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Design of a Smart Microgrid Laboratory Platform for University Campus

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Abstract. The smart microgrid platform project has been initiated to integrate a renewable energy laboratory on the campus with real-time data monitoring capacity. This expected smart micro grid will complement the construction process of the campus, as it is planned to be deployed in stages. The overall design of this microgrid laboratory platform is based on the methodologies of system design development processes, where the design goes through different stages such as the informational design stage, the conceptual design stage, the preliminary design stage and finally the detail design stage. All these mentioned stages have their own steps to be followed to get to the desired design of the smart microgrid laboratory system. From the literature research is concluded that there has not yet been made an attempt to design an electrical energy system with the design methods of product or system development process. These design methodologies are actually developed for the design of mechanical and mechatronic systems. The mechatronics are defined at R&D (research and development) level as complex systems which can be organized into ten technical areas: Motion Control, Robotics, Automotive Systems, Intelligent Control, Actuators and Sensors, Modeling and Design, System Integration, Manufacturing, Micro Devices and Optoelectronics, and Vibration and Noise control. Nowadays the application area of mechatronics is remarkably broad. This technology is firmly used in the automation of machines, biomedical systems, energy and power systems, vehicular systems, data communication systems and computer aided design. Since smart microgrids are also complex systems with various integrated elements, the approach of a modified design method of a modular system design was utilized for this laboratory platform. In this context the paper aims to present the initial stages of a modular system design for the smart microgrid lab platform, where the target technical specifications of the smart microgrid system are the key characteristics for the deployment of the modular design as required by the customer. Along the roadmap of this design the main aspects will be presented in this paper, such as the identifications of the stakeholders and clients, the necessities of the customers, the identification of the requirements of the customer and the product/system requirements and the categorization of these requirements with the QFD (Quality Function Deployment or ``House of Quality´´). All the followed steps to be presented in this article will contribute to a structured and analyzed process of the modular design of the smart microgrid laboratory platform to start with the conceptual design stage of this system.

Keywords. Microgrid, Modular design, Renewable energy, Smart (micro)grid, Laboratory platform, Design requirements, Real-time testing, Design stages

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Introduction

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 and all these products and services have the same point in common, the need for electricity to operate [1].

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. These events motivate to use new technologies for electricity generation. In order to reduce the dependence on oil and gas, and preserve the environment, the use of renewable energy sources is introduced [2].

To address these challenges in the energy distribution systems, a new concept of power networks is developed, integrating distributed generation and loads associated with them as a single power system unit called the microgrid. The characteristics of microgrid depend primarily on the size and nature of distributed generation units, such as where they are installed and their respective availability of primary power [3].

Micro grids 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, 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 micro grids and the smart grids 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, [4], [5]. Therefore they are also called smart microgrids. 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 to [6].

The micro grids are an excellent contribution for research and studies of real main utility grid problems and for the implementation of intelligent systems, because they are smaller grids and consists of almost all the components of the main centralized grid in a small scale [7], [8].

The main objective of this smart microgrid design is to establish a design for a laboratory platform which will be a basic structure for teaching, research, practical tests, analysis and an energy support for the laboratory itself.

This article aims to describe the initial design stage of the design of a smart microgrid laboratory platform for the university campus Gama with a modular system design approach. This smart microgrid will be interconnected with the main local utility grid of the campus, but can also disconnect and support islanded operation. The present work is divided in three sections: the first part provides a brief description of the campus Gama and the smart microgrid project; the second part presents the modular system design approach and roadmap; the third part presents the initial design stage which is the informational design of the modular system, the fourth part presents the conceptual design its first step of this design stage, which is the establishment of the global function and the last part discusses the final considerations.

1. Description of Campus Gama and The Smart Microgrid Project

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 1 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 and a few additional containers which are functioning as small laboratory environments and study areas.

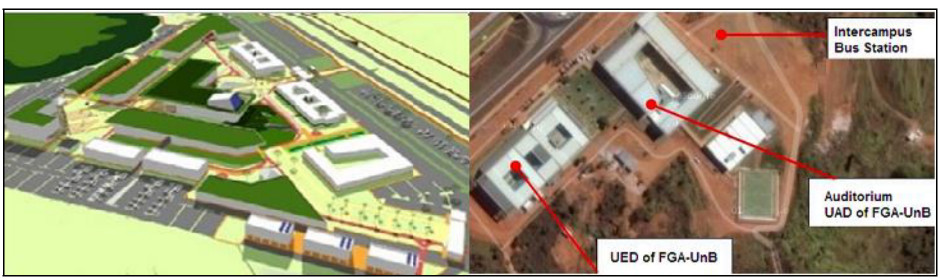

Figure 1. Planned and actual construction of campus Gama.

At present the campus has an apparent power demand of 207.33 kW. The average monthly consumption is 40,000 kWh. The main building and laboratories do not utilize air conditioners, so the demand is currently low. But when the campus grows larger, the demand will definitely increase.

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 [9]. Another objective of the campus is to integrate renewable energy generation in their infrastructure to generate green energy and maintain an energy support system. This perception was the first step towards the smart microgrid idea on the campus Gama in year 2012. In the scope of the first perception this smart microgrid laboratory platform design started. A smart micro grid laboratory is very essential on a campus with engineering courses. This facility will be very useful for the different departments, because this laboratory will enhance various engineering courses such as control, automation, computer, electronics and energy. At the same time is taken also into consideration that this campus is 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 smart microgrid 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. Educational application of this laboratory-based smart grid and its real-time operation analysis capability provide a platform for research of the most challenging aspects of real utility power system and its operation in real-time.

2. The Modular Design Approach and Roadmap

The proposed smart microgrid laboratory platform can be designed using the fundamentals of the modular 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. Modularization of a product or process is described by [10] 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. Modularization is defined by [11] 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 or systems. 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.

[12] 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.

A systems-level perspective drives the selection of technology platforms and individual components, this is also the case for the proposed smart microgrid laboratory design based on their functional and performance attributes in this work. To propose a method for the microgrid laboratory platform project a roadmap was made throughout this work. In this article the modular system design will be presented up to the first step of phase 2; the conceptual design. The general roadmap for the design of this modular system is presented in Figure 2.

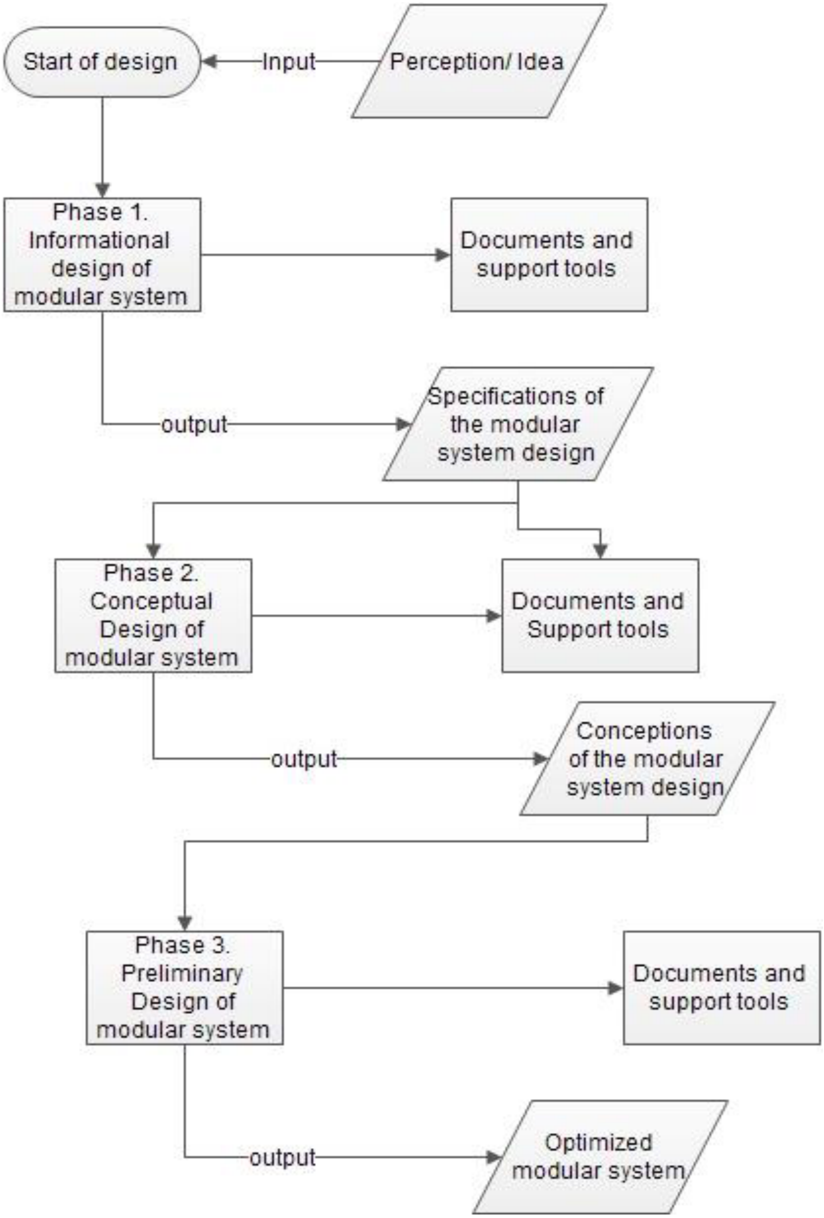

Figure 2. Roadmap of the smart microgrid modular system design.

3. Informational Design of Modular Smart Microgrid System

The informational design of modular system corresponds to methods and techniques to help the designer to clarify the problem presented by the design, in order to support him in two aspects namely: define the design problem to study and establish specifications for the development of the design. The term "informational project" 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 recently the informational design was called "definition of design problem" [13]. This informational design phase of the design process is shown in Figure 3. 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 1. Informational design of the smart microgrid modular system.

Phase 1: Informational Design of Modular system		Input	Output	Documents and Support Tools
Stage 1.1	Task1 Search for information to clarify the problem and establish the life-cycle of the system	Collected Information to contextualize the problem	Clarification of the problem	Life-cycle of the system/product
Stage 1.2	Task 2 Identify clients and their necessities	Goals to be achieved	List of necessities of the clients	Life-cycle of the system/product
Stage 1.3	Establish the requirements of the clients of the modular system	Needs of the clients	List of requirements of the clients	Transformation method of the necessities in requirements of the clients
Stage 1.4	Establish the requirements of the modular system design	Requirements of the clients	Requirements of the design	Mudge Diagram and transformation of the client´s requirements into design requirements
Stage 1.5	Prioritize the design requirements of the modular system	Requirements of the design	Design requirements classified by level of importance	Matrix of Quality function Deployment (QFD)
Stage 1.6	Establish the smart microgrid modular system specifications	Design requirements classified by level of importance	Design requirements specified to meet the modular system design	Table of the smart microgrid modular system design specifications

Stage 1.1 upto stage 1.4 as presented in Table 1, are all concluded in the life-cycle of the smart microgrid system. The product/system 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. This life-cycle is presented in Table 2. The requirements of the clients are transformed from the necessities for each life cycle fase. 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.

Table 2. Life cycle of the system.

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	

Stage 1.5 represents a tool used to accomplish the prioritization of system requirements which 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 [14].

Stage 1.6 enhances the results of the QFD and presents the technical specifications of the proposed smart microgrid design. Table 3 illustrates part of the these technical specifications of the smart microgrid laboratory system elaborated from the QFD.

Table 3. Part of the specifications of the smart microgrid system.

Specifications	Metric-Unit	Objectives	Sensor	Undesirable output
High level of supervisory control system	seconds (s); minutes(min);and hours (h)	Aims to achieve an optimal operation	Measure power, current and voltage	Not detecting the over load situations
High level ofcommunication system	Kbps; or Mbps at frequency (Hz)	To monitor the overall power system from a distance (not locally) in real-time	Transporting data to monitoring and control systems	Not functioning communication
High remote monitoring system capacity	Mbps or kbps at Hz	Parameters can be monitored through remote monitoring system	Wireless sensor systems to sense the data of the microgrid parameters	Failure of remote monitoring system
High level of monitoring via software systems such as SCADA	seconds (s) or minutes	Generation of charts and reports with historical data; Detection of alarms and automated event logging	Transformation of the analog data into digital data	Shutting down of the power system

4. The Conceptual Design

The conceptual design is the phase of the design process that generates a design of a system from a detected and clear need of the customers to meet their need in the best possible way. The conceptual design includes two major sub phases: 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 [15].

In Figure 2 is presented the global function of this smart microgrid 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.

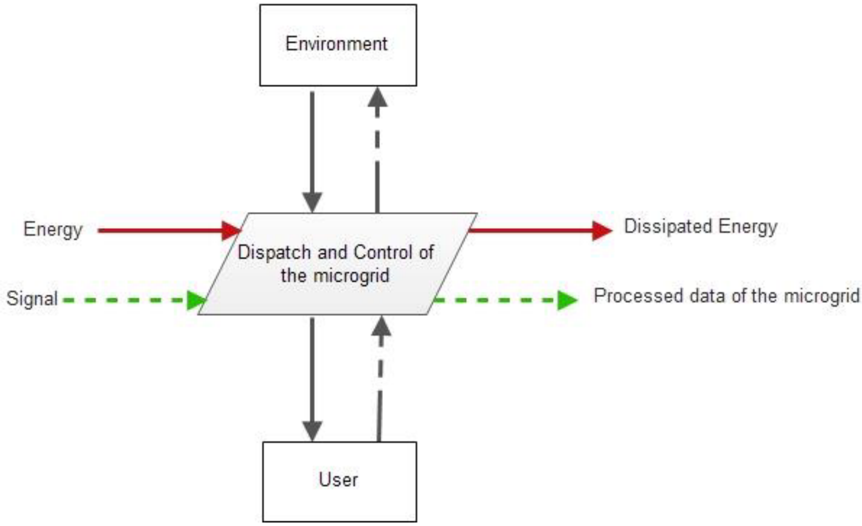

Figure 3. Global function of the smart microgrid system.

5. Final Remarks

This paper presents a part of the modular system design approach of the smart microgrid system. The first phase is here presented as the informational design phase. The importancy of this phase is the establishment of the specifications of the smart microgrid platform with the defined requirements of the system to be designed through different tools and documents as known in the design of products or systems. In this work is elaborated the modular system method approach, because the methodologies of the modular system are used throughout the design. The design of the smart microgrid laboratory platform for the university campus is divided in stages and steps with their inputs and outputs. The life cycle of the system presents the stages through which the smart microgrid platform goes from the beginning of the design process up to the end of the system, where the design is completed and the system is already in full operation in this case. In this work is finally presented the first step of the conceptual design phase, that enhances a process that is also divided in different stages. The first step of the conceptual design phase is here the establishment of the functional structure of the smart microgrid platform. In this work is presented the global function of the system as the first step, whereby the next stage will be to define the partial functions and the elementary functions. These functions will represent the overall functions of the smart microgrid system design. Through the roadmap followed for the design of the smart microgrid system, the next step in the conceptual design phase will be the identification of the modules of the smart microgrid system. These modules will enable the design of a modular system for the smart microgrid platform of the university campus, to be developed in stages.

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