making complaints about received reports	
educational institutions (such as universities)	Medium	Medium	Getting the change to learn	Helping the operational team	By not contributing any activity	Information and feedback meetings every 2 months
platform construction team	Low	Medium	Getting the work done in time	Reach the operational date	Cancelling his work	Informational meetings weekly
research organizations	Low	Low	To do research	Give advice	Not engaging	Weekly meetings
electrical energy distribution companies	Medium	Low	Renewable energy	Give needed advice	Nothing	
microgrid operators	Low	Medium	A functioning microgrid	Work acurately	Stop the operations	Keep in contact
microgrid construction companies	Low	Medium	Construction requirements	Doing his work properly	Not delivering the tasks in time	Operational Reports monthly
intelligent metering system developers and suppliers	Low	Medium	Happy client	Delivering the goods in time	Not delivering in time	Weekly contact
utility grid operators	Medium	Medium	The Utility grid	Protect the utility grid		Keep in contact
power	Low	Medium	Happy client	Installing	Not delivering	

Stakeholder	**Impact** *How much does the project impact them? (Low, Medium, High)*	**Influence** *How much influence do they have over the project? (Low, Medium, High)*	**What is important to the stakeholder?**	**How could the stakeholder contribute to the project?**	**How could the stakeholder block the project?**	**Strategy for engaging the stakeholder**
management (EMS) and control systems suppliers				properly		
governmental energy legislators	Low	Medium	Following the energy generation rules		Stop the operation if operated against the rules	Contact

Source: Elaborated by the Author.

Task 1.2.2 Identify the necessities of these clients and users

Necessities are defined by Nunes (2008) as something that a person needs, which is also recognized as a desire for a product or specific services. The concept of necessity is of paramount importance in all the humanities and social sciences said. This importance of the needs for social and human sciences lies in the fact that they are the needs that lead to the action of the individual and to your satisfaction, which is usually a fact of motivation.

The necessities of the clients

The clients have certain expectations to define how this product should be functional according to their standards, which are called requirements. The necessities are gathered from the literature of many papers and research studies done by institutions and universities such as the Berkeley labs, Sandia National Laboratories, CERTS laboratories etc.

The necessities of the clients are listed as follows:

- Need an environment to do tests, studies, to teach and instruct trainings with real time data from a smart microgrid
- To do power analysis based on renewable energy generation
- To introduce clean (renewable) energy to support the low carbon emission generation
- Ability to run tests and simulations securely with real time data measurements
- To use communication systems and software in a microgrid system
- To integrate renewable energy generation on the campus in a small scale
- To monitor and operate the energy storage (in case of batteries)
- Monitor and operate the Distributed generation

- Minimal maintenance
- To teach and do research in a safe microgrid laboratory environment
- To be able to remotely manage and control the microgrid system
- To improve the energy reliability
- To define boundaries and behaviors of the system
- Ability to optimize system efficiency within the microgrid
- Switch to function in island mode during outages
- Learn and educate to manage the power system data of the smart microgrid
- To use computers to visualize all micogrid components data on screens
- Need a broad view of the microgrid system performance
- Have a robust energy system
- To be able to visualize switching operations in the microgrid
- To analyze results from real time cases and tests cases
- Ability to collect reports of real time cases and test cases
- To collect real time data from energy demand, consume and solar energy generation

STAGE 1.3 Establish the requirements of the clients of the modular system

Concept of requirements

According to Back and Forcellini (2003) apud Santos and Sanches (2008), the only justification for the development of a design activity for a product/system is the existence of recognized needs. They define the design as an activity geared to meet the needs and there should be designed according to these needs in the process. Requirements define the capabilities that a system must have (functional) or properties of that system (non-functional) that meet the users' needs to perform a specific set of task.

TASK 1.3.1 Transform the language of the clients into suitable context for the design

The requirements of the clients are transformed from the necessities for each life cycle phase. According to Rozenfeld (2006), after the identification of the needs, initially described according to the language of customers, they can be rewritten in the form called requirements of the customer. The requirements can be functional (what the product needs to do) or nonfunctional (the qualities that the product must have) and restrictions are global requirements of the product.

According to Fonseca (2000), the deployment of customers their needs in the requirements of customers, is firstly distributed throughout the product/system life-cycle management in order to more easily identify which of them are redundant. Subsequently, each of the requirements is studied and, if necessary, decomposed in order to discover, in engineering language, what the customer really wants as recommended:

- Short phrase composed of verbs be, being or having, followed by one or more substantive;
- Short phrase composed of one word that is not to be, being or having another noun in this case, the requirement possibly form a product function) .

In Table 16 is presented the requirements of the clients, which are transformed from the necessities and organized for each phase of the product/ project life cycle.

Table 16: The requirementsof the client in the system life cycle.

Life cycle of the system	Requirements of the client	Identification of stakeholders/ clients
Planning	To be a safe and secure power system architecture for experiments	Project manager, Project financier, Institution/Universities, governmental energy legislators
	To support low carbon emission power generation	Students,Reseachers,Green energy organizations;
Design	To have a two-way flow of electricity and information	Smart metering (technology) suppliers
	To be utilising an overall power system control	Power electronics suppliers
	To enhance a plug-and-play infrasrtucture	Platform construction team (students, contractors etc)
Testing	To integrate measuring systems for different parameters	Measurement systems suppliers
	To predict system behavior	Educational institution
Operation	To prevent black-outs	Microgrid operators, utility grid operators
	To operate in different scenarios	Smart metering systems suppliers
	To enable remote operation	
Maintenance	To be a low maintenance power system	Smart metering systems suppliers
Monitor & Control	To be a self-healing microgrid	Control & monitoring systems/software suppliers
	To implement control strategies for generating units & power transfer to the loads	Power management (EMS) and control systems suppliers
	To be monitoring all system parameters	
	To consist demand-side- and outage- management	

Source: Elaborated by the Author.

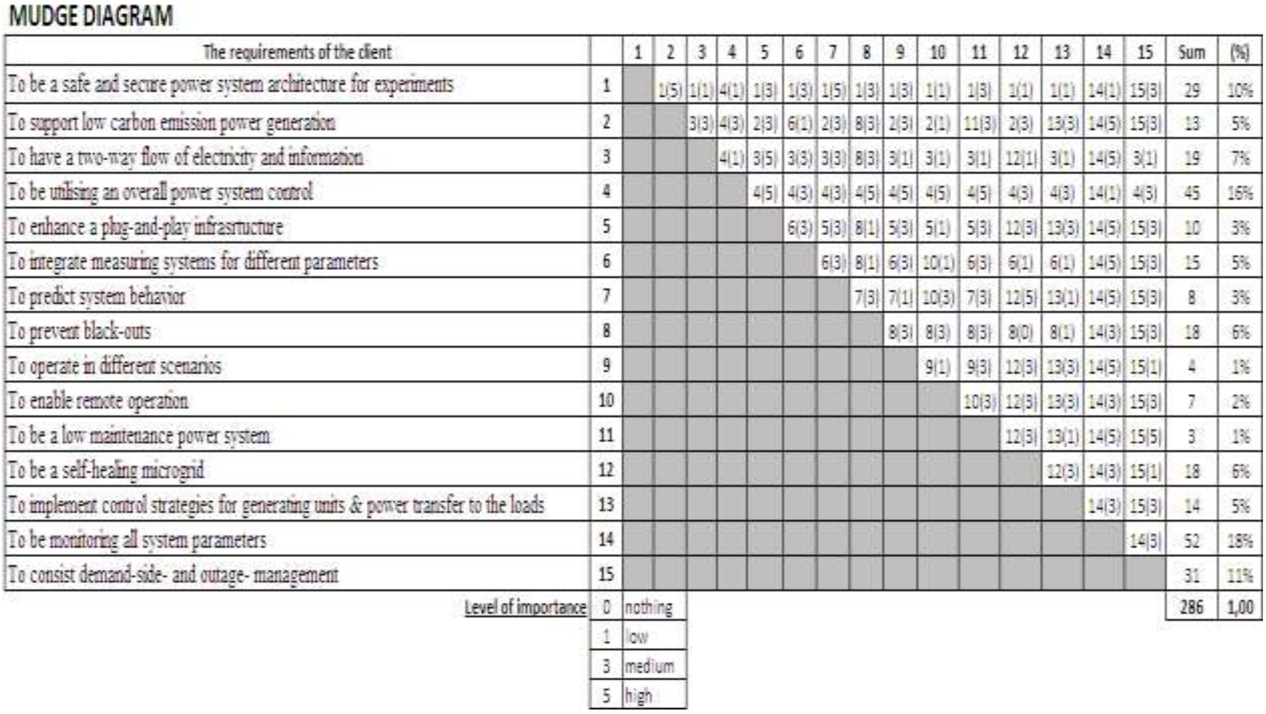
STAGE 1.4 Establish the requirements of the design of the modular system

TASK 1.4.1 Review and valorize the customer requirements

In order to valorize each client´s requirement, the most close to reality, we use the diagram of Mudge. The diagram of Mudge consists of an array where both the first column and the first row is comprised of the items in comparison. The Mudge diagram is seen as a tool to compare the client´s requirements in pairs so that at the end of the comparison, the relative importance will be known, Ullmann (2010).

According to Rozenfeld et al. (2006), and Ullman (2010), the Mudge diagram consists of a matrix where the first column and the first line are composed of the compared items (customer requirements). In the Mudge diagram is compared each requirement of the lines with all requirements of the columns except the same. First, the project team decides which pair requirement is the most important (the cell of the matrix takes the number of this requirement), after which decides whether the level of importance, much more (most) important (value five)more important(value three) and slightly more important (value one). The relative value of each requirement is obtained by summing the values observed across the diagram. The process of valuation of customer requirements was performed using the Mudge diagram, as presented in Table 17, and the end results will be used for further hierarchy of the client´s requirements.

Table 17: Mudge diagram with the requirements of the client.



MUDGE DIAGRAM

The requirements of the client		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Sum	(%)
To be a safe and secure power system architecture for experiments	1		1(5)	1(1)	4(1)	1(3)	1(3)	1(5)	1(3)	1(3)	1(1)	1(3)	1(1)	1(1)	14(1)	15(3)	29	10%
To support low carbon emission power generation	2			3(3)	4(3)	2(3)	6(1)	2(3)	8(3)	2(3)	2(1)	11(3)	2(3)	13(3)	14(5)	15(3)	13	5%
To have a two-way flow of electricity and information	3				4(1)	3(5)	3(3)	3(3)	8(3)	3(1)	3(1)	3(1)	12(1)	3(1)	14(5)	3(1)	19	7%
To be utilising an overall power system control	4					4(5)	4(3)	4(3)	4(5)	4(5)	4(5)	4(5)	4(3)	4(3)	14(1)	4(3)	45	16%
To enhance a plug-and-play infrasructure	5						6(3)	5(3)	8(1)	5(3)	5(1)	5(3)	12(3)	13(3)	14(5)	15(3)	10	3%
To integrate measuring systems for different parameters	6							6(3)	8(1)	6(3)	10(1)	6(3)	6(1)	6(1)	14(5)	15(3)	15	5%
To predict system behavior	7								7(3)	7(1)	10(3)	7(3)	12(5)	13(1)	14(5)	15(3)	8	3%
To prevent black-outs	8									8(3)	8(3)	8(3)	8(0)	8(1)	14(3)	15(3)	18	6%
To operate in different scenarios	9										9(1)	9(3)	12(3)	13(3)	14(5)	15(1)	4	1%
To enable remote operation	10											10(3)	12(3)	13(3)	14(3)	15(3)	7	2%
To be a low maintenance power system	11												12(3)	13(1)	14(5)	15(5)	3	1%
To be a self-healing microgrid	12													12(3)	14(3)	15(1)	18	6%
To implement control strategies for generating units & power transfer to the loads	13														14(3)	15(3)	14	5%
To be monitoring all system parameters	14															14(3)	52	18%
To consist demand-side- and outage- management	15																31	11%
Level of importance	0	nothing															286	1,00
	1	low																
	3	medium																
	5	high																

Source: Elaborated by the Author.

After the Mudge diagram is applied to valorize each client´s requirement, the requirements can be classified according to their importance. The hierarchical structure according to their valuation is the result of the Mudge diagram and presented as follows in Table 18.

Table 18: The requirements of the client in hierarchical structure.

1.	To be monitoring all system parameters
2.	To be utilising an overall power system control
3.	To consist demand-side- and outage- management
4.	To be a safe and secure power system architecture for experiments
5.	To have a two-way flow of electricity and information
6.	To prevent black-outs
7.	To be a self-healing microgrid
8.	To integrate measuring systems for different parameters
9.	To implement control strategies for generating units & power transfer to the loads
10.	To support low carbon emission power generation
11.	To enhance a plug-and-play infrastructure
12.	To predict system behavior
13.	To enable remote operation
14.	To operate in different scenarios
15.	To be a low maintenance power system

Source: Elaborated by the Author.

TASK 1.4.2 Establish technical terms to represent how to meet the requirements of the clients of the modular system

The next step is to transform the client´s requirements into product/system requirements. After the application of a hierarchical method of customer requirements by the Mudge diagram, the next step is to turn the features that customers want the product/system to have (these features already in requirement form) into system requirements.

In this task can then be established the design requirements that are the conversion of customer needs (requirements) in a engineering language technique, as the product to be developed can be written via technical characteristics, able to be measured by some kind of sensor (BACK and FORCELLINI, 2003 apud Santos and Sanches, 2008). For the definition of design requirements, Blanchard and Fabricky BACK and FORCELLINI, 2003) suggest a sequence of questions to be formed.

1. How the product/system must perform in terms of characteristics and operations?
2. What is the expected useful life of the product/system?
3. How the product/system will be operated in terms of hours?
4. How will the product/system be distributed?
5. What are the efficiency characteristics that the product/system should display as cost, availability, reliability, maintainability, etc.?

6. What are the characteristics related to the environment that the product should have? In an environment that the product will work? (Santos and Sanches 2008)

Another method found in the literature for the transformation from the requirements of the client into requirements of the modular system is given by Maribondo (2000) apud (GIACOMINI, 2004). This method uses the question “how the design could meet and address the requirements”, to present in which way the requirement of the client will add to functioning of the modular system. This method is used for establishment of the modular system requirements set-up in this task.

In the next table, Table 19, this transformation of the requirements of the clients into requirements of the system is shown.

Table 19: Transformation of the requirements of the client into requirements of the modular system (design).

	Requirements of the client (What)	How the design could meet & address the requirements	Requirements of the design (How)
1.	To be monitoring all system parameters	With a communication system and software systems	High level monitoring of the microgrid in real-time
2.	To be utilising an overall power system control	By a central controller that is coupled with individual controllers or power electronics	Dispatch and control the microgrid
3.	To consist demand-side- and outage- management	By using OMS and DMS systems	Optimal management of loads, demands and outages of the microgrid
4.	To be a safe and secure power system architecture for experiments	With intelligent protection schemes, wide area protection, standards etc.	High utilization of electric standards & protection relays
		Use a static switch as the main protective device, with backup trip function provided by utility-grade relays. Source breakers for over current protection	High level integration of static switch and/or source breakers
5.	To have a two-way flow of electricity and information	By using smart meters	High performance smart metering devices & bi-directional converters
6.	To prevent black-outs	By automated switches	High level of automatic transition to/from and operate islanded
		By operating in a synchronized and/or current-sourced mode when utility-inter connected	Integrate a phasor measurement unit (PMU)
		By applying energy storage technology and energy support	High energy storage and support capacity
7.	To be a self-healing microgrid	With a fault monitoring system	High level performance to detect, isolate and restore faults in the microgrid
8.	To integrate measuring systems for different parameters	By interfaces between communication system and microgrid devices	Great enhanced interface infrastructure
9.	To implement control strategies for generating units & power transfer to the loads	With the use of power electronics	High control improvement with power electronics
10.	To support low carbon emission power generation	By using renewable energy sources	High integration level of DER units in the microgrid
11.	To enhance a plug-and-play infrastructure	By a flexible design through the use of bi-directional inverters to add elements to the microgrid	High level stabilization of the AC-bus voltage magnitude and frequency
12.	To predict system behavior	By wheater forecasting; demand and load management	Integration of a high level performing weather station
13.	To enable remote operation	Use a remote monitoring system	Optimal operation level by remote monitoring over wire-less connection
14.	To operate in different scenarios	Seamless switching devices or technology	High level control for frequency, Volt/VAR in grid- connected & island mode
15.	To be a low maintenance power system	Lower maintenance because of close monitoring of the supplies	High performance ability of the system

Source: Elaborated by the Author.

STAGE 1.5 Prioritize the design requirements of the modular system

Ranking the system requirements

A tool used to accomplish the prioritization of system requirements, is called the House of Quality Matrix or QFD (Quality Function Deployment). The objective is to prioritize the system requirements transformed from the needs and desires of the customers in the system design process, serving as a basic plan for the conceptual design of the system.

A correlation is made between the customer´s requirements and system/product requirements, to establish the level of importance of each requirement of the system. With this information, the designer can prioritize design decisions in favor of those considered the most important requirements Maribondo (2000) apud (GIACOMINI, 2004).

House of Quality Matrix or QFD (Quality Function Deployment) is presented in ANEX 1. The prioritization of the requirements of the system can be carried out two ways:

1. Disregarding the roof information of the House of Quality Matrix (QFD).
2. Regarding the roof information of the House of Quality Matrix (QFD).

This task shall be done with the prioritization of the requirements of the system with the method of disregarding the roof information of the House of Quality (QFD), so only the lower quadrant of the QFD shall be taken into consideration, as presented in ANNEX 1.

TASK 1.5.1 Apply the matrix of Quality Function Deployment (QFD)

The QFD is presented in an attachment, and the final results are presented in Table 20.

Table 20: Results of the Quality Function Deployment.

Requirements of the system	Grade of importancy	Percentage	Classification
Dispatch and control the microgrid	52	9%	1
High level monitoring of the microgrid in real-time	45	7%	2
Optimal operation level by remote monitoring over wire-less connection	40	7%	3
High performance ability of the system	38	6%	4
High level of automatic transition to/from and operate islanded	37	6%	5
High utilization of electric standards & protection relays	36	6%	6
High performance smart metering devices & bi-directional converters	35	6%	7
Optimal management of loads, demands and outages of the microgrid	35	6%	8
High control improvement with power electronics	34	6%	9
High level performance to detect, isolate and restore faults in the microgrid	32	5%	10
High energy storage and support capacity	31	5%	11
High level stabilization of the AC-bus voltage magnitude and frequency	29	5%	12
Integration of a high level performing weather station	27	4%	14
Great enhanced interface infrastructure	26	4%	15
High integration level of DER units in the microgrid	23	4%	16
Integrate a phasor measurement unit (PMU)	20	3%	17
High level control for frequency, Volt/VAR in grid- connected & island mode	19	3%	18
High level integration of static switch and/or source breakers	18	3%	19

Source: Elaborated by the Author.

STAGE 1.6 Establish the design specifications of the modular system

According to Rozenfeld (2006), specifications or specifications-objectives of a product/system are quantified and measurable parameters that the product is designed to have. So in addition to units, the specifications should have values, which are numbers that establish the required performance. Specifications, and act as guides to generate solutions to the design problem, provide the basis on which the evaluation criteria and decision-making will be assembled. The end results expected from the informational project stage are the design specifications with their objectives and constraints. These results of the Quality Function Deployment (QFD) or also named the House of Quality, evolves the results of the correlation between the requirements of the design themselves and the correlation between the Requirements of clients (RC) and the requirements of the system. The second result type will be further used to complete the specifications of the system, because these are categorized in hierarchy according to their importance in view of the customers. This list of project specifications, will serve as a fundamental basis for the continuation of the other phases, because it will lead to the conceptual and preliminary design stage, as well as restrict them to always follow the requirements raised from the customer's needs, becoming as a link between the phases, interacting and integrating the whole course of the design.

TASK 1.6.1. Apply the design specifications table

As indicated earlier, this task will present the results of the QFD, which prioritizes the requirements of the system, which will here be presented in the table of target specifications of the system. System specifications of the design are presented in Table 21 as follows.

Table 21: Design specifications of the system.

Requirements of the system	Specifications	Metric-Unit	Objectives	Sensor	Undesirable output	Comments
Dispatch and control the microgrid	The dispatch and control of all active components of a microgrid is done in periodic sampling of arbitrary ranges like 1s, 10s, 1min, 1h, etc.;	Time scales in seconds (s), minutes(min) and hours (h)	Aims to achieve an optimal operation of the complete system.	Measure power, current and voltage at locations for sending information to control system	Not detecting the over load situations in time to prevent blackouts	Conform the electrical energy criteria technical norms
High level monitoring of the microgrid in real-time	Monitoring of the microgrid in order to evaluate the real-time data that reflects the stability of the entire grid.	In kbps and Mbps at (frequency) Hz	For monitor the overall power system from a distance (not locally) in real-time.	Transporting data to monitoring and control systems.	Not functioning communication.	The communication infrastructure can be centralized or decentralized and they may make use of multiple technologies such as wireless, Ethernet and power line communication;
Optimal operation level by remote monitoring over wire-less connection	Remote Monitoring System to collect and analyze data from sensors and a central application server, and store and transfer data over wireless Internet (or web over GPRS).	In Mbps or kbps at Hz	Parameters of renewable energy generators, battery, appliances, etc., can be monitored through Remote Monitoring System.	Wireless sensor systems to sense the data of the microgrid parameters such as temperature, power, current, voltage and generation capacity.	Failure of remote monitoring system.	Remote Monitoring Systems can provide the consumer and provider of usefull information.
High performance ability of the system	Continuous monitoring for performance ability increasement.	[Time frames programmed:] in seconds (s) or minutes	Generation of charts and reports with historical data; Detection of alarms and automated event logging etc.	transformation of the analog data into digital data for presenting on computer screen.	Shutting down of the power system.	Dedicated virtual private networks can be implemented to specify security features and separate different user traffic.

Continuation of Table 21: Design specifications of the system.

High level of automatic transition to/from and operate islanded	High frequency switching for automatic transition can clamp the instantaneous currents and turn off in very short time frames	micro seconds (us) @ frequency in Hertz (Hz)	The transition can be necessary in times of utility blackouts or DER low energy impact. Usually with an Open/Close speed: in 10us-100us @60Hz	Measuring frequency, voltage and current	no transition capabilities when needed	Most acceptable switch for microgrid to connect & disconnect public grid for double mode inverter
High utilization of electric standards & protection relays	Restrictions by electric standards and DG current protection relay; DG current & voltage protection has standard over current differential protection and voltage and frequency relays as backup. The time-selective operation of relays is about 150 ms.	milliseconds (ms)	1. IEC 61850-power utility automation 2. IEC 61970/61968-Common Information Model (CIM)for energy and distribution management 3. IEC TR 62357 for service oriented architecture 4. IEC 62351 for security 5. IEC 62056 data exchange for meters 6. IEC 61508 for funcional safety.	Usually measuring over-current, and over voltage and unacceptable values for signaling the control system for closing switches to isolate the area.	Failure to detect faults and resulting in system failure.	These protection relays mainly fail to detect high impedance faults (HIF). Microprocessor relays can detect HIF.
High performance smart metering devices & bi-directional converters	Smart meters provide data “energy signature”, its unique pattern of energy consumption. In Normal mode of operation, the Bi-Directional Converter maintains the battery system at a float charge. In Battery mode of operation, it converts DC power from the battery, through the DC-to-DC Converter, to regulated and conditioned sine wave AC power for supporting the critical load.	Power Rating in kW; Max Current in (Ampére) A	Smart meters give you the calibration capability to analyze energy usage patterns. Smart meters usually produce a 15-minute (and instantaneous) interval meter data.	Measuring unbalances in the energy network.	not functioning smart meters and bi-directional converters, causing the power system to get unbalanced and shut down.	Smart meters measure different parameters such as current, voltage, load, peaks, temperature etc. Utilities use 15-minute-interval data to determine peak demand charges. The Bi-Directional Converter is a pulse width modulated (PWM) design.
Optimal management of loads, demands and outages of the microgrid	The basic concept of every outage management is its ability to understand the relationship between customers and the network; Demand management utilizes combined load flow analysis data with real-time data points.	minutes	To analyze the location and extent of an outage; To enhance the picture of the grid. Their time frames are programmed usually 10-25 minutes.	Measuring load, demand, consume, and power flow for analysis by management software.	Barely available energy support from the microgrid due to extremely low capacity.	Reduce outage time through integration with Smart Meter technology.

Continuation of Table 21: Design specifications of the system.

High control improvement with power electronics	Power electronics are used to change the characteristics (voltage and current magnitude, phase and/or frequency) of electrical power.	In Voltage (V); (Power rating) in kVA;	Functions of power electronics interface modules: power conversion, power conditioning (PQ),	Measuring defined parameters for data transfer to control system		Different power conversions: AC-AC; AC-DC; DC-AC; DC-DC; AC-DC-AC
High level performance to detect, isolate and restore faults in the microgrid	Detecting, isolating and restoring faults during over voltage/over current and sudden load dips in the power systems	Minutes	To find the fault location in the power system, isolate the fault and restore the situation in the grid	Measuring voltage in phasors and voltage dips or over voltage cases	Not functioning in faults causing failures, blackouts of complete power system	
High energy storage and support capacity	The energy storage will store the needed energy to function as energy support for the system in low energy generation or outage	In kVAh or MW [Power Rating : 0.001 - 50 MW (Lead Acid); Discharge duration: 1h; Efficiency: 70-92%; Durability (years): 5-15 (~10)]	Balancing power demand between the generation side and the load side is the first priority for energy storage devices	Measuring balance between power demand and generation	No available energy in times of utility grid failure and low generation of intermittent source	Storage of maximum energy demands during off- peak hours and being able to supply all loads when required.
High level stabilization of the AC-bus voltage magnitude and frequency	Produce AC voltage (or current) of controllable magnitude and phase for stabilization.	In Watts (W) or kilowatts(kW)	Power conditioning at voltage sources such as, battery banks and solar photovoltaic cells.	Power conditioning	Failure of power system	
Integration of a high level performing weather station	Continuous data transfer from weather station to laboratory platform	In hour/day; Temperature (T); Barometric Pressure: Typical range 950 to 1050 mBar ;Wind Speed in Miles/hour	Available data for solar and wind energy generation	CPU for sensor data acquisition (analog; digital or intelligent sensors)	No daily availability of data from wheater staion	The weather conditions or valuable for intermittent energy source to predict the power generation
Great enhanced interface infrastructure	Interfaces for PV systems, small hydro, micro turbine, battery, flywheel, wind turbine, etc.	(Power flow control (+P, +/-Q)) in Watts (W)	Various interface modules with objectives such as power conversion, power conditioning (PQ),	Registering the out-of-service time, and power flow	Not guaranteed operations	
High integration level of DER units in the microgrid	Integrating Distributed Generation units	In kiloWatts (kW) (1kW - 5000kW)	The purpose of distributed generation is to provide a source of active electric power.	Power electronics	Not generating electrical energy and no availability of energy to the customers	Distributed generation units connected directly to the distribution network or connected to the network on the customer site of the meter.
Integrating a phasor measurement unit (PMU)	Integration of PMU are used in a control system that keeps the system operating in a safe region, because microgrids lack the inertia of an interconnected power system	[In near-real-time updates up to] 60 frames /second (reporting rate) with adjustable reporting rates of 200/240 frames per second	PMUs are ideal for measuring voltage magnitude, angles, frequency, and slip between any two portions of the electric system.	Measurements of electrical waves (synchrophasor)	Not functioning PMU, causing the power system to fail	PMU functionality is available in protective relays, voltage regulators, reclosers, and meters

Continuation of Table 21: Design specifications of the system.

To improve control with power electronics	Power electronics are used to change the characteristics (voltage and current magnitude, phase and/or frequency) of electrical power to suit any particular application.	In Voltage (V); (Power rating) in kVA;	Functions of power electronics interface modules: power conversion, power conditioning (PQ), protection of output interface & filters, DER and load control, ancillary services, and monitoring and control	Measuring defined parameters for data transfer to control system		Different power conversions: AC-AC; AC-DC; DC-AC; DC-DC; AC-DC-AC
To integrate a static switch and/or source breakers	The static transfer switch (STS) is an electrical device that allows instantaneous transfer of power sources to the load. This superior switching time means that if one power source fails the STS switches to the back-up power source so quickly that the load never recognizes the transfer made.	In seconds (s) (Time frame: < 10 seconds)	Static Transfer Switch are automatic static switching equipments designed to transfer electric loads between two independent AC power sources without interruption.	Measuring the balance between load and power flow	Not responding transfer switch, causing low power available situations called load shedding	Not responding transfer switch, causing low power available situations called load shedding

Source: Elaborated by the Author.

3.3 FINAL CONSIDERATIONS

This chapter presented the modular system approach for the design of the SMGP system. The SMGP system design fitted the profile of a modular design is described as design of modular systems: comprises one product that preserves the interchangeability of some parts (Mohamad et al., 2013) .

The implementation of the real-time data monitoring system was an established goal along the idea of monitoring and control via a laboratory platform. There were several challenges along the way such as the computer not being able to store the data on time and delaying to upload one report. The implemented system seems simple, but that was not the case. It took several weeks to get the software properly installed in the electro-laboratory and it took another few weeks to figure out all the configurations and program a few scripts to make the communication with the SENTRON PAC 3100 multi-meter possible and visible via the SCADA Br. Sofware on the computer display. It eventually required team work to get it all set-up and running. The computer was further updated with an extended memory storage to store all the required data. The collected data of the energy profile of the campus Gama gives an idea of the maximum consume of the campus and this data can be usefull in the development steps of the SMGP.

This informational design phase has as final result the required target specifications as presented in Table 21 of the to be designed power system that will do purpose as a living smart microgrid laboratory. To get to these specifications, several steps have been followed that were separated in 6 stages, each with different task starting at the collection of information to clarify the task of the design of the system, whereas the lifecycle of the system is established. This chapter further identifies the clients of this system through a stakeholders analysis, which is followed up by the requirements of the clients from their necessities and transforming them finally into requirements of the system. The final result of the informational design phase, Table 21, flows out the hierarchical categorization of the requirements of the system through a Quality Function Deployment (QFD) Matrix. These specifications and requirements of the clients generated in this chapter will be of great relevance for the next phase of the system design, the conceptual design. The list of specifications of the system design serves as input for the conceptual design phase. The next chapter shall define the study of specific product modules of the conceptual design for the analysis of the functional models and a study of the functional analysis process will also be carried out in the conceptual design.

CHAPTER 4. CONCEPTUAL DESIGN OF MODULAR SYSTEM

The conceptual design is the phase of the design process that generates a concept of a system from a detected and clear need of the customers to meet their need in the best possible way. The conceptual design phase has as objectives: generation of ideas, proposing a concept of the architecture of the product/system; and selecting a concept that best suits the requirements of the clients. The conceptual phase also includes two major steps: functional analysis and synthesis of solutions. In this second phase of the design process, the system is being modeled primarily in terms of the function that the system is capable of performing as a whole, then in terms of reduced complexity of the functional structures representing the full function of the product (FERREIRA, 1997). In this chapter will be of great importance the functional structures built from standardized basic operations, they allow better manipulation in search of functional alternatives to the product and facilitate the search process by solution principles.

4.1 SCOPE OF THE CONCEPTUAL DESIGN PHASE

A definition of the conceptual design states that this is the phase of the project that takes the problem statement from and generates general solutions in the form of alternatives. It is the phase that requires the highest demands of the designer and where there are greater possibilities for great improvements (FERREIRA, 1997). A conceptual design is part of the design process in which the key problems are identified through abstraction to establish the structure functions in search for appropriate solution principles and combinations. In this phase the basic path of the solution is exposed by developing a
design solution (PHAL and BEITZ, 1995) apud (FERREIRA, 1997).

The objective of this phase is to provide a roadmap to help designers to submit design concepts for the development of a modular system or the modularization of a group of existing systems, which is the case in this SMGP design. The design specifications established in the previous phase are very important, because they should represent what the design should have or process in order to meet various demands. To approach this design solution in the form of alternatives, the global function performance is broken down into its basic functions, which form the basis for other decisions taken in this phase of the project. For this reason the roadmap is established in this phase to be followed in the modular system design. The roadmap adopted for the conceptual design of the product is described in Table 22, which details the tasks followed for each stage of the conceptual design phase. In this chapter shall further be worked out the different tasks as presented in the roadmap of Table 22, whereas each stage with their individual task will be further detailed for the SMGP design towards the output of this phase.

Table 22: Roadmap for SMGP conceptual design phase.

Phase 2	**Conceptual design of the modular (SMGP) system**		Input	Output	Documents and support tools
Stage 2.1	Arrangement of the functional synthesis of the system		Specifications list of the SMGP system	Functional structure of the SMGP system	Technical Information; Task/Problem clarification
	Task 2.1.1	Identify the global function of the SMGP			
	Task 2.1.2	Establish the partial functions of the SMGP			
	Task 2.1.3	Establish structured elementary functions			
Stage 2.2	Search for technical solution principles		Functional structure of the SMGP system	Principle solutions of the SMGP system	Morphological Matrix
	Task 2.2.1	Choose the functional structure that best meets the system design problem			
	Task 2.2.2	Create solution principles for the identified elementary functions			
Stage 2.3	Generate SMGP design concept		Principle solutions of the SMGP system	Constructive modules of the modular system	Heuristic Method
	Task 2.3.1	Identify the modules for the design concept			
	Task 2.3.2	Establish modular SMGP design concept			

Source: Elaborated by the Author.

4.2 STAGE 2.1 ARRANGEMENT OF THE FUNCTIONAL SYNTHESIS OF THE SYSTEM

In this stage the main task is to establish the functional synthesis or structure for the operations of the system to be designed and develop elementary functions to further establish the group of functions for the modules of the system. The functional decomposition or functional model is the performance to establish all functions of a system in sub-functions to be easier implied and recognized. These sub-functions are related to energy flow, material or signal, which interact with the system to form the functional structure (FLEIG, 2008).

4.2.1 TASK 2.1.1 IDENTIFICATION OF THE GLOBAL FUNCTION OF THE SYSTEM

In the functional modeling, the first task in the search for a structure of functions for the system to be designed is to create a global function model of this system. The global function is the total function of the system which must express the main function (or main functions) of a system trough the relationship between their inputs and outputs. This task is the correlation of the consumer needs, defined in Phase 1, by an overall function of the system. It should represent a summary of what to expect from the system functionality. The graphical representation of the total function is normally performed by means of a block subject to flows of energy, material and signal (or information), which are system inputs and outputs, as presented in Figure 22, (Hölttä-Otto, 2005)(FLEIG, 2008).

Figure 22. Graphical representation of the global function. Source: Reproduced by the author from Rozenfeld et al., (2006).

In this SMGP (Smart Micro Grid Platform) system, we will not have the input or output flow of material. These functional structures where primarily developed for mechatronic products or systems, which usually have material inputs like in the case of an automatic washing machine where the material inputs are clean water, soap, clothes. In the case of a diesel generator, there will be an input of material in the form of diesel fuel, but in the main or total function of this SMGP system the element of material input and output will be left out to expel any confusions. The total function of the SMGP system to be designed as living or real-time laboratory is defined as "Dispatch and Control of the microgrid".

This expression is also a simplified representation of the system design context, the system input and output quantities and the system interfaces as presented in Figure 23.

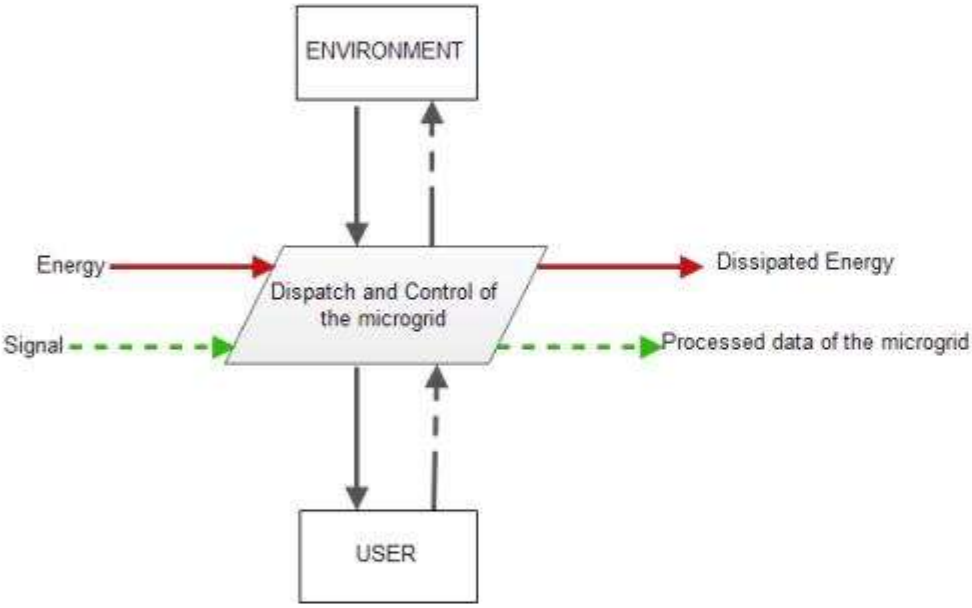


Figure 23: The global function of the SMG system.

In this global function model of the SMGP, the environment is defined as the laboratory itself and the user is the operator of the SMGP system, which can be a student, professor, researcher or one of the identified stakeholders. The energy here described in the global function (Figure 23) is defined as electrical energy at the input and at the output as dissipated energy which is the electrical energy consumed by the SMGP system and the energy dissipated by heat throughout the system. The signal at the input of the system is the collected data of the overall SMGP system and the output is the processed data that is digitalized and can be presented to the operator on a computer screen via certain implemented software in the SMGP system.

4.2.2 TASK 2.1.2 ESTABLISHMENT OF THE PARTIAL FUNCTIONS

The first step of deployment of the global function has the establishment of the partial functions as result. The partial functions present a simpler context of the global function of the system. These partial functions present the main functions of the SMGP system, which will be further deployed into elementary or basic functions in the next task. To define this presented partial function structure, must be considered that this system consist of many devices which shall finally be categorized in following in modules function structures. These partial functions present a summarized process of the SMGP system, which are functionally presented and coupled like shown in Figure 24, but in the actual system the subsystems each have their functions and these subsystems are all connected together via network cables to receive or deliver electrical energy within the SMGP system and through interfaces to receive signals and deliver data to the SMGP management/monitor and control center, which will be operated by an operator in an laboratory environment.

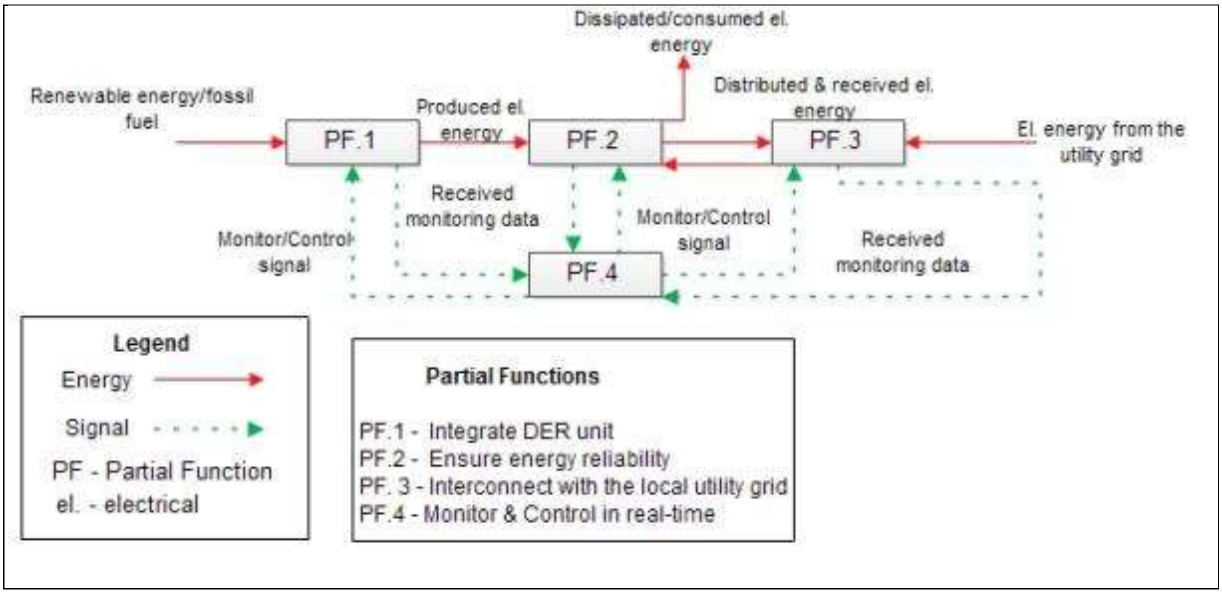


Figure 24: Partial Functions of the SMG system.

4.2.3 TASK 2.1.3 ESTABLISHMENT OF STRUCTURED ELEMENTARY FUNCTIONS

After the global function is established, the next levels of functions can be elaborated, called the models of the partial functional structure to get to the stage to establish solving principles. The global function is thereby decomposed in partial functions which will be further decomposed in elementary functions of the SMGP system. The decomposition of a structure of functions, in addition to facilitate the search for solutions, provides a better understanding of the design context (problem). For this task are established three alternative elementary function structures and presented in the next. These are presented in the Figures 25, 26 and 27. These three alternatives presented in the figures present the signals and energy flows in the systems.

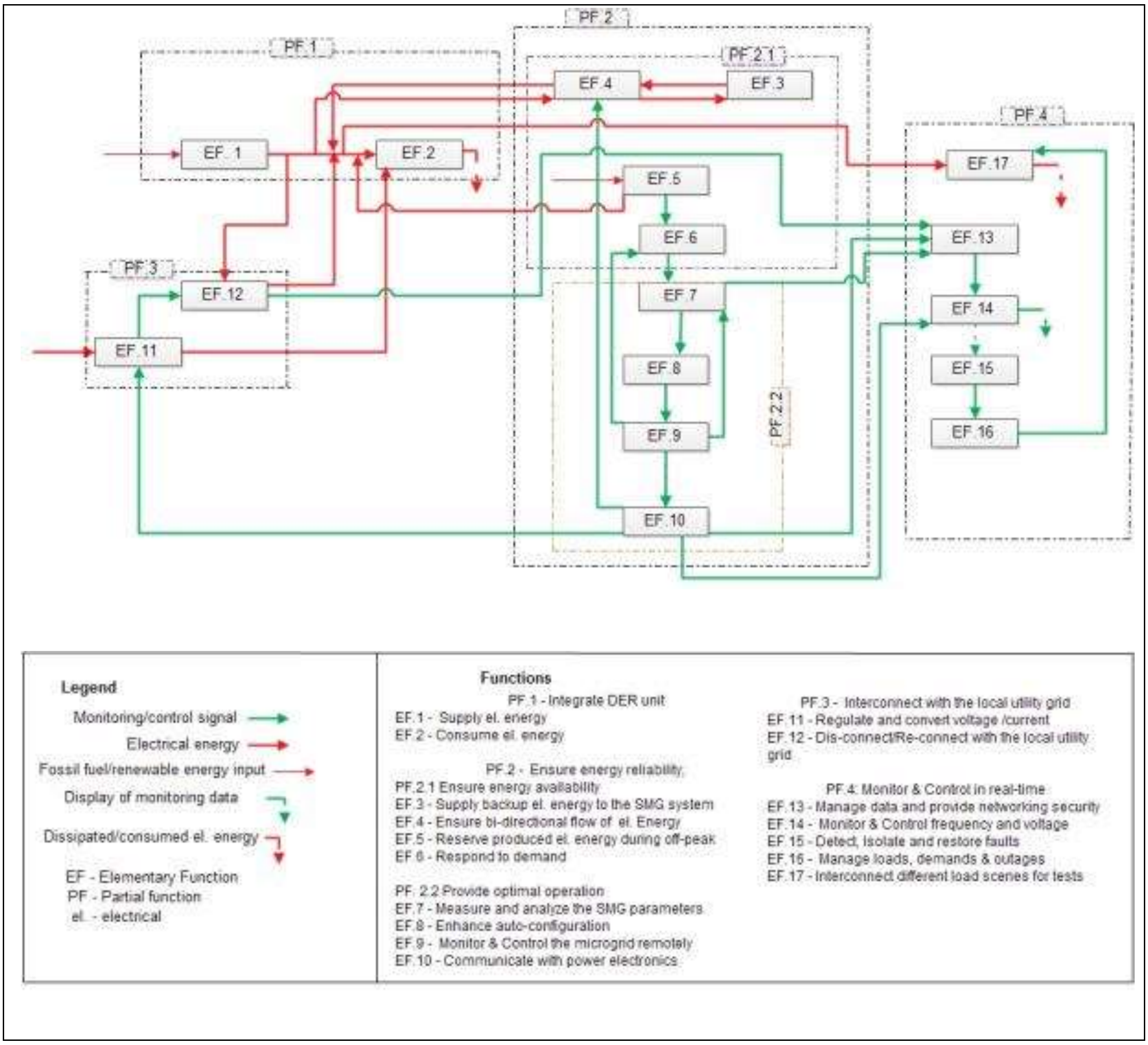
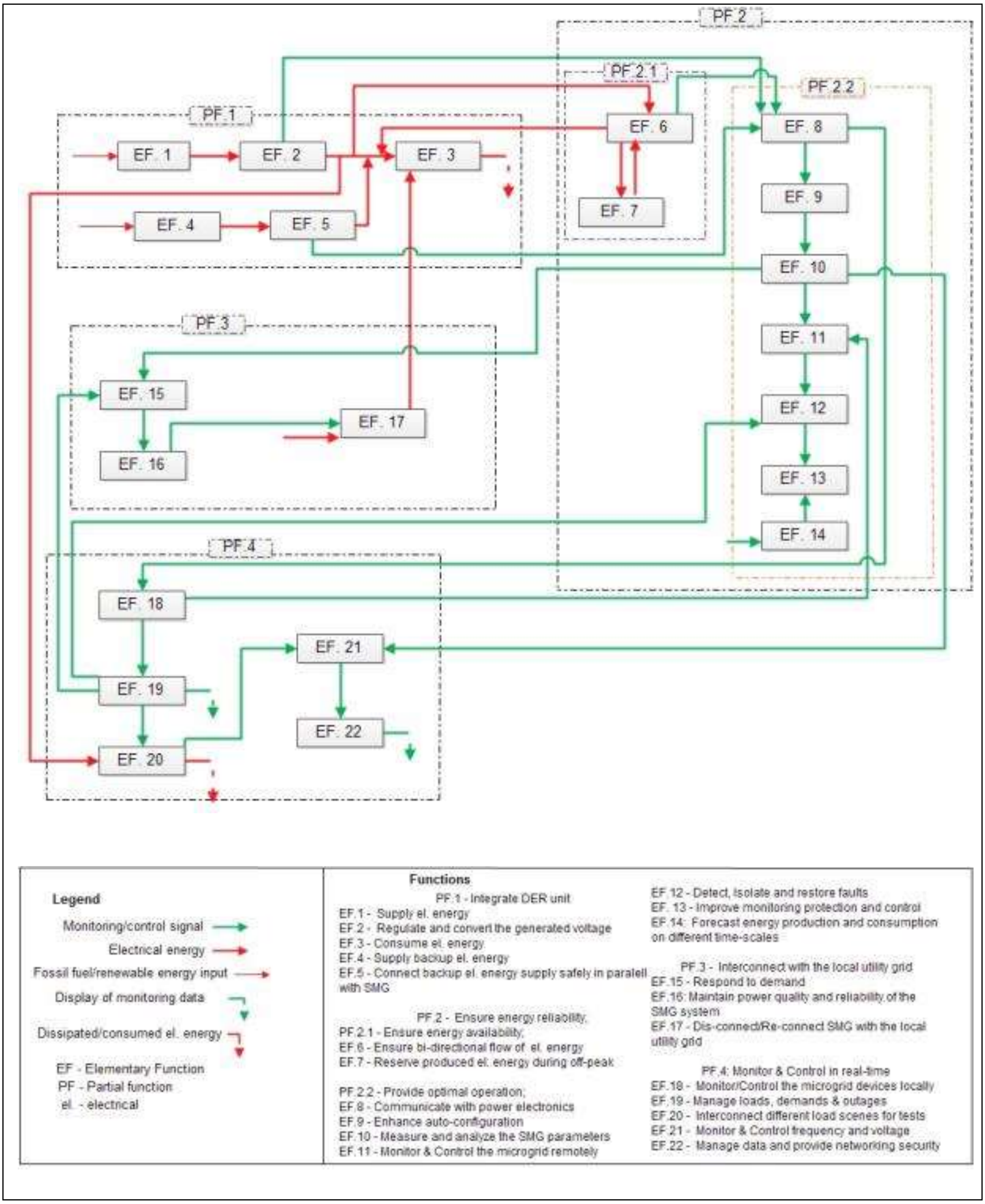


Figure 25: Elementary functions of SMGP system 1.



Functions

PF.1 - Integrate DER unit

EF.1 - Supply el. energy
EF.2 - Regulate and convert the generated voltage
EF.3 - Consume el. energy
EF.4 - Supply backup el. energy
EF.5 - Connect backup el. energy supply safely in paralell with SMG

PF.2 - Ensure energy reliability;

PF.2.1 - Ensure energy availability;
EF.6 - Ensure bi-directional flow of el. energy
EF.7 - Reserve produced el. energy during off-peak

PF.2.2 - Provide optimal operation;
EF.8 - Communicate with power electronics
EF.9 - Enhance auto-configuration
EF.10 - Measure and analyze the SMG parameters
EF.11 - Monitor & Control the microgrid remotely
EF.12 - Detect, isolate and restore faults
EF. 13 - Improve monitoring protection and control
EF.14: Forecast energy production and consumption on different time-scales

PF.3 - Interconnect with the local utility grid

EF.15 - Respond to demand
EF.16: Maintain power quality and reliability of the SMG system
EF.17 - Dis-connect/Re-connect SMG with the local utility grid

PF.4: Monitor & Control in real-time

EF.18 - Monitor/Control the microgrid devices locally
EF.19 - Manage loads, demands & outages
EF.20 - Interconnect different load scenes for tests
EF.21 - Monitor & Control frequency and voltage
EF.22 - Manage data and provide networking security

Figure 26: Elementary functions of SMGP system 2.

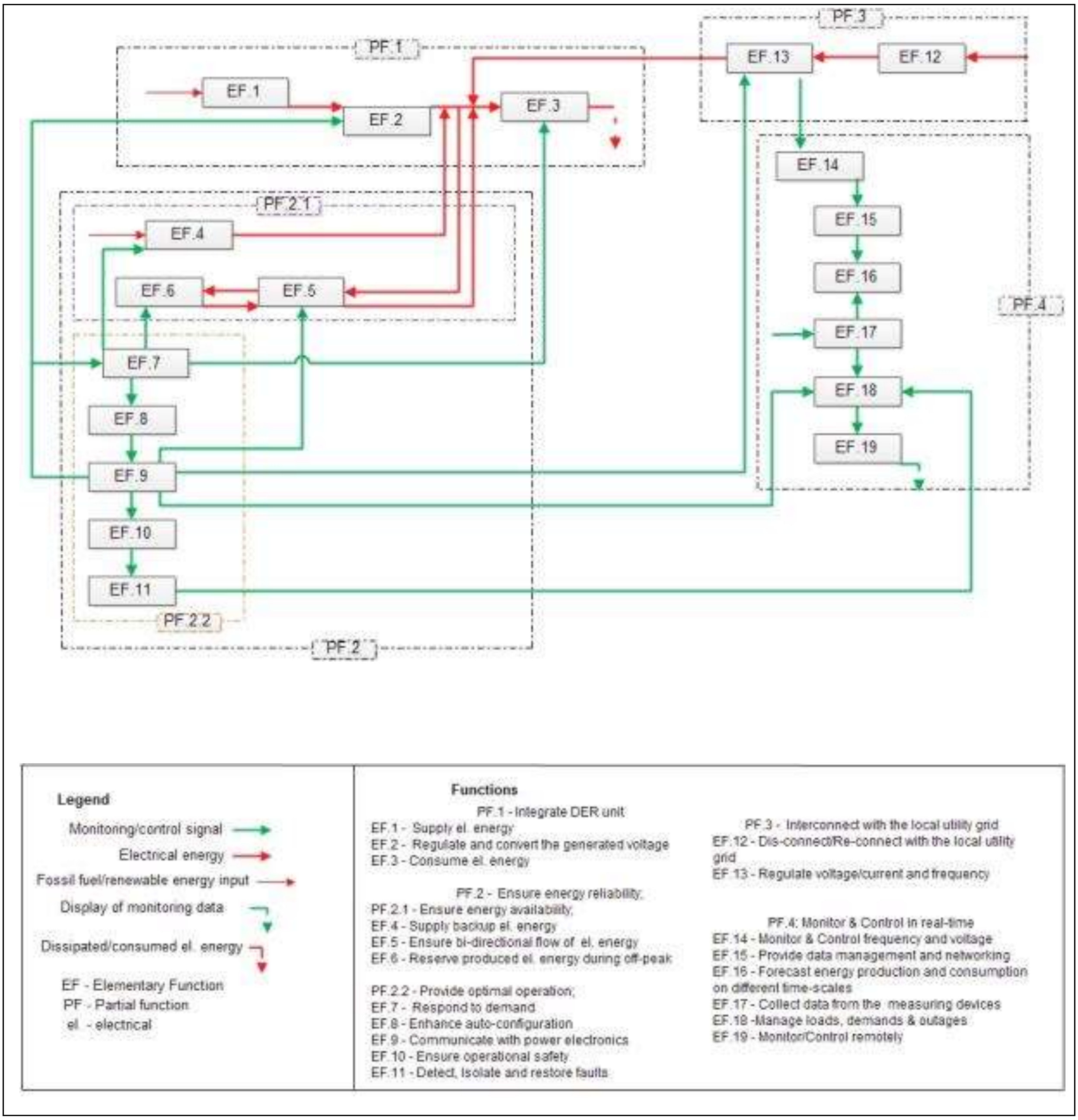


Figure 27: Elementary functions of SMGP system 3.

4.3 STAGE 2.2 SEARCH FOR SOLUTION PRINCIPLES

This stage is to search for the solution principles. After determination of the system´s global function, partial functions and elementary functions which lead to a functional structure of the SMG system, the next stage is to find solution principles for the elementary functions of the system, which were determined in the previous stage. These solution principles can be combined to one or more basic (principal) solution for the overall (global) function, (SCALICE, 2003).

According to Rozenfeld et al. (2006), each functional structure describes an alternative functional shaping of the system. For each of the multiple (basic) functions, are generated solutions principles able to perform them. The combination of these principles will result in the product solution alternative. For each alternative is defined an architecture that contains the product structure in terms of its components and connections. Such architectures are best developed giving rise to conceptions. These will undergo a selection process to point one that best suits the product-target specifications.

To search for the solution principles in this stage, three tasks will be followed to get to the final result, which are the solution principles.

4.3.1 TASK 2.2.1 CHOOSE THE BEST FUNCTIONAL STRUCTURE TO MEET SYSTEM DESIGN PROBLEM

For choosing the functional structure of the alternative that best meets the design problem or that best suits the customer needs, the matrix of the selection of the alternative functional structure is used, according to Maribondo (2000). In this matrix are used the grades five, three, one and zero, whereas the grade 5 represents an excellent performance, grade 3 represents a satisfactory performance, grade 1 represents a poor performance and grade 0 is used when the concept is the same or equivalent by reference.

The matrix of selection of the alternative functional structure alternative is presented in Table 23. In this table the column named value, consists the values presented to each of the requirements of the clients in the matrix of the Quality Function Deployment (QFD), by the client.

The main difference between the functional structures is presented by the differentiation of the elementary functions derived from the partial functions. For example in alternative 1, the DER (Distributed energy Resource) unit is composed of only the main energy supply that has a renewable energy input, while in the other alternatives the back-up supply is also integrated in the DER unit. These mentioned functions will have to do with the connection and placement of the modules in the actual design. The overall function of these alternatives remains the same, only their functional deployment from the partial functions is different and thereby is also taken into consideration the interfaces between the to be constructed modules, for example you can have a system with more breaker switches to have a better control and safety over your SMG system, but will consider more operational steps for one action. The alternative solutions for functional structure will be further taken into consideration in the following stages.

Table 23: Matrix of selection of the alternative functional structure.

Requirements of the Client		**Functional Structure alternatives of the SMG system**		
	Value	**Alternative 1**	**Alternative 2**	**Alternative 3**
To be monitoring all system parameters	5	5	5	5
To be utilising an overall power system control	5	5	5	5
To consist demand-side- and outage- management	5	0	0	0
To be a safe and secure power system architecture for experiments	5	3	5	3
To have a two-way flow of electricity and information	4	0	0	0
To prevent black-outs	4	0	0	0
To be a self-healing microgrid	4	0	0	0
To integrate measuring systems for different parameters	3	5	5	3
To Implement control strategies for generating units & power transfer to the loads	3	1	5	5
To support low carbon emission power generation	3	0	0	0
To enhance a plug-and-play infrastructure	3	0	0	0
To predict DER system behavior	2	1	5	5
To enable remote operation	2	5	5	1
To operate in different scenarios	1	0	0	0
To be a low maintenance power system	1	0	0	0
Total sum		25	35	27

Based on the requirements of the clients is resulted from the matrix of selection of the alternative functional structure that alternative 2, presented in Figure 26, has the highest score of 35. This will be the functional structure choice for this SMGP system design.

4.3.2 TASK 2.2.2 DEVELOP SOLUTION PRINCIPLES FOR THE IDENTIFIED ELEMENTARY FUNCTIONS

Once the functional structure of the SMG system is defined, the search for alternative solution principles that meet each of the functions contained in the structure can be initiated.

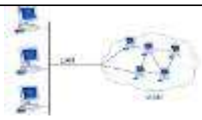
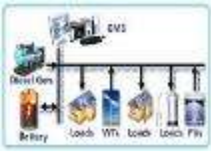
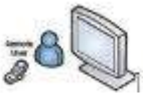
According to Back et al. (2008), the search for principles can be a survey of technical literature, solutions adopted in similar existing technical systems or using catalogs or solution principles database.

This search points principles in specific directions to assist the translation of the functional structure of the system in a more technical language and may indicate the physical composition of various components used in the future for the construction of a prototype. For this task is used as tool the morphological matrix method which is used to generate solution principles, where search is done through the elementary functions of the system that present the complex problem in simpler parts and make it possible to use this tool to search for alternatives through catalogs, experiences, research, creativity and brainstorming to obtain the best possible solution combination. The morphological analysis is a technique that divides the problem into sub problems, seeking to analyze them and understand their relations in a systematic and structured way. From this technique the morphological matrix developed which is a tool to study consistently large numbers of possible combinations of the elements or components of a product or system, (Zavadil et al., 2014). For the development of generated alternative concepts is presented the matrix for selection of alternative solution principles for the functional structure in Table 24.

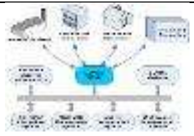
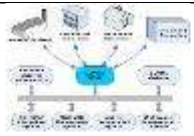
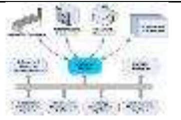
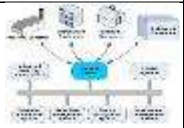
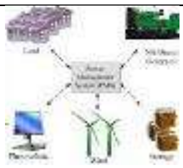
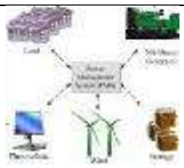
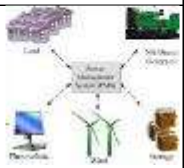
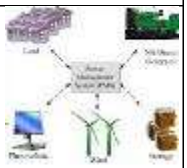
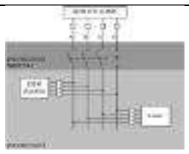
Table 24: Matrix for selection of alternative solution principles for the functional structure.

Functions	Solution Principles			
	Option 1	Option 2	Option 3	Option 4
EF.1 Supply renewable energy	 Solar (Photovoltaic) Energy	 Wind Energy	 Micro-hydro energy	 Biomass energy
EF.2 Regulate and convert the generated voltage	 MPPT Charge controller	 DC-AC Grid-tied Inverter	 DC-DC boost converter	 DC-DC buck converter
EF.3 Consume el. Energ	 Public Services: Hospital	 Industry	 Residencial: Households	 Electric Vehicles
EF.4 Supply backup el. Energy	 Diesel Generator	 Diesel Generator	 Diesel engine electric gen.	 Biogas generator
EF.5 Connect backup el. energy supply safely in paralell with SMG	 Synchronization control	 Synchronization control	 Microprocessor based synchronizer	 Auto-synchronization controller
EF.6 Ensure bi-directional flow of el. energy	 Grid-tied inverter	 Single phase grid-tied inverter	 Three-phase grid-tied inverter	 Hybrid grid-tied inverter

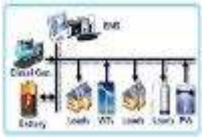
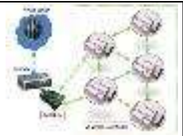
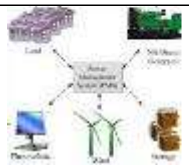
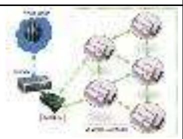
Continuation of Table 24: Matrix for alternative solution principles.

EF.7 Reserve produced el. energy during off-peak	 Lead-acid (Pb-acid) Batteries	 Nickel-Cadmium (NiCd) Batteries	 AGM Deep-cycle Batteries	 Lithium-ion (Li-ion)Batteries
EF.8 Communicate with power electronics	 Wifi communication	 LAN/WAN Internet	 ZigBee Communication	 WiMAX Communication
EF.9 Enhance auto-configuration	 Power electronics: 3p grid-tied Inverter	 Charge controller	 DC-AC (Wind & Solar) Grid-tied solar inverter	 Charge controller
EF.10 Measure and analyze the SMG parameters	 Smart meter	 Smart meter	 Smart meter	 Smart meter
EF.11 Monitor & Control remotely	 Microgrid central controller	 Energy Management System	 SCADA	 DAQ PCI/PCI Express
EF.12 Detect, Isolate and restore faults	 FLIR System	 FLIR System	 FLIR System	 FLIR System
EF.13 Improve monitoring protection and control	 PMU:Phasor Measurement unit	 PMU	 PMU	 PMU

Continuation of Table 24: Matrix for alternative solution principles.

EF.14 Forecast energy production and consumption on different time-scales	 Weather Station	 Weather Station	 Weather Station	 Weather Station
EF.15 Respond to demand	 DRMS:Demand Response Management System	 DRMS	 DRMS	 DRMS
EF.16 Maintain power quality and reliability of the SMG system	 Power Management System: PMS	 Power Management System: PMS	 Power Management System: PMS	 Power Management System: PMS
EF.17 Dis-connect/Re-connect with the local utility grid	 Static Transfer switch	 Automatic Transfer Switch	 Static Transfer switch	 Static Transfer switch
EF.18 Monitor/Control the microgrid devices locally	 Microgrid Central Controller (SCADA)	 Microgrid Central Controller (DAQ)	 Microgrid Central Controller (SCADA)	 Microgrid Central Controller (DAQ)

Continuation of Table 24: Matrix for alternative solution principles.

EF.19 Manage loads, demands & outages	 Energy Management system, OMS & DRMS	 Microgrid Central Controller (SCADA)	 Microgrid Central Controller	 Energy Management system, OMS & DRMS
EF.20 Interconnect different load scenes for tests	 Real Time Digital Simulator (RTDS)	 Real Time Digital Simulator (RTDS)	 System Design Software	 System Design Software
EF.21 Monitor and control frequency and voltage	 Voltage/Var controller & Frequency controller	 Voltage/Var controller & Frequency controller	 Voltage/Var controller & Frequency controller	 Voltage/Var controller & Frequency controller
EF.22 Provide data management and networking security	 Power Management System: PMS	 Microgrid Central Controller (SCADA	 Migrogrid Central controller	 Three-phase grid tied inverter

4.4 STAGE 2.3 GENERATE CONCEPTS OF THE SMG SYSTEM

Modularity is described as a property of a complex system and is divided in subsystems that will form the actual modules. These modules must interact with each other to guarantee the appropriate functionality of the complete system, (BALDWIN & CLARK, 2004). To generate concepts the first task is to establish the modules of the modular system.

4.4.1 TASK 2.3.1 IDENTIFY THE MODULES FOR THE DESIGN CONCEPTS

To identify the modules of the SMG system in this section the heuristic method shall be used. The heuristic method allows the identification of the modules trough the functional designing of the system and is widely applied in electro-mechanics and other product architectures (DAHMUS et. al., 2001), (STONE et al., 2004). This method is described by Stone et al. (2000) as a new approach to identify modules for product architecture which provides a systematic procedure for grouping elements and specifying collaborations. After defining the modules, the road is clear to develop different layouts and component options. The heuristic method is based on systematizing a functional model of a product into a certain structure to identify the modules. The foundation of this method is assigned by function dependencies.

Function dependencies are defined as the style of flows in the functional structure through the subfunctions of products or systems, whereas the structure can be parallel, sequential or coupled. The flow indicates the energy, material or signal that travels through the sub-functions of a device (STONE et al., 2000).

4.4.1.1 HEURISTIC METHODS

Stone et al. (2000) developed a set of three heuristics to identify potential modules. He presents this method with the following definitions:

> “A method of examination in which the designer uses a set of steps, empirical in nature, yet proven scientifically valid, to identify modules in a design problem”.

Whereas “proven scientifically valid” assigns to:

> “A hypothesis, formulated after systematic, objective data collection, that has successfully passed its empirical”.

The method needs a functional structure of the system, where sub-functions are then gathered based on flow (energy, material, or signal) conjunctions. The three heuristics are illustrated and described next:

1. Dominant flow heuristic: This method determines the flow through the sub-functions of a functional structure up to the point where it leaves the system or converts into another flow. With this act the sub-functions can be collected that will define a module based on the flow which establishes the interface of the module (Figure 28).

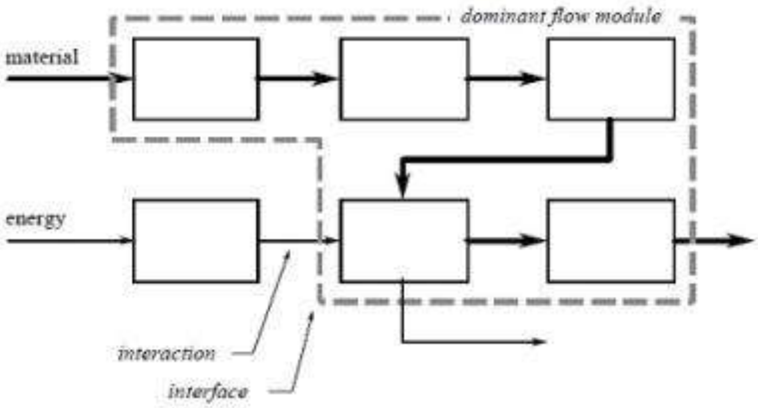


Figure 28: Dominant flow heuristic applied to a generic function structure.

2. Branching flow heuristic: This method depends on the recognition of flows that departs into function strings which are parallel. If these are recognized the modules will present each branch of the flow. At the last sub-function the module (each branch) needs to interface with the product ahead of the branching of the flow. The connection between the product and the module are established by flows which pass over their interface (Figure 29).

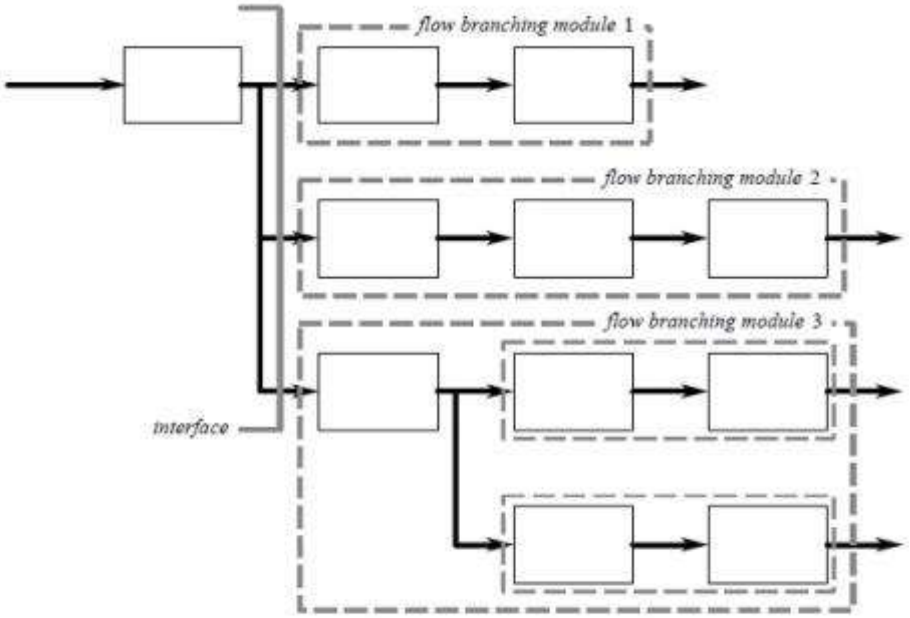


Figure 29: Flow branching heuristic applied to a generic function structure.

1. Conversion-Transmission flow heuristic: In this method (Figure 30) the flow of conversion sub-functions is identified. The flow here is presented by energy or material that converts into another type of material or energy. The conversion sub-functions are frequently already components are modules themselves. These sub-functions can also be in a string, which constitutes one module.

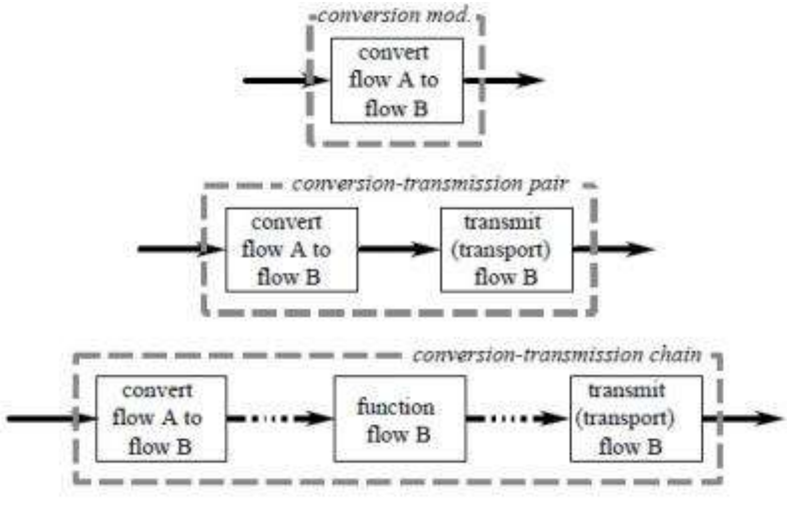


Figure 30: Conversion–transmission applied to a generic set of sub-functions.

4.4.1.2 HEURISTIC METHOD APPROACH TO IDENTIFY THE SMG MODULES

The selected functional structure is presented previously in Figure 26. For identifying the modules the three heuristic methods shall be utilized in this task, through analysis to see if they can identify any modules in this functional structure of SMG. The next step will be the selection of one of these modular identification types to generate concepts for this SMGP system. The first heuristic method applied is the dominant flow, which is presented in Figure 31 and resulted in four modules for the SMGP system.

1. The Dominant flow heuristic:

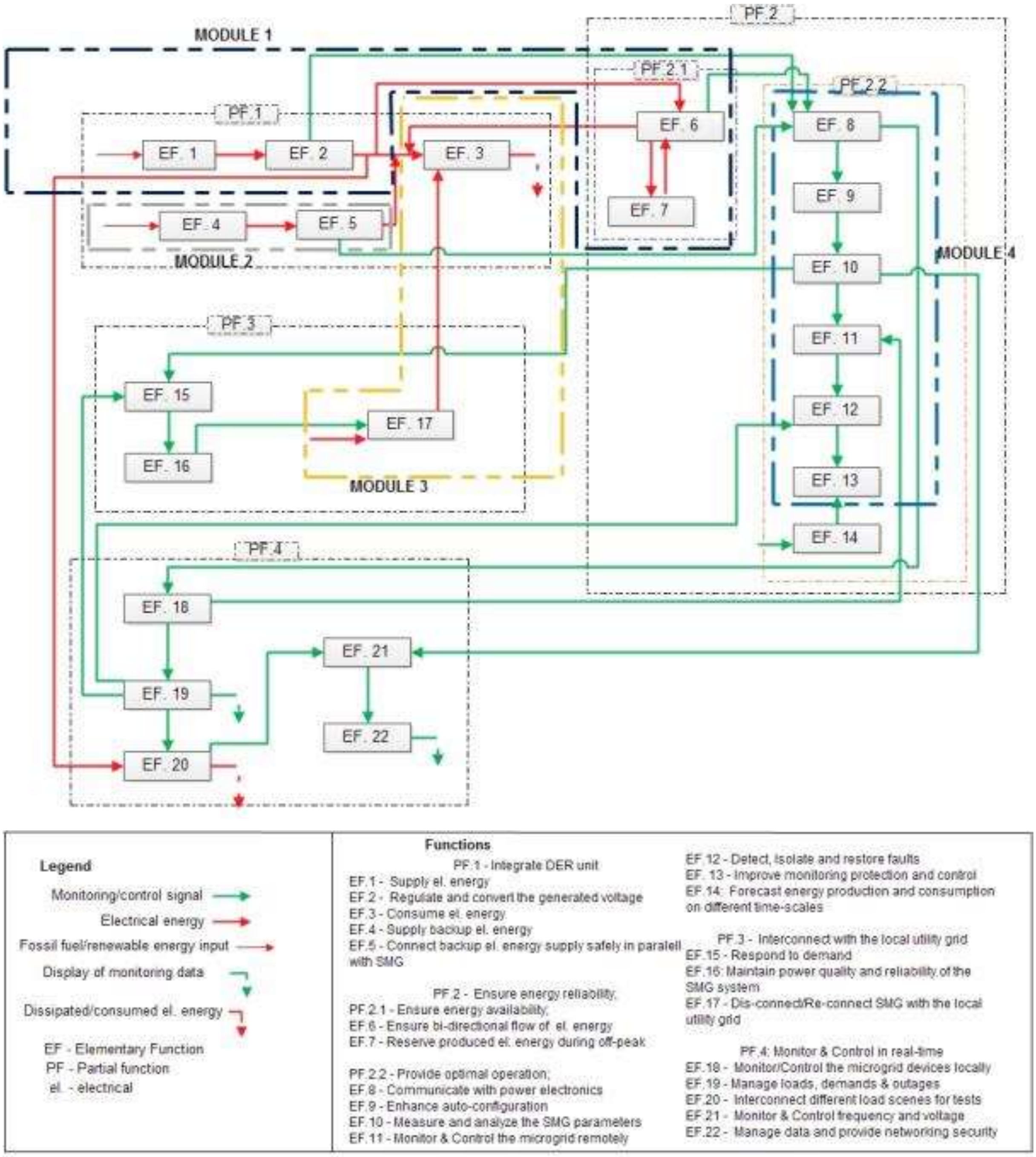


Figure 31: Dominant flow heuristic identified modules of the SMG system.

The four modules identified in Figure 31, by the Dominant heuristic flow method are:

Module 1 = EF1+ EF2 + EF6 + EF7

Module 2 = EF4 + EF5

Module 3 = EF3 + EF17

Module 4 = EF8 + EF9 +EF10 + EF11 + EF12+ EF13

2. The branching flow heuristic:

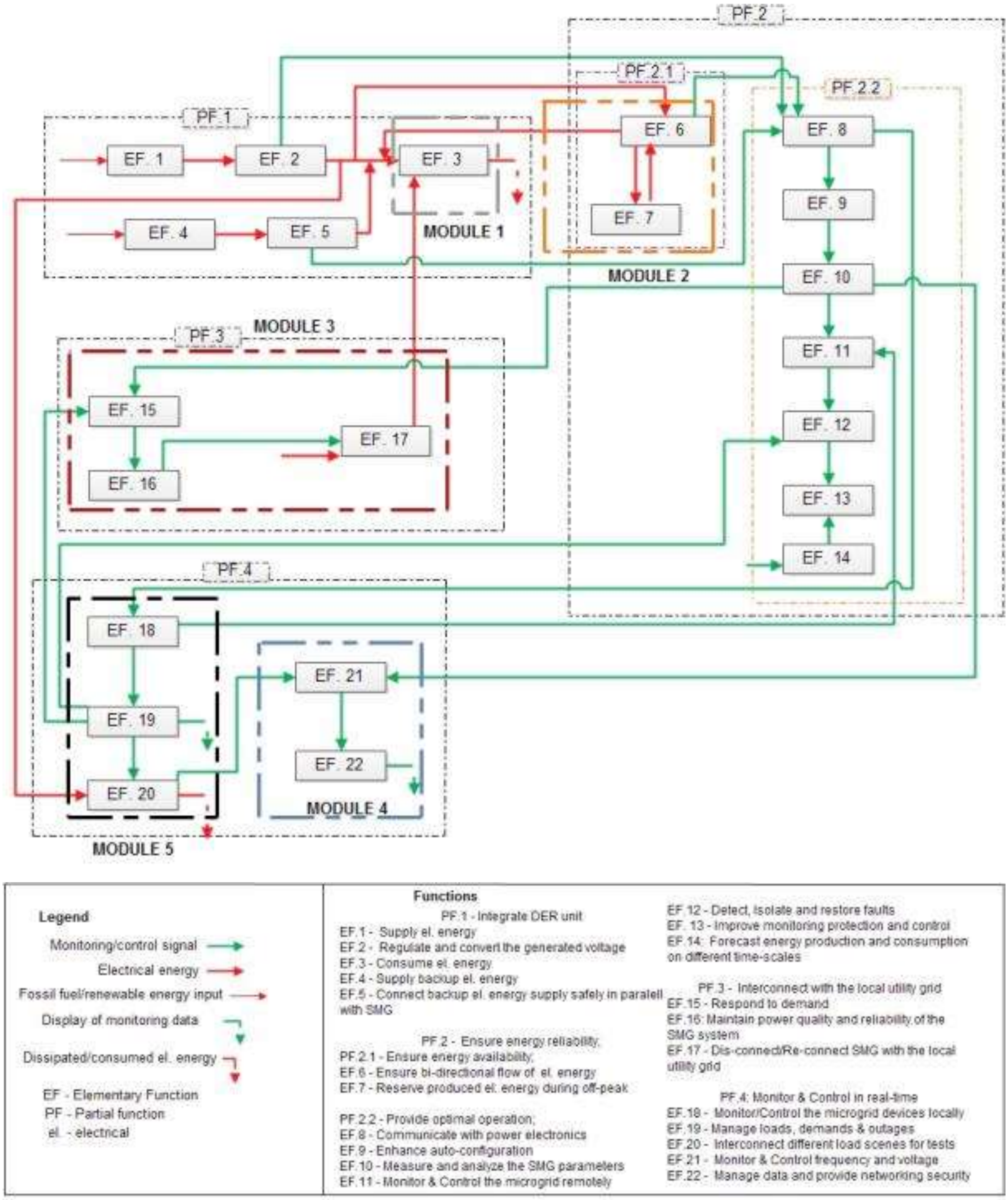


Figure 32. The branching flow heuristc for module identification in the SMG system

The five modules identified in Figure 32, by the branching heuristic flow method are:

Module 1 = EF3

Module 2 = EF6 + EF7

Module 3 = EF15 + EF16 + EF17

Module 4 = EF21 + EF22

Module 5 = EF18 + EG19+ EF20

3. Conversion-Transmission flow heuristic:

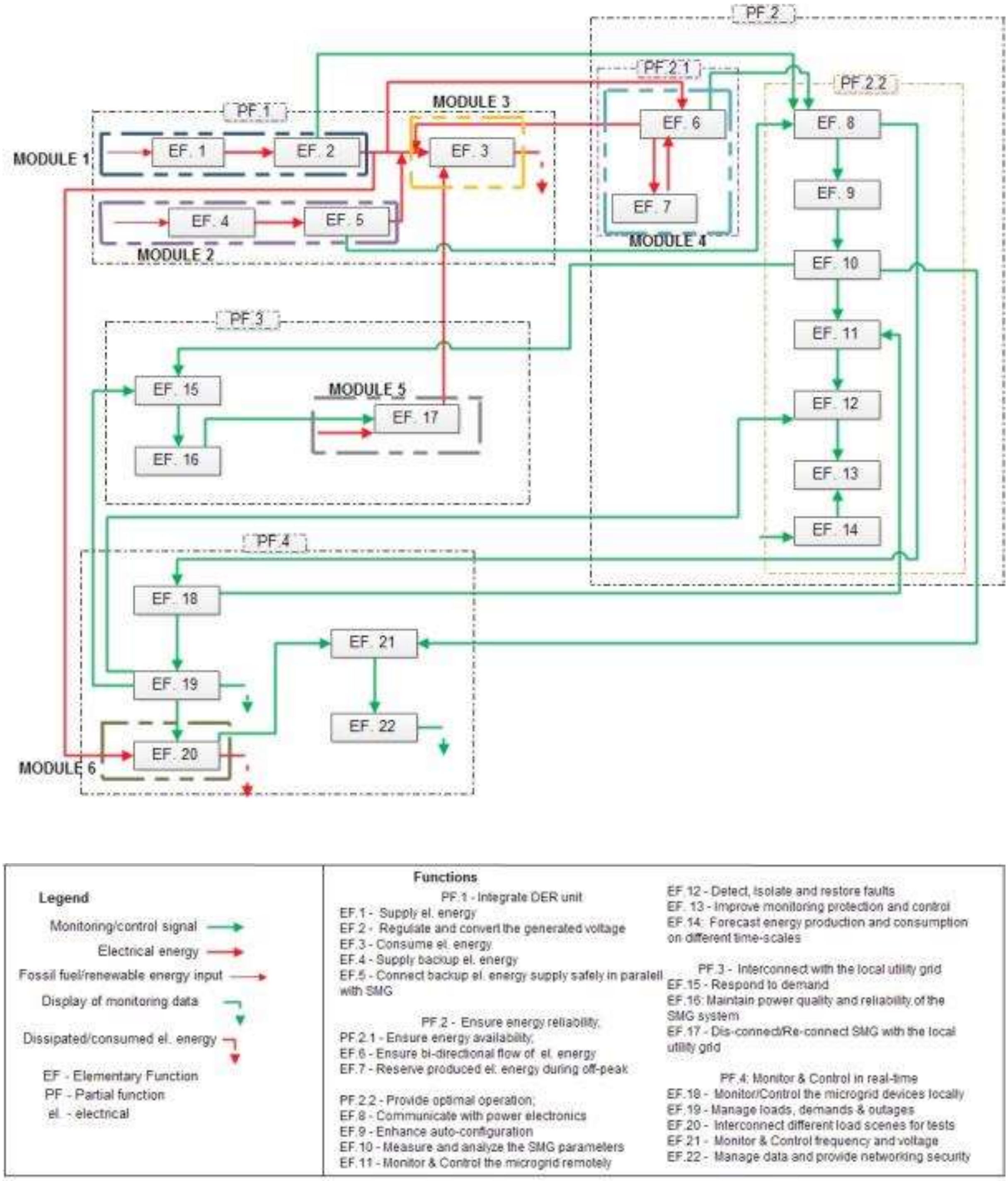


Figure 33: The Conversion-Transmission flow heuristic for the SMGP.

The six modules identified in Figure 33, by the Conversion-Transmission flow heuristic method are:
Module 1 = EF1 + EF2
Module 2 = EF4 + EF5
Module 3 = EF3
Module 4 = EF6 + EF7
Module 5 = EF17
Module 6 = EF20

According to Stone et al. (2004) the heuristic that identifies the least number of modules, should be selected. In this case the dominant flow heuristic contributes to the minimal number of modules, which are four modules.

The identification and definition of modules aim to gather function modules depending on apparent technological performances based on the sub-functions of the SMG system

These identified modules can cover the following aspects or features in the overall SMG system:
Module 1: Power generation and storing
Module 2: Backup energy generator
Module 3: Utility power supply to consumers
Module 4: Energy management, monitoring and control

The next step is to focus on the conceptual design and using these modules of which each will be coupled to certain components as solution to the function that is required by the SMGP system. The functions which were not selected into modules will be surely used in the design of concepts and related through their interface (flow) with the identified modules.

4.4.2 TASK 2.3.2 ESTABLISH MODULAR SMG DESIGN CONCEPT

At this point in the stage of “concepts generation”, the creativity phase can take place to propose module concepts for the SMGP system with the alternative solution principles as presented in Table 24. The concepts should have some approximate aspects and shape. The final objective is to select one of these concepts to work further with to the next stage in design. In this work from this point on the focus for the concepts generation of module 1 will be on photovoltaic solar power generation. The main reason for this is sought from the beginning of this work, where one of the motivators was a proposed research project in the R&D notice of the electric utility of the Federal District (CEB), named "Eletroposto Solar" to install 10kW of electricity micro generation through panels PV connected to the network and to implement an electric vehicle charging station on campus Gama. With this first image in mind the solar energy is chosen as the best alternative for module 1 and also the reason that a weather station was installed for years on the campus Gama, which gathered also solar measuring reports, which were supporting to implement a photovoltaic system on the campus. The last results of solar radiation where of year 2014, with a maximum measured value of 621 W/m^2 average solar radiation (Avg) on a peak hour of 12:24h on that day. The two generated concepts as presented next are presenting the smart microgrid system with its subsystems which were earlier described as subfunctions with their alternative solution principles in Table 24.

Concepts of the SMGP system:

Starting with the concepts of the identified modules included in the SMGP system.
Module 1: Power generation and storing
Module 2: Backup energy generator
Module 3: Utility power supply and loads
Module 4: Energy management, monitoring and control

The following three (3) concepts were generated, with the selected solution principles of Table 24.

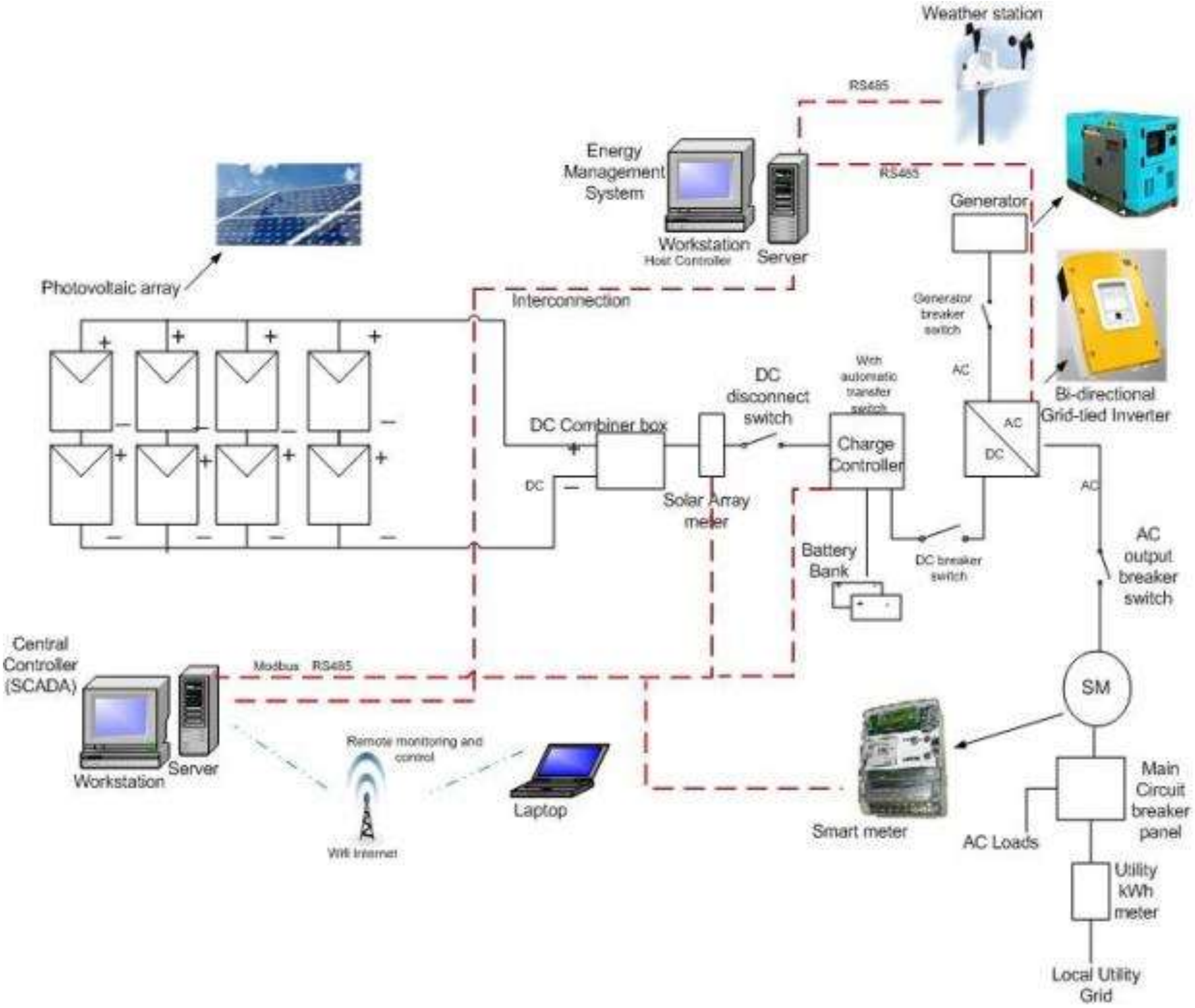


Figure 34: Concept 1 of the SMGP system.

As shown in Figure 34, the PV system, as explained in a former section, generates the solar energy into DC electricity. It is then transported through wires or cables (positive and negative poles) to the charge controller to charge the batteries and connects with the Grid-tied inverter. The Grid-tied inverter regulates and coverts the DC generated voltage of the photovoltaic system into AC voltage that is normally used by consumers. The Modules 1, 2, 3 and 4 are all enclosed in the SMGP system.

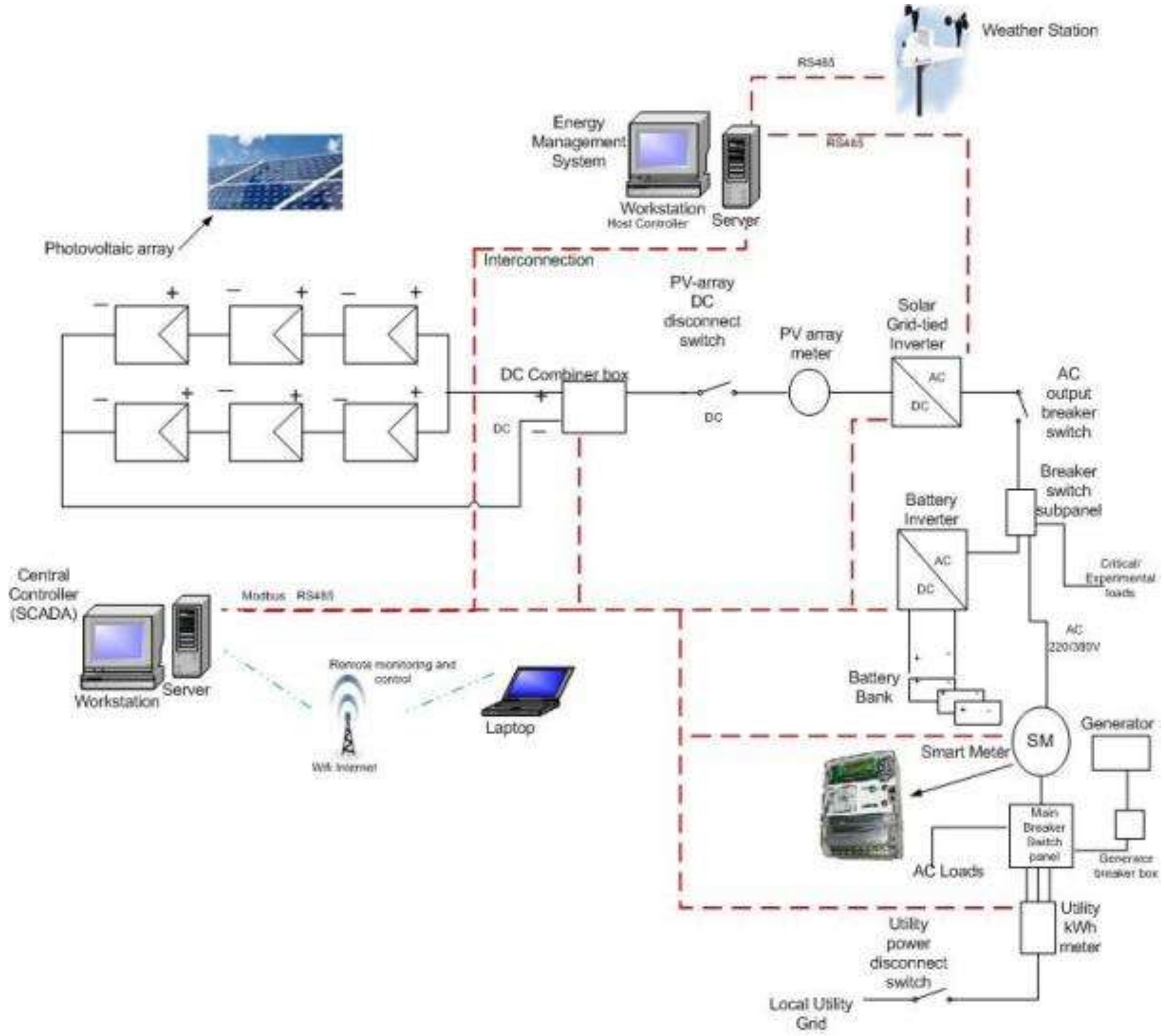


Figure 35: Concept 2 of the SMGP system.

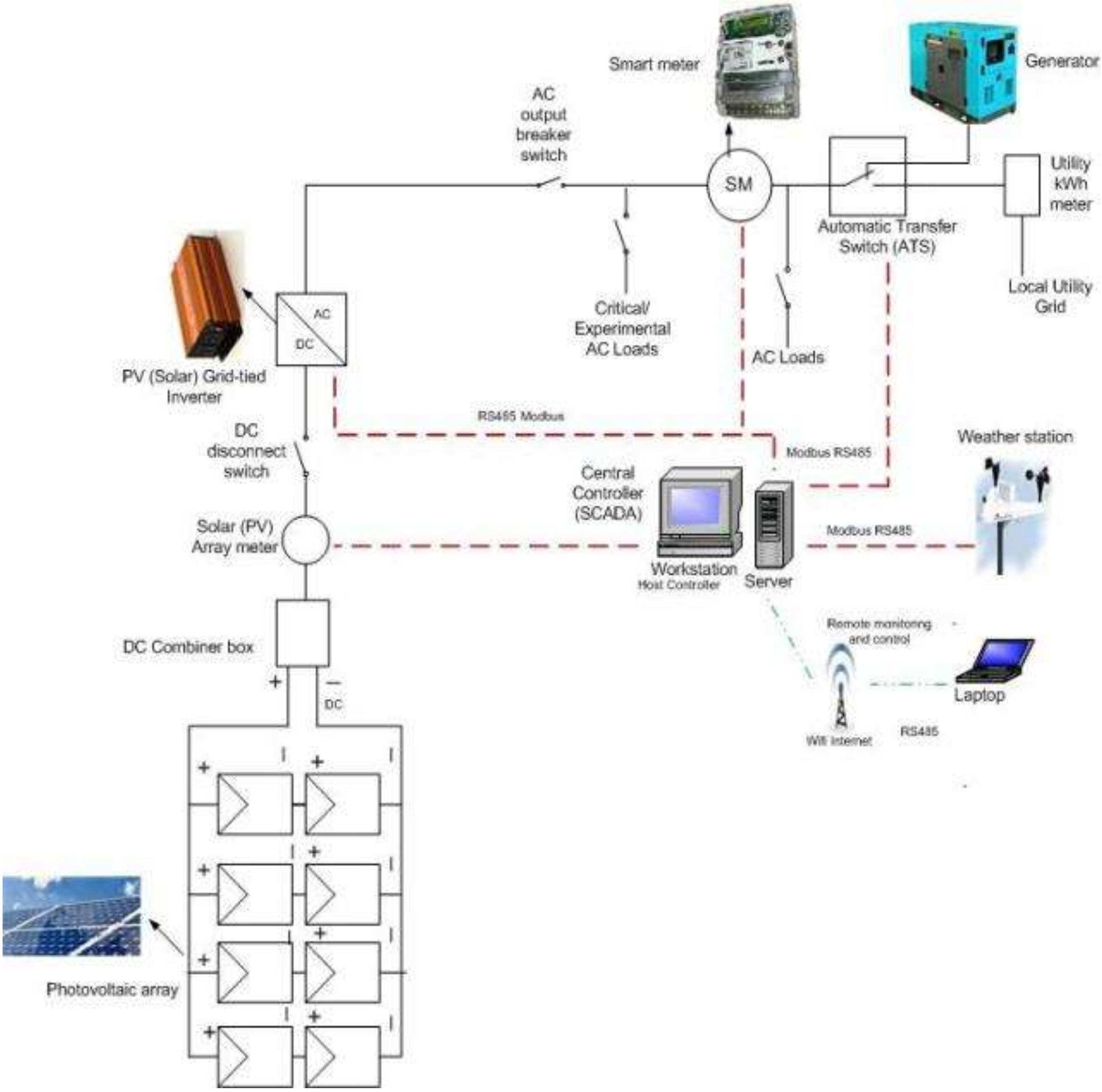


Figure 36: Concept 3 of the SMGP system.

4.4.2.1 DESCRIPTION OF THE GENERATED SMGP CONCEPTS

Concept 1:

In this configuration, presented in Figure 34, the system has the PV array to generate and supply renewable energy to the smart microgrid that is DC energy. The DC combiner box is used for combining all the wires of the PV system array strings in parallel connections. In this box the output wirers from a couple of are multiple number of strings are joined together to provide a single DC source. The combiner box sizing is customized depending upon the number of strings with each input fused separately. It is rated for outdoor use and contains over-current protection devices and the necessary bus bars and terminals for combining the inputs. The DC combiner box consists of DC disconnect switches for safe maintenance which in some types can even be controlled remotely. Next we have a DC breaker switch installed to disconnect the PV system DC input from the charge controller in case needed for emergency or maintenance. The charge controller is used to regulate the voltage and current from the solar arrays to the battery in order to prevent overcharging and also over discharging and is also called a battery charger. There are many technologies have been included into the design of solar charge controller, for instance, the MPPT charge controller included maximum power point tracking algorithm to optimize the energy production of PV cell or module.

The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. The DC energy next passes a DC disconnect switch that is used to disconnect the inverter from the DC input source. The energy is next transmitted through the inverter which converts the DC energy into AC and also regulates this converted energy for further transmission. This inverter is also a hybrid inverter in this case, because it also has the ability to connect the backup energy diesel generator.

The AC energy of 220/380V is than transmitted through wires to the breaker switch panel and distributed to the connected loads. The main breaker switch panel is further connected with the local utility grid via a static breaker switch. Through the system there are meters collected to measure the different microgrid parameters such as voltage, current, active, reactive power, PV array parameters etc. The central controller connects with all the power electronic devices in the SMGP system that provides the tools such as energy management, monitoring, control, data collection and more to validate the real time information and parameters needed for testing and simulation models in the research area of smart microgrid with distributed energy resources, dispatch and control.

Concept 2:

Concept 2, presented in Figure 35, functions not very differently from concept 2, the difference between these two concepts lies in the components chosen and the interconnection structure of the SMG system. In concept 1 of the SMG system, the structure of the system is a little simpler. There is made use of one inverter in the system that has an interconnection with the battery bank and the solar system and the generator to transmit the collected AC energy trough the system. The backup generator that runs on diesel or biodiesel has a typical AC output, which can be transmitted through the inverter direct use, or it can be converted into DC for battery storage. There are generator types that run on other fuels such as, petroleum, gasoline, propane and other fuels, but for this SMG system shall be chosen for a diesel generator, as presented also in the solution options of Table3,an additional reason behind this is also an economical aspect, because the campus Gama already has a 50kVA generator standing and could be easily utilized for the energy backup of the SMG system on times of utility energy failure, but primary to monitor and control different electrical energy sources in one smart microgrid system. In this configuration of concept 2, the PV array system and the energy storage unit have their own inverter and the generator is connected with the SMG system through the main breaker switch panel.

The acquisition of data and the control system (hardware and software) is capable for the supervision and control of the research platform. The software program, responsible for monitoring and supervision is able to handle the data acquisition, and to control the outputs variable of the components.

The active loads can be controlled by the centralized controller which is able to receive the data, and the events from wireless switches and smart meters. The rest of the functionalities regarding the transmission of the electrical energy through the system are similar.

Concept 3:

This concept, presented in Figure 36, of the SMGP system has the same main functionalities as the two former concepts but still is very different in structure. This concept doesn´t have a battery bank, so the energy back-up is done only by the generator and not by the energy storage of batteries. This concept also encloses a connection to the main utility grid or local utility grid, which is here constructed by the automatic transfer switch (ATS). The loads in this concept are all individual connected in the microgrid with breaker switches and the central controller system is the overall monitoring system that manages the microgrid through the solar grid-tied inverter, PV array meter, smart meter, ATS and weather station.

4.4.3 SELECTING AN ALTERNATIVE CONCEPT

For the selection of one concept from the two alternative generated SMGP concepts, the method of Pugh from Back, et al. (2008) can be utilized. Analyzing the strengths (advantages), weaknesses (disadvantages) and equivalence (equality) of the proposed concepts, it is possible to identify and choose the best concept to be adopted for the design of the product.

The three concepts alternatives are registered in Table 25 in the right columns, and on the left of the lines are placed the product/system requirements (specifications) and the weight of each requirement of the system that is extracted from the QFD and presented by the level of importance in percentage.

To indicate which of the concepts have positive points, negative or equivalence with each other, shall be used the following symbols:

(-1) drawbacks/disadvantage over the concept of reference;

(0) equivalent to the concept of reference;

(1) advantage over the concept of reference.

In this method of Pugh presented in Table 25, the concept 1 will be used as the concept of reference.

Table 25: Pugh Matrix for selecting a concept.

Requirements of the product	**Value (Weight)**	**Concept 1**	**Concept 2**	**Concept 3**
Dispatch and control the microgrid	9	0	0	0
High level monitoring of the microgrid in real-time	7	0	0	-1
Optimal operation level by remote monitoring over wire-less connection	7	0	0	0
High performance ability of the system	6	0	0	0
High level of automatic transition to/from and operate islanded	6	0	0	1
High utilization of electric standards & protection relays	6	0	0	0
High performance smart metering devices & bi-directional converters	6	0	1	0
Optimal management of loads, demands and outages of the microgrid	6	0	1	0
High control improvement with power electronics	6	0	1	0
High level performance to detect, isolate and restore faults in the microgrid	5	0	0	0
High energy storage and support capacity	5	0	1	0
High level stabilization of the AC-bus voltage magnitude and frequency	5	0	0	0
Integration of a high level performing weather station	4	0	0	0
Great enhanced interface infrastructure	4	0	0	0
High integration level of DER units in the microgrid	4	0	0	0
Integrate a phasor measurement unit (PMU)	3	0	0	0
High level control for frequency, Volt/VAR in grid-connected & island mode	3	0	0	0
High level integration of static switch and/or source breakers	3	0	0	0
Total Sum (negative)			0	-7
Total sum (positive)			23	6

Source: Elaborated by the Author

From the results of the method of Pugh is concluded that the concept 2 is the best option according to the higher numbers of advantages available and this concept meets the requirements of the system the best. Even with this method of Pugh it is recommended to use common knowledge to decide which concept would be a better choice.

In concept 2, is the best alternative, because you have multiple inverters (power electronics devices) and the identified modules in the system can interface better with each other per individual block, which is not the case in concept 1. In concept 1, the main interface is the connection with the one and only hybrid inverter and if the microgrid has to be enlarged with extra DER systems, the complete system will have get out of operation and re-dimensioning of the complete SMGP would be required. Concept 3 also is a good option but considering all the requirements of the system in reference with concept 1, the concept 2 is the best alternative.

In Figure 37 is presented the location of the SMGP (Smart MicroGrid Platform) to be installed on the campus Gama. Not all the containers of the campus Gama are presented in this figure, since there were lastly are 13 containers set-up on the campus and the number is still growing. The location of the SMGP design will be in one of the containers, where the connection of the electrical energy distribution grid of the campus Gama is connected to the installed containers on the campus Gama in the one container containing a main breaker switch board. This will be further connected with the concept 2 of the SMGP as presented in Figure 35. The photovoltaic (PV) arrays will be installed on the roofs of the containers, including the main container with the installed SMGP that will function as a real-time laboratory environment. There are two lines from CEB to building UED and further to the container of the SMGP, because these are established by the distribution line connections to the SENTRON PAC 3100 multimeters in UED. All the connections to the container of the SMGP, such as the generator and PV arrays etc., will be further monitored and dispatched in the SMGP by the SCADA.Br software and additional data analysis tools and techniques.

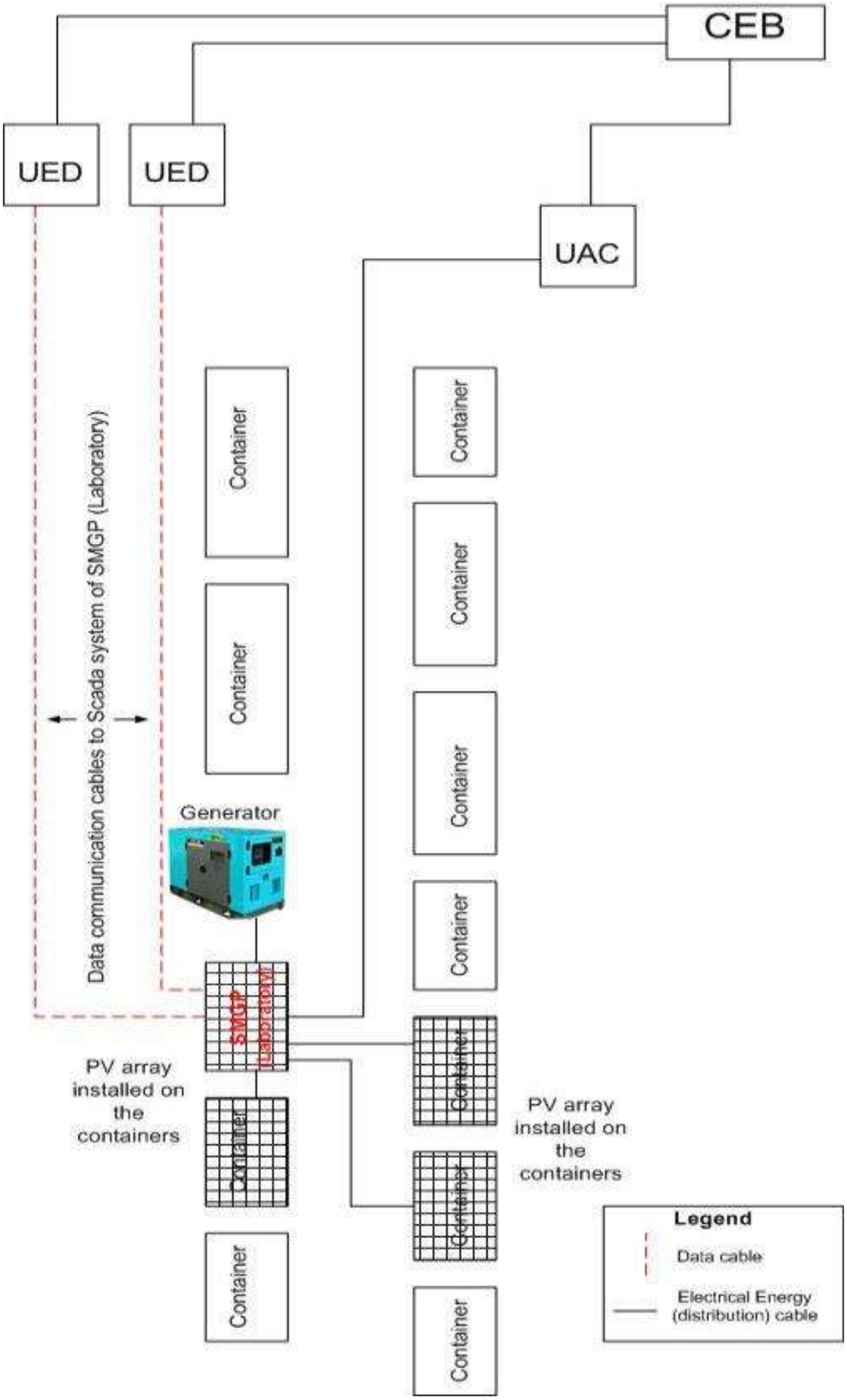


Figure 37: The SMGP installation location on the campus Gama. Source: Elaborated by the Author

4.5 FINAL CONSIDERATIONS

After the completion of this conceptual design phase a concept model is given of the proposed SMGP system that will function as a real-time platform for laboratory studies, test and research. After the application of the heuristics, any ungrouped sub-functions should be assembled into an existing module or a new sub module that has interactions with other modules through their flows. This step ensures their assignment to a development team (Stone, 1997). Through the conceptual design phase, the tasks and functional structures of the system are presented with a modular approach methodology. This is done to validate a scientific schematic structure of the whole design of this SMGP system. At the end of this conceptual design phase, there were three concepts generated. To check which one could be more valid for further development has been utilized the Pugh method and common sense for these three concepts. Finally one concept is chosen, concept 2, for further development of the SMGP system. The flows as regarded to in this conceptual design are described as the interactions between the modules. This heuristic method uses flow information to identify the modules. As all methods to use, it is not possible to strictly apply methods to any system, as in this research, some modifications had to be done to apply tools and methods to have the outcome of modules for this SMGP system. As seen in the literature of product or system design methods a, the theory of design is not just an easy academic exercise, but a useful tool in real world applications.

CHAPTER 5. CONCLUSION AND FUTURE WORKS

In research a work is never completely finished, there is always room for improvements and continuation in future works and this research work is not excluded from this statement. On the start of this research the main objective was a conceptual design of a smart microgrid platform, which will function as a real-time laboratory platform for power system monitoring and control. This objective was achieved through this research. The applied structural methods and schematics in this research gave a clear understanding of the functionalities of the smart microgrid platform. This chapter presents conclusions of the research and points out the main contributions and recommendations for future work.

5.1 CONCLUSIONS

Through literature research the state of the art of smart microgrids are described from the root until the recent reviews of smart microgrid developments of which a few examples are specified in Chapter 2. From this initial research point, the decision was made later on the process to develop the smart microgrid platform as a modular conceptual design. Through further literature research was concluded that the modular design approach would be the best fit, but it was actually part of the product development methodologies and those are primarily developed for mechanical and mechatronic systems. The decision was still taken to apply the different structures and methods related to a modular design to develop the SMGP and analyze the outcome. It was intensive work to describe the physical functions of the SMGP system units or subsystems with verbs to develop the system specifications, because a smart microgrid is not like one physical product it consist of different subsystems of which each have multiple devices that have different functionalities.

The objectives specified in the beginning of this research work were all met throughout this work. In Chapter 2 was identified the smart grid through literature research and the relation between the microgrid and the smartgrid. The microgrid specifications and technologies were also part of Chapter 2 contents.

The objective to present the campus Gama and the experimental setup to measure the electricity consume of one of the buildings of the campus Gama was met in Chapter 2, in the description of the problem concerning the campus Gama. The specifications listing of the electricity demand and consume of the campus Gama, was done in the scope of this work, to compare the results with an experimental setup for the consume measurements made in one building. This setup included an interconnection of two utility distribution multi-meters, type SENTRON PAC 3100 with a Supervisory control and data acquisition system of type SCADA Br., through a modbus RS485 interconnection. This experimental measurement scene was setup in the hydro lab of the campus Gama for this research work and created the first step in gathering and monitoring real-time data on the campus Gama possible.

The objective to specify the smart microgrid platform design with a modular method was met in Chapter 3 and 4. In chapter 3 the informational design step was completely presented with a roadmap and different steps, were the stakeholders were identified, the requirements of the clients and of the system were specified with specific tools and methods to outline the phase schematically with proven product design development tools that were normally used in the development of mechatronic products development. Through trial and error the final results of the informational design phase was reached in the form of the technical specifications of the SMGP system. In Chapter 4 the main objective of this research work was reached through the conceptual design phase. This phase gave a clear understanding of the system through a heuristic function structure method. Hereby the global function structure of the smart microgrid platform was described and presented. This global function structure presents the main function of the SMGP system, which is dispatch and control. The foundation for this global function is stated in the beginning that the SMGP system should be used as a laboratory platform for real-time monitoring and control and the integration of distributed energy resources (DERs) and is related to the system requirements specifications outcome of the informational design. The global function was further decomposed in elementary or basic functions to design the functional structure of the SMGP system that will compile the identified modules. The function structure becomes the foundation for the heuristic methods of identifying modules.

Concluded is that the three heuristic methods provide a systematic approach to identifying modules of a device using a function structure. These modules are actually grouped devices or elements of the SMGP that have a certain function. The theory provides a systematic approach to achieving customer need based modules. The applied modular design method supports a systematic way of describing the modular devices and can even offer innovative modules that were not present before in existing systems. In the functional structure, modules are identified as a group of functions which are connected together through interfaces called flows. These flows or also used in this research work to identify the modules of the SMGP system in a not complicated way as developed by Stone et al. (2004). The final results of this research are the three generated concepts of which one was selected for further development in the next phase of development in the future works.

5.2 FUTURE WORKS

The next stage in this SMGP design process would be the preliminary design as presented in the roadmap in this work. This stage would start with the dimensioning of the individual module components such as the battery bank, inverters, photovoltaic panels etc. This dimensioning step involves also calculations to determine if the panels should be connected in parallel or serie depending on the kWp outcome desired and the kWp of each panel to construct the array.

The following task would be the layout of the platform in a laboratory structure or environment, which will be one of the containers suited on the campus. All measurements and safety issues should be taken into consideration such as the required and available space, the grounding system and wire types and diameters.

The final stage of design will be the detailed design, where all the details of the before mentioned modular concept design will be considered and a fully evaluated and a lay out structure of the SMGP design will be presented for further testing and implementation.

All these next stages have different methods and tools involved to evaluate and establish the different tasks and will requires also very intensive work based on different engineering fields involved in the smart grid architecture such as the electro-technical, the communication and information technology engineering and the energy engineering.

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ANNEX

ANNEX Ⅰ QUALITY FUNCTION DEPLOYMENT (QFD)

ANNEX Ⅱ CAMPUS GAMA ENERGY CONSUME, DEMAND AND TARIFF STRUCTURE DATA

Peak Hour Consume (kWh)				
Year 2014	Period	Consume (kWh)	Tariff (R$/kWh)	Value (R$)
Month				
January	U (Wet)	2035	0.3436317	705.48
February	U (Wet)	2092	0.3349618	700.74
March	U (Wet)	2643	0.3454294	912.97
April	U (Wet)	4267	0.3477753	1,483.96
May	S (Dry)	3465	0.3482579	1,206.71
June	S (Dry)	4219	0.3417130	1,441,69
July	S (Dry)	3315	0.3497141	1,159.30
August	S (Dry)	3369	0.3475827	1,171,01
September	S (Dry)	4579	0.4354901	1,994.11
October	S (Dry)	5075	0.385825	1,958.06
November	S (Dry)	3805	0.4396231	1,672.77
December	U (Wet)	3378	0.4404222	1,487.746

Off-Peak Hour Consume (kWh)				
Year 2014	Period	Consume (kWh)	Tariff (R$/kWh)	Value (R$)
Month				
January	U (Wet)	18283	0.2180223	3,986.10
February	U (Wet)	21205	0.2125215	4,506.52
March	U (Wet)	23336	0.2191629	5,114.39
April	U (Wet)	40118	0.2206513	8,852.09
May	S (Dry)	34889	0.2209575	7,708.99
June	S (Dry)	38082	0.2168050	8,256.37
July	S (Dry)	27620	0.2218814	6,128.36
August	S (Dry)	28589	0.2205291	6,304.71
September	S (Dry)	42213	0.2715194	11,461.65
October	S (Dry)	44198	0.2734475	12,085.83
November	S (Dry)	40040	0.2740963	10,974.82
December	U (Wet)	33515	0.2745945	9,203.03

Peak Hour Demand (kW)				
Year 2014	Period	Demand (kW)	Tariff (R$/kW)	Value (R$)
Month				
January	U (Wet)	600	19.0358789	11,421.53
February	U (Wet)	600	18.5555987	11,133.36
March	U (Wet)	600	19.1354604	11,481.28
April	U (Wet)	600	19.2654180	11,559.25
May	S (Dry)	600	19.2921560	11,575.29
June	S (Dry)	600	18.9295921	11,357.76
July	S (Dry)	600	19.3728204	11,623.69
August	S (Dry)	600	19.2547444	11,552.85
September	S (Dry)	600	20.3649937	12,219.00
October	S (Dry)	600	20.5096073	12,305.76
November	S (Dry)	600	20.5582693	12,334.96
December	U (Wet)	600	20.5956375	12,357.38

Off-Peak Hour Demand (kW)				
Year 2014	Period	Demand (kW)	Tariff (R$/kW)	Value (R$)
Month				
January	U (Wet)	350	5.3957814	1888.52
February	U (Wet)	350	5.2596445	1840.88
March	U (Wet)	350	5.4240081	1898.40
April	U (Wet)	350	5.4608450	1911.30
May	S (Dry)	350	5.4684239	1913.88
June	S (Dry)	350	5.3656541	1877.98
July	S (Dry)	350	5.4912886	1921.95
August	S (Dry)	350	5.4578196	1910,24
September	S (Dry)	350	6.3597400	2225.91
October	S (Dry)	350	6.4049011	2241.72
November	S (Dry)	350	6.4200976	2170.34
December	U (Wet)	350	6.4317673	2251.12

Year 2015	**Period**	**Peak hour Consume (kWh)**	**Off-Peak hour Consume (kWh)**
Months			
January	U (Wet)	1734	16656
February	U (Wet)	2569	21430
March	U (Wet)	2692	23647
April	U (Wet)	4439	40221
May	S (Dry)	4250	39415
June	S (Dry)	4819	38942
July	S (Dry)	4423	35310
August	S (Dry)	3496	26240
September	S (Dry)	4793	44984
October	S (Dry)	5057	46060
November	S (Dry)	4984	48742
December	U (Wet)	4283	44848
Total		47539	426495
Média		3961,583333	35541,25

Peak Hour Consume (kWh)				
Year 2015	Period	Consume (kWh)	Tariff (R$/kWh)	Value (R$)
Month				
January	U (Wet)	1,734	0,4347088	753,99
February	U (Wet)	2,569	0,4799526	1232,98
March	U (Wet)	2,692	0,6111964	1645,17
April	U (Wet)	4,439	0,6049468	2685,46
May	S (Dry)	4,25	0,608309	2585,19
June	S (Dry)		0,6197621	2986,63
July	S (Dry)		0,6349527	2808,39
August	S (Dry)		0,6151467	2150,55
September	S (Dry)		0,6725811	3223,68
October	S (Dry)		0,7116337	3598,73
November	S (Dry)		0,7035094	5491,59
December	U (Wet)		0,7120398	3017,62
Total			7,4087391	32179,98
Média			0,617394925	2681,665

Off- Peak Hour Consume (kWh)				
Year 2015	Period	Consume (kWh)	Tariff (R$/kWh)	Value (R$)
Month				
January	U (Wet)	16,656	0,2710322	4514,44
February	U (Wet)	21,43	0,3149554	6749,41
March	U (Wet)	23,647	0,4381962	10362,01
April	U (Wet)	40,221	0,4337156	17444,32
May	S (Dry)	39,415	0,4361261	17189,74
June	S (Dry)		0,4443374	17303,38
July	S (Dry)		0,4552283	16074,11
August	S (Dry)		0,4410283	11572,58
September	S (Dry)		0,4879283	21948,96
October	S (Dry)		0,5183774	23876,46
November	S (Dry)		0,5124593	23394,27
December	U (Wet)		0,5186731	23261,45
Total			5,2720576	193691,13
Média			0,439338133	16140,9275

Off- Peak Hour Demand(kW)				
Year 2015	Period	Demand (kW)	Tariff (R$/kW)	Value (R$)
Month				
January	U (Wet)	350	6	2221,92
February	U (Wet)	350	6	2239,84
March	U (Wet)	350	7	2306,3
April	U (Wet)	350	7	2282,71
May	S (Dry)	350	7	2295,4
June	S (Dry)		6,6817664	2338,61
July	S (Dry)		6,8455396	2395,93
August	S (Dry)		6,6320075	2321,2
September	S (Dry)		6,9011434	2415,4
October	S (Dry)		7,1428562	2499,99
November	S (Dry)		7,0613102	2471,45
December	U (Wet)		7,1469324	2501,42
Total			81	28290,17
Média			7	2357,514

Peak Hour Demand(kW)				
Year 2015	Period	Demand (kW)	Tariff (R$/kW)	Value (R$)
Month				
January	U (Wet)	600	20	12197,07
February	U (Wet)	600	20	12295,49
March	U (Wet)	600	21	12673,46
April	U (Wet)	600	21	12543,87
May	S (Dry)	600	21	12613,59
June	S (Dry)		21,418459	12851,07
July	S (Dry)		21,9434358	13166,06
August	S (Dry)		21,2589566	12755,37
September	S (Dry)		22,1824741	13309,48
October	S (Dry)		22,9968607	13798,11
November	S (Dry)		22,7343182	9093,72
December	U (Wet)		23,0099842	13805
Total			259	151102,29
Média			22	12591,8575

ANNEX III ANALYSIS AND DESCRIPTION OF THE SOLUTION PRINCIPLES

As presented in Table 24, are the solution principles of the SMGP system design. A few of these solution principles will be further described and analyzed to give a good understanding of their functionality in the SMGP system, since the majority of these are already presented in chapter 2. Some of these solution principles will be used for the SMGP system to be designed and will have various functions, therefore it is appropriate to add to this section of Task 2.2.2, a brief description of these components or devices that make part of the alternative solutions to the design problem and to support the selection of the best design solution.

Renewable energy sources: these sources are also called DER that defines the Distributed Energy Sources or DG (Distributed Generation). Although DERs or DGs could be renewable or non-renewable as described in paragraph 2.3, for this subject shall be focused only on the renewable sources: Wind, Solar, Micro-Hydro and Biomass. Renewable energy is defined as a term used for energy types that are not depleted by use over time or not deplete primary energy sources (World Energy Counsil, 2004) .

A. Wind energy

Wind turbines (Figure 37) harness wind's kinetic energy and convert it into electricity. The turbine does this by slowing down the stream of air flowing past it and the resulting change in momentum is converted to electrical output via a generator. The wind strikes the blades and causes the rotor to spin. When the wind is strong enough, the rotational (mechanical) energy in the rotor is converted to electrical energy within the generator. The voltage of the electricity produced by the wind turbine is then increased by a transformer and substation to enable it to be fed into the electricity grid

Most wind turbines have three blades and sit atop a steel tubular tower, and they range in size from 80-foot-tall turbines that can power a single home or farm (< 100kW) to utility-scale turbines (>100kW) that power hundreds of homes (Kalmikov & Dykes, 2010), (Australian Goverment, 2014), (New South Wales Government, 2010), (Molina & Alvarez, 2011).

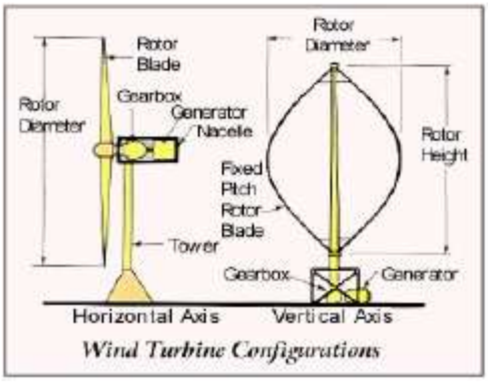


Figure 38: The horizontal and vertical wind turbine configurations.

B. Photovoltaic Solar Energy

Photovoltaic solar energy is the direct conversion of sunlight into electricity. The energy of solar radiation or sunlight is precisely applied in two specific arrangements:

2. Execute transformation into electricity that takes place in semiconductor devices called solar cells.
3. Building up heat in solar collectors.

Sunlight, which is raw energy, enters a solar cell and transmits enough energy to some electrons negatively charged atomic particles) to free them. A built-in-potential barrier in the cell acts on these electrons to produce a voltage (the so-called photovoltage), which can be used to drive a current through a circuit. The straightforward transformation of solar radiation or sunlight into electricity is often described as a photovoltaic (PV) energy conversion, because it is based on the photovoltaic effect. The construction of the PV cell to an array is presented in Figure 38. In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. The whole field of solar energy transformation into electricity is therefore designated as the “photovoltaics”, (Markvart, 2002), (Zeman, 2003).

Photovoltaic is defined as “light-electricity”, because “photo” is a stem from the Greek word “phõs” meaning light and "Volt” is a shortening of Alessandro Volta’s (1745-1827) name who was a pioneer in the study of electricity. If spoken about photovoltaics, a few descriptions have to be given to the used definitions in the context of photovoltaic energy:

- **Radiation**: the sun is an emitter of radiation which is the energy flux incident on a unit area in W/m2
- **Irradiance**: the total power from a radiant source falling on a unit area in kW/m2 that is used for the calibration of solar cells and modules.

- **Photovoltaic/solar cells**: semiconductor devices that use sunlight to generate electricity and are generally very small and each one may only be capable of generating a few watts of electricity.
- **Solar panels or modules**: a number of solar cells are connected together to form a solar panel or PV module to generate solar electricity in larger amount to be used. These flat-plate PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture more sunlight.
- **Solar array**: multiple solar panels the connection of a group of solar panels electrically wired together to form a much larger PV installation (PV system) called an array, and in general the larger the total surface area of the array, the more solar electricity it will produce.

The panels in an array can be electrically connected together in a series (for a higher voltage requirement), a parallel (for a higher current requirement), or a mixture of the two. The size of a photovoltaic array can consist of a few individual PV modules or panels connected together in an urban environment and mounted on a rooftop, or may consist of many hundreds of PV panels interconnected together in a field to supply power for a whole town or neighborhood. The flexibility of the modular photovoltaic array (PV system) allows designers to create solar power systems that can meet a wide variety of electrical needs, no matter how large or small (Markvart, 2002), (Zeman, 2003), (IRENA - International Renewable Energy Agency, 2012).

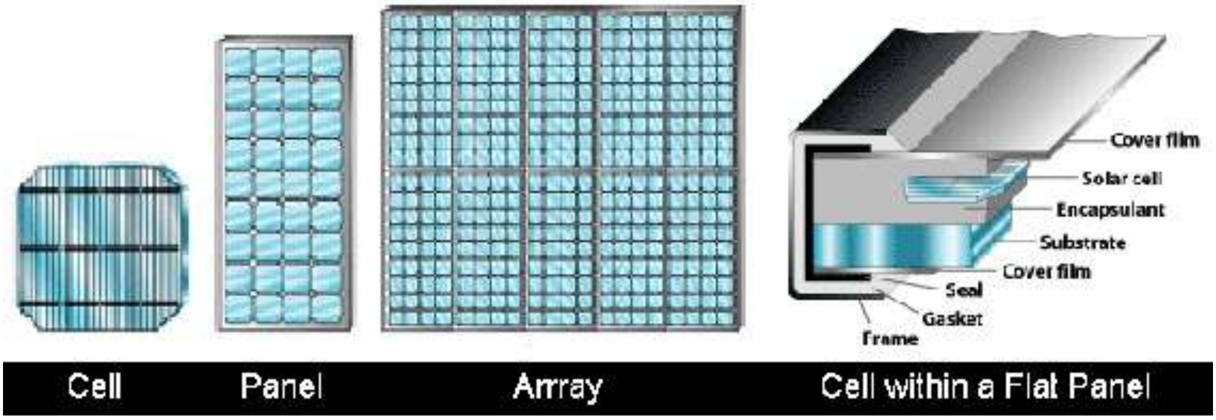


Figure 39: Photovoltaic build up from cell to array. Source: www.global-greenhouse-warming.com.

The PV modules or panels are categorized in a few main types based on their solar cell composition (as presented in Figure 39):

- **Crystalline Silicon (c-Si)**: Silicon is a substance used in PV solar technology which generates an electrical current when sunlight is absorbed in a process known as the photovoltaic effect. Like semiconductors, solar PV technology needs purified silicon to get the best efficiency, and the price behind PV solar manufacturing is often driven by the crystalline silicon purification process.

- **Monocrystalline silicon (mono-Si):** They are composed of cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.
- **Polycrystalline silicon (p-Si):** Eventually known as multi-crystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and re-crystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than mono-crystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.
- **Thick-film silicon**: Is a variant on multi-crystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, it is normally encapsulated in a transparent insulating polymer with a tempered glass cover and then bound into a metal framed module.
- **Amorphous silicon (a-Si)**: Are member of the Thin-Film Solar cells made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure. As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces or bonding directly onto roofing materials. This technology is, however, less efficient than crystalline silicon, with typical efficiencies of around 6%, (IEA-International Energy Agency, 2014), (IRENA - International Renewable Energy Agency, 2012)
- **Other Thin-Film Solar Cells (TFSC)**:

Depositing one or several thin layers of photovoltaic material onto a substrate is the basic gist of how thin-film solar cells are manufactured. They are also known as thin-film photovoltaic cells (TFPV). The different types of thin-film solar cells can be categorized by which photovoltaic material is deposited onto the substrate:

- Cadmium telluride (CdTe)
- Copper indium gallium selenide (CIS/CIGS)
- Organic photovoltaic cells (OPC)

Depending on the technology, thin-film module prototypes have reached efficiencies between 7–13% and production modules operate at about 9%, (IEA-International Energy Agency, 2014), (IRENA - International Renewable Energy Agency, 2012).

Figure 40: Photovoltaic types. Source: http://www.sapa-solar.com/pv-cells.html

C. Micro Hydro Power

Hydro power is named small hydro-power when usually in a scale of 0.1– 1 MW (Kempener et al., 2015) . Micro-hydro is frequently defined for a scale from 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid (Singh, 2009).

Hydropower itself is the oldest known renewable energy source and with a possible 720 GW capacity, it is responsible for the greatest part renewable energy source. Many rivers and streams are appropriate for small hydro-power installations (<10 MW capacity) and in large parts of the world there is a need for electric power in remote areas where these resources are available. Micro hydro systems or small hydro installations are usually run-of-river developments where water is used only as it is available, and with no water storage reservoir (World Energy Counsil, 2004).

A hydraulic turbine converts the kinetic energy of flowing water into mechanical energy by the turning of its blades or vanes. A hydroelectric generator rotor is turned by the hydraulic turbines which converts this mechanical energy into electricity (Nasir, 2013). Micro hydro power plants are in comparison with same size wind, wave and solar power plants more beneficial on a few points:

- Good efficiency (70-90%), better than other energy technologies.
- Capacity factors of high values (> 50%) compared with 10% for solar and 30% for wind power plant.
- Minimum rate of change; the output power varies in small portions from day to day not from minute to minute (Nasir (2009)

Communication infrastructure: is seen as the heart of a smart microgrid to ensure a reliable and stable renewable energy systems operation. The SMG can be defined as an advanced framework based on the service-oriented architectures for combining micro-grid modeling, monitoring and control. The main objectives of a smart microgrid (SMG) are to establish a reliable and secure grid with high efficiency and cost-effective generation, distribution and consumption. These objectives can only turn into reality with the existence of a suitable communication infrastructure that will accommodate, control, data transfer and information exchange in the SMG. Under the communication infrastructure in smart microgrids (SMGs) is also included the information and communication technology (ICT), because it covers the tasks of management, control and data and information transfer. The smart microgrids, which are small scaled smart grids, are the networks that interconnect both the information and communication technology (ICT) and the power network and enable an active network with two-way communication capability. The smart grid is a two-way flow of electricity and information between energy producers and consumers, which makes a widely-distributed and automated controlled energy delivery network. By utilizing two-way communications, it becomes possible to replace the traditional power system with more intelligent infrastructures (Llaria et al., 2016), (Shamshiri et al., 2012).

Various communication technologies can be part of the communication infrastructure such as Ethernet, fiber, power line communications and wireless. The performance of the communication technologies in the communication between the SMG components or agents is mainly based on the structure of the SMGP and its control system. For example you can have a centralized controlled SMGP system or decentralized (Safdar et al., 2013):

- Centralized Controller: there is a main controller in the MG that collects the required data from agents and performs necessary actions;
- Decentralized controller: every agent has its own controller that will take actions according to their policies in order to balance demand and supply coming from distributed sources and the main grid.

The construction of a SMG communication network or infrastructure is generally based on three main aspects, namely the microgrid devices, data traffic volume, and number of renewable energy systems. Figure 25 presents the three layers of the SMG communication infrastructure: the application layer, network layer, and device layer (Ahmed et al., 2015).

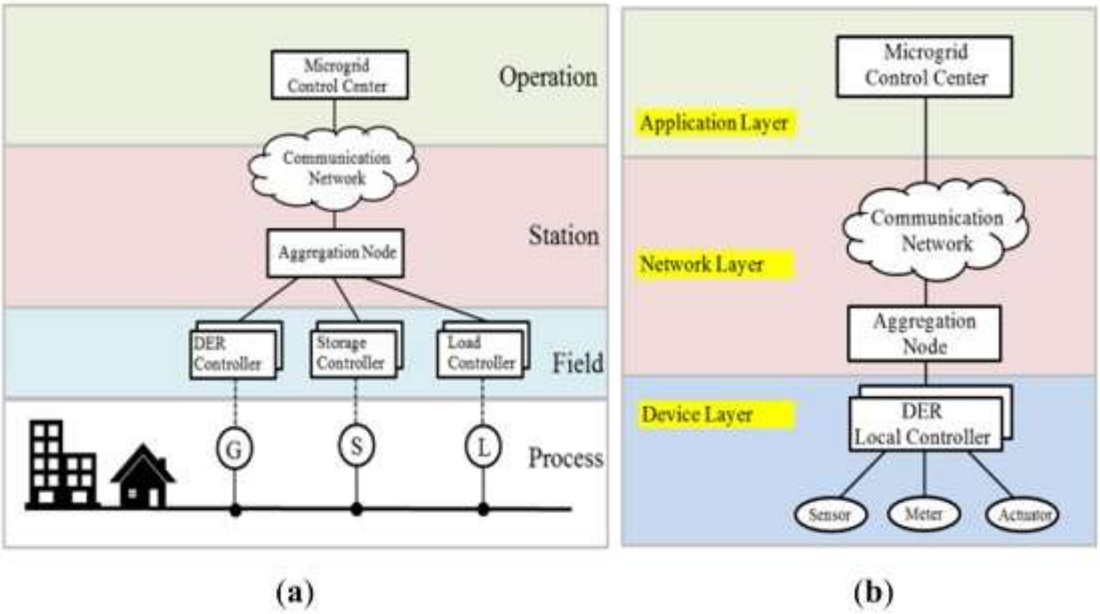


Figure 41: (a) Smart microgrid (SMG) customer premises domain and hierarchical zones; (b) Microgrid three layers communication network construction Source: Adapted from Ahmed et al. ,(2015).

The three layers as presented in Figure 40 are further described next:

- The device layer expresses diverse devices such as sensor nodes and meters for measuring the various parameters for instance the voltage, current and temperature from the renewable energy units. Each renewable energy unit has a local controller. The local controller monitors and controls the operation of the renewable energy unit based on local measurements.
- The network layer performs the connection between the device layer components and the microgrid control center. It is required of the network layer to accommodate real-time monitoring and control of the microgrid system. It can consist of wired or wireless communication technology.
- The application layer is subjected to energy management and remote monitoring and control of the microgrid system. It comprises the SCADA system that obtains the measurement data via the network layer (Ahmed et al., 2015).

The Communication networks that make up the communication infrastructure of SMGs could be categorized as follows, (Safdar et al., 2013), (Elyengui et al., 2013):

A. **WAN-Wide Area Network**: Is mainly operated to transfer the overall collected data to grid-operators, and command messages to the consumers. Furthermore, WAN could be used to diffuse control information from a data center to consumer appliances or to power plants in order to improve the efficiency of energy distribution. In situations where control centers are located far from the substations or consumers, the real-time measurements taken at the electric devices are sent to control centers through the Wide Area Network and instructions are sent to the electric devices from the control centers. WAN applications such as wide-area control, monitoring and protection require transmitting a large number of data points at a very high frequency to be able to ensure real-time delivery of control and monitoring information in the grid. Therefore, WANs ensure a high-bandwidth from geographic ranges to regional or even national, two-way communications implementation for extended distance that have effective monitoring and sensing applications. This implies that communication technologies that provide long distance coverage (up to 100km), and support a much higher data rate (10Mbps – 1Gbps) such as Fiber Optic, Cellular and WiMax are required.

B. **NAN-Neighborhood Area Network:** NAN accommodates data flow between customer/field devices and data accumulation points. This data comes from the smart metering, demand response and distributed automation, which are also known as Advanced Metering Infrastructure applications. NAN is for instance mainly suitable for communication between devices such as smart meters and with a router to form an interconnected mesh of smart devices in a medium sized community MG; involving a few building (residential areas or little villages) or installed in large buildings such as hospitals. A Field Area Network (FAN) is deployed to collect data from power lines, mobile workforce, towers, and so on, for power grid monitoring. The NAN/FAN applications need communication technologies that support higher data capacity rates (100kbps – 10Mbps) and larger distance (up to 10km), ZigBee, WiFi , PLC long distance wired and wireless technologies, such as WiMAX, Cellular, Digital Subscriber Line (DSL) and Coaxial Cable can be used for this purpose.

C. **HAN-Home Area Network**: This network permits devices located within a home to communicate with each other. In the smart grid context, these devices could include smart meters and home energy management devices. Therefore the HAN can also enable applications like Demand Response (DR), Automatic Metering Infrastructure (AMI), smart devices monitoring and control at the customer’s premises. The Building Area Network (BAN) is similar to a HAN, but is implemented in a Business and Industrial Area Network (IAN) is implemented in an Industry. Customers use these applications to receive real time energy prices and send their energy consumption information towards the central data systems. These applications do not require frequent/continuous sending of their data therefore communication technologies that provide data rates up to 100 kbps with short distance coverage (up to 100m) are sufficient for their functionality. ZigBee, WiFi, ZWave, power line carrier (PLC, or known as Home Plug), Bluetooth, and Ethernet technologies are widely used to support HAN/BAN/IAN applications.

Communication technologies

The protocols used in the different categories of the communications network depend on the technology being implemented. These communication technologies as presented in Table 25 are categorized in wired and wireless protocols. In the next part are described a few main wired and wireless protocols:

Wired communication technology:

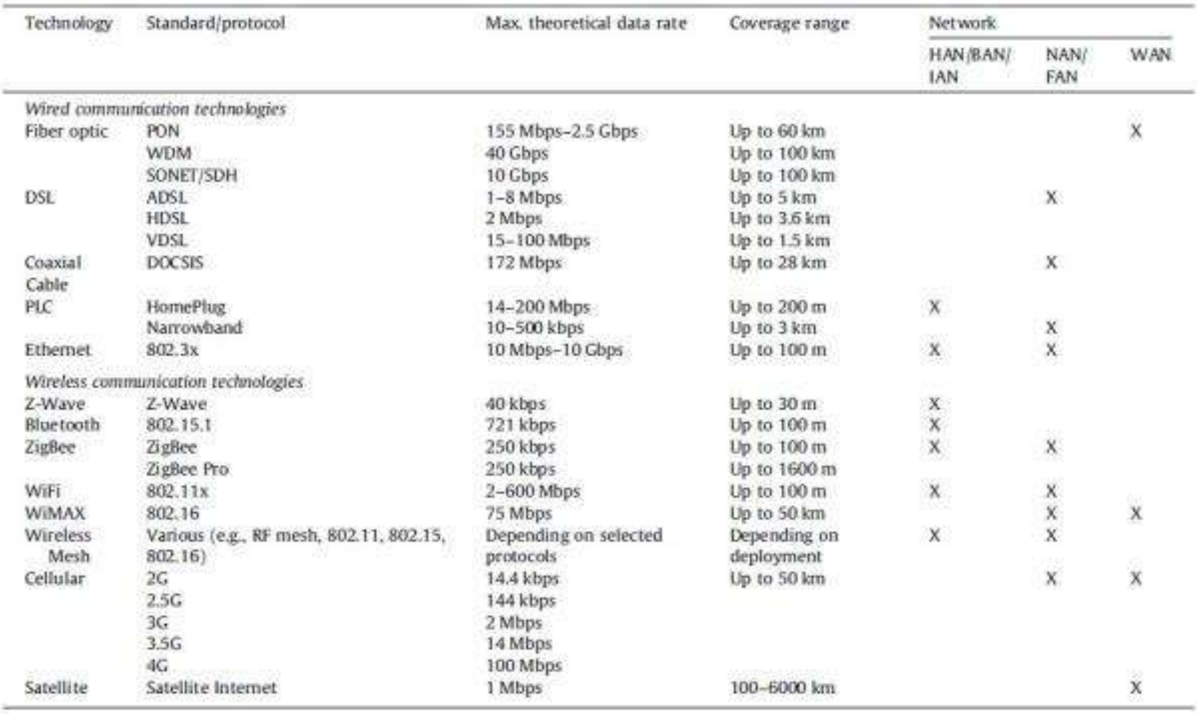
- **Power line communication (PLC)**: Is a technique that uses the existing power lines to transmit high speed (2 - 3 Mbps) data signals from one device to the other. PLC has been the first choice for communication with the electricity meter due to the direct connection with the meter and successful implementations of AMI in urban areas where other solutions struggle to meet the needs of utilities (Sendin et al., 2015).
- **Fiber communication: Is an optical communiucation that is mainly applied for the connection of** substations to operation and control centers in the backbone network. The advantages of the fiber communication are its capacity to transmit over large distances with very high bandwidth, and robustness against radio and electromagnetic interferences making it an appropriate choice for high voltage systems, (Elyengui et al., 2013).

Wireless communication technology:

- **ZigBee**: Is a wireless communications technology that is relatively low in power usage, data rate, complexity and cost of deployment. ZigBee is also known as the low-rate wireless personal area networks (LR-WPANs). It is an ideal technology for smart lightning, energy monitoring, home automation, and automatic meter reading, etc. The communication between smart meters, as well as among intelligent home appliances and in home displays, is very important. ZigBee operates in the 2.4 GHz with a transmission range between 1 and 100 m with a 250 Kb/s data, can be utilized within an unlicensed spectrum, has an easy network implementation, is a standardized protocol based on the IEEE 802.15.4 standard load control and reduction, demand response, real-time pricing programs, real-time system monitoring and advanced metering support (Elyengui et al., 2013), (Safdar et al., 2013).
- **WIFI: Is based on the** IEEE 802.11 standard of wireless communication technology and refers to Wireless Fidelity. WiFi operates in unlicensed spectrum of frequency bands (2.4 GHz and 5 GHz) and can allow high data rates up to a few Gbps, along with a coverage range of about 200 m (Elyengui et al., 2013).

- **WiMAX**: actually stands for Worldwide Interoperability for Microwave Access, and is a wireless communication standard based on the 802.16 series meaning to result in worldwide interoperability for microwave access. WiMAX allows long distance up to 48 Km broadband with up to 100Mbps of data rate. Furthermore the WiMAX is a considerably low cost compared with other wireless standards. WiMax operates in a licensed spectrum (2.3, 2.5 and 3.5 GHz) and an unlicensed spectrumte (at the 5.8GHz) frequency band. Licensed spectrums permit higher power and longer distance transmission, which are more appropriate requirements for long distance communication. Power outage detection and restoration can be monitored and controlled in through WIMAX support (Elyengui et al., 2013), (Safdar et al., 2013) .

Table 26: Comparison of communication technologies for the smart grid.



Technology	Standard/protocol	Max. theoretical data rate	Coverage range	Network		
				HAN/BAN/IAN	NAN/FAN	WAN
Wired communication technologies						
Fiber optic	PON	155 Mbps–2.5 Gbps	Up to 60 km			X
	WDM	40 Gbps	Up to 100 km			
	SONET/SDH	10 Gbps	Up to 100 km			
DSL	ADSL	1–8 Mbps	Up to 5 km		X	
	HDSL	2 Mbps	Up to 3.6 km			
	VDSL	15–100 Mbps	Up to 1.5 km			
Coaxial Cable	DOCSIS	172 Mbps	Up to 28 km		X	
PLC	HomePlug	14–200 Mbps	Up to 200 m	X		
	Narrowband	10–500 kbps	Up to 3 km		X	
Ethernet	802.3x	10 Mbps–10 Gbps	Up to 100 m	X	X	
Wireless communication technologies						
Z-Wave	Z-Wave	40 kbps	Up to 30 m	X		
Bluetooth	802.15.1	721 kbps	Up to 100 m	X		
ZigBee	ZigBee	250 kbps	Up to 100 m	X	X	
	ZigBee Pro	250 kbps	Up to 1600 m			
WiFi	802.11x	2–600 Mbps	Up to 100 m	X	X	
WiMAX	802.16	75 Mbps	Up to 50 km		X	X
Wireless Mesh	Various (e.g., RF mesh, 802.11, 802.15, 802.16)	Depending on selected protocols	Depending on deployment	X	X	
Cellular	2G	14.4 kbps	Up to 50 km		X	X
	2.5G	144 kbps				
	3G	2 Mbps				
	3.5G	14 Mbps				
	4G	100 Mbps				
Satellite	Satellite Internet	1 Mbps	100–6000 km			X

Source: Adapted from Kuzlu et al. ,(2014)

In Figure 34 is presented a smart microgrid basic structure, with its microgrid central controller. This SMGP can operate in standalone mode, that´s when the microgrid could be isolated from the main power grid as a result of geographical isolation or failure of the main grid. According to the microgrid power balance, it may be operated in different modes.

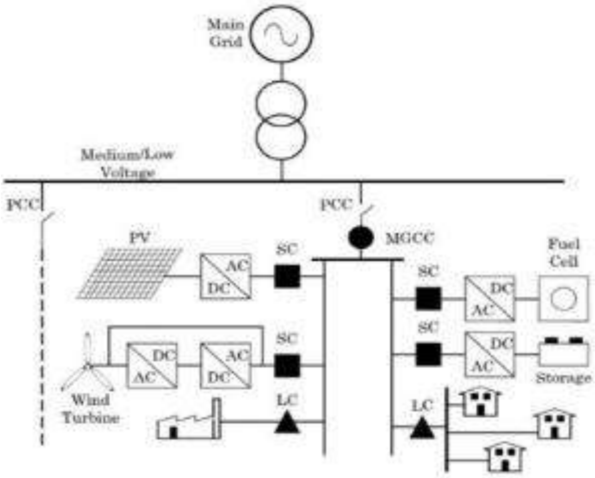


Figure 42: Overview of a basic structure of a smart microgrid (SMG) including the main grid Source: adapted from Llaria et al. ,(2016).

The following components are also presented as solution principles and are the basic components of the SMG system related to the communication infrastructure levels to provide an outstanding overall monitoring and control of the SMG system (Ahmed et al., 2015), (Llaria et al., 2016):

MGCC- Microgrid Central Controller: the microgrid operation is managed through a microgrid control center, which is responsible for real-time monitoring and also enables stable operation and control of all equipment in the system. This is the principal element of the SMG system and provides remarkable management duties in the primary level.

SCs-Source Controllers and LCs-Load controllers (or Charge Controllers): are responsible for the communication link between the central controller and the power electronics (Inverters & Converters) in the SMG system and function in the secondary level of the communication infrastructure.

The Point of Common Coupling (PCC): is the coupling point between the SMG and the main grid, physically based on a static switch. This static switch or breaker will connect, disconnect and reconnect the SMG system with the main grid and enables the SMG to function in island mode or in the grid-connected mode, where the microgrid is viewed as an integral part of the electric power system (Llaria et al., 2016) (Ahmed et al., 2015)**.**

Smart meters: are smart devices that can transfer data and information of the consumer or microgrid unit through a two-way communication and advance software. The main objective is to involve the consumer in the power system to provide them with data and information of mainly the electricity consume and demand (SHAMSHIRI et al., 2012).

FLIR – Fault Location, Isolate and Restore system: is based on Self-Healing and Self-Healing grids have a network with high reliability and inherent security in all levels and enhance decentralized control and wide spread use of sensors and measuring equipment. The remote terminal units (RTUs) communicate through a general packet radio service (GPRS) network to recognize the fault location, isolate and restore (FLIR) supplies in steps automatically. Automatic FLIR schemes can be deployed with a fully centralized architecture that comprises a distribution management system (DMS) and supports a complete picture of the network structure, or a local, centralized architecture which utilizes intelligent master controllers, either communicating with a restricted number of slave devices (Coster et al., 2013) .

SCADA- Supervisory Control and Data acquisition System: Is used to approximate the system states and is based on traditional monitoring technologies with algorithms. The SCADA rely on a single set of measurements and therefore use static state estimators. In order to estimate the state of the power system regularly, this process is repeated at suitable intervals of time. (Rana & Li, 2015)

Weather Station:

On the campus Gama a weather station type WeatherHawk-XP is installed. This weather station is a easy-install design type for utilization in the education field, resource area and consumers. It is a prior programmed system to supply real-time daily or hourly understandable meteorological data such as wind speed, wind direction, air temperature, relative humidity, barometric pressure, solar radiation and rainfall, containing complex calculation of ETo (evapo transpiration) specifically applied to landscape and crop management and is adaptable to various home automation protocols. A tool of the WeatherHawk weather station is an internet-compatible Virtual Weather Station software that enables the display of sensor information. This weather station of the campus Gama is a direct connected or wire-connected type, which has a direct connection to a host device (PC or server) through an RS232 serial data I/O located on the bottom of the weather station. The construction consist meteorological sensors, and a protective case that houses the on-board microprocessor, rechargeable battery pack and spread spectrum radio transceiver. The WeatherHawk weather station encloses the following sensor technologies based on weather measurement (Campbell Scientific Ltd, n.d.):

- Wind speed and direction use rotating anemometer and vane devices commonly used on professional wind velocity measurement systems.
- Rain is measured using a volumetric tipping bucket, self-draining rain gauge for rainfall.
- Barometric pressure, relative humidity, air temperature and solar radiation measurements are made by a combination of industrial and scientific grade sensors (Piezoresistive transducer, Precision, temperature corrected, bulk polymer, Thermistor, Silicon pyranometer).

The weather station runs on a 0.8 Ahr lead-acid battery that is recharged via AC power or a solar panel and compiles an on-board microprocessor that automatically measures the sensors, then stores the data in an on-board data logger before transmitting the data to a user-supplied PC (Campbell Scientific Ltd, n.d.).