Faculdade de Engenharia da Universidade do Porto

Monitoring photovoltaic converters using Wireless Sensor Networks

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Activity report

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DELIVERY VERSION

Programa Doutoral em Engenharia Electrotécnica e de Computadores

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July 8, 2017

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Contents

1 Introduction

This chapter presents the context, motivation and document structure of the activity report of monitoring photovoltaic converters using Wireless Sensor Networks.

1.1 Context and motivation of PhD

The railway system is responsible for 1.3% of entire European energy consumption, Birol and Loubinoux (2016). The discussion of the energy efficiency in railways is a grown topic due to its contribution to the global energy consumption.

The energy efficiency analysis and management requires a detailed mapping of the energy consumption/generation in the railway system.

This detailed mapping of the energy flows should include, not only the rolling stock level but also the traction substations and the auxiliary services.

The knowledge of all the load curves permits the load prevision, peak shaving and energy cost optimization for all global railway system.

1.2 Context and motivation of monitoring PV converters using WSN's

This activity report is inserted in the scope of a microgeneration project of the SYSTEC Research Unit. Currently, several work has been done in this project to implement a monitoring subsystem. This work focuses on data collection from each power converter and also on its control by sending references and actions. At the moment of this proposal, no work has been done to implement the monitoring feature in the PV converters. This way, a wireless network implementation is proposed to monitor the PV power converters.

The PV converter uses a non-isolated high gain DC/DC topology and has a PIC32 microcontroller which implements a MPPT algorithm in the control loop. It is currently possible to connect a device with wireless capabilities to the PV power converter. The converter is able to provide power and data. The data collected from the monitoring device is sent to an aggregator node for post processing and data storage. Currently, several work has already been done to have a reliable wired data aggregator/concentrator. This subsystem is also responsible for sending user commands to the power converters and presenting the user interface in a webpage remotely accessed via a web browser.

1.3 Document structure

This document is divided in 5 chapters, each of them incorporate the relevant subsections to present the subjects mentioned.

Table 1.1: Document structure

Chapter	Title
1	Introduction
2	System Specification
3	Development of Wireless Monitoring System
4	Results and Discussion
5	Conclusions and Future Work

2 System Specification

In this chapter, the system specification is defined, starting with the overview of the existing communication systems and defining the SRS. After that is made a market survey on the existing technologies and raised the protocols, standards and communication KPI's.

2.1 Overview of the existing wireless communication system

In the attachment 1 is presented a work that highlights the communication systems for energy metering systems used in smart meters. On the field of the wireless technologies we can list the following technologies to be applied in this work:

- IEEE 802.15.4 (ZigBee);
- DASH7;
- IEEE 802.11 (Wireless LAN (WLAN) or Wi-Fi);
- IEEE 802.16 (WIMAX);
- GSM or GPRS;
- LTE/LTE-Advanced.

For the purpose of this work, the usage of medium distances is advantageous (on distances of hundreds of meters). Complementary, solutions that depends on a service provided by a communication enterprise are not interesting.

The research areas of interest on the WSNs in the last decade are the following:

- Propagation characteristics & channel modeling
- Protocols design (routing, MAC)
- Energy conservation
- Security
- Topology Control

2.2 System Requirement Specification

In the attachment 2 is present the SRS document. This document uses the following structure (based on a template from Generic Ethernet Gateway (GWAY) developed by Chrysler Group LLC):

Introduction This part describes the purpose of the document, the scope and the context of the system/project where is implemented;

Overall Description In this part is described the system, it's objectives and features as well as some design and implementation constraints;

Specific requirements This part defines the specification of the requirements that the system must comply with;

Data Model and Description This part covers the definition of the system in UML diagrams and descriptions.

The definition of the system with this document allows the system specification according to the main goal of this activity: the development of a Wireless network to monitor existent PV power converters.

2.3 Market survey on wireless technologies

The market survey was conducted to cover recent technologies among manufacturers with enhanced market share.

2.3.1 Atmel – SAM R21 Xplained Pro Evaluation Kit

http://www.atmel.com/tools/atsamr21-xpro.aspx

The Atmel SAM R21 Xplained Pro evaluation kit is a hardware platform to evaluate the ATSAMR21G18A microcontroller. Supported by the Atmel Studio integrated development platform, the kit provides easy access to the features of the Atmel ATSAMR21G18A and explains how to integrate the device in a custom design. The Xplained Pro MCU series evaluation kits include an on-board Embedded Debugger, and no external tools are necessary to program or debug the ATSAMR21G18A. The Xplained Pro extension kits offers additional peripherals to extend the features of the board and ease the development of custom designs.

In synthesis, this platform is based on a single chip solution that integrates in the same integrated circuit an ARM® Cortex®-M0+ processor and an integrated ultra-low-power 2.4GHz ISM band transceiver. It's relevance is on the ultra-low-power consumption (less that $70\mu A$ in active mode and less than $3.5\mu A$ in sleep mode).

Figure 2.1: SAM R21 Xplained Pro module.

2.3.2 CC1310 SimpleLink™ Sub-1 GHz Ultra-Low Power Wireless Microcontroller

http://www.ti.com/product/CC1310

The CC1310 is a member of the CC26xx and CC13xx family of cost-effective, ultra-low-power, 2.4-GHz and Sub-1 GHz RF devices. Very low active RF and microcontroller (MCU) current consumption, in addition to flexible low-power modes, provide excellent battery lifetime and allow long-range operation on small coin-cell batteries and in energy-harvesting applications.

The CC1310 device is the first device in a Sub-1 GHz family of cost-effective, ultra-low-power wireless MCUs. The CC1310 device combines a flexible, very low power RF transceiver with a powerful 48-MHz Cortex®-M3 microcontroller in a platform supporting multiple physical layers and RF standards. A dedicated Radio Controller (Cortex®-M0) handles low-level RF protocol commands that are stored in ROM or RAM, thus ensuring ultra-low power and flexibility.

Figure 2.2: CC1310 evaluation board.

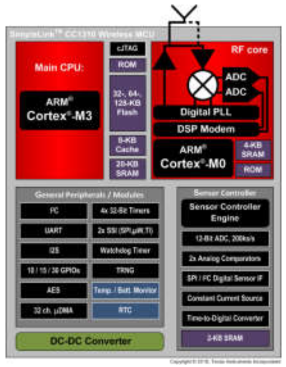

Figure 2.3: CC1310 chip architecture.

The CC1310 is a Texas Instruments platform launched to operate the sub-GHz frequency band. It depends on a ARM® Cortex®-M3 processor and an integrated ultra-low-power RF Core. It is integrated in the category of "Wireless MCU's" due to it's integration of CPU and RF core, similarly to the Atmel SAM-R21 previoulsy presented platform.

2.3.3 Adafruit Feather 32u4 Radio (RFM69HCW)

https://learn.adafruit.com/adafruit-feather-32u4-radio-with-rfm69hcw-module/overview

This Adafruit Feather 32u4 Radio (RFM69HCW) 900MHz microcontroller packet radio transceiver with built in USB and battery charging. 32u4 with a 900MHz radio module cooked in an Adafruit Feather. Great for making wireless networks that can go further than 2.4GHz 802.15.4 and similar, are more flexible than Bluetooth LE and without the high power requirements of WiFi. The 900MHz radio version can be used for either 868MHz or 915MHz transmission/reception. At the Feather, 32u4's heart is at ATmega32u4 clocked at 8MHz and at 3.3V logic. This chip has 32K of flash and 2K of RAM, with built in USB so not only does it have a USB-to-Serial program and debug capability built in with no need for an FTDI-like chip, it can also act like a mouse, keyboard, USB MIDI device, etc.

2.3.4 Adafruit Feather HUZZAH ESP8266

https://learn.adafruit.com/adafruit-feather-huzzah-esp8266/overview

This is the Adafruit Feather HUZZAH ESP8266 - our take on an 'all-in-one' ESP8266 WiFi development board with built in USB and battery charging. At the Feather HUZZAH's heart is an ESP8266 WiFi microcontroller clocked at 80 MHz and at 3.3V logic. This microcontroller contains a Tensilica chip core as well as a full WiFi stack. You can program the microcontroller using the Arduino IDE for an easy-to-run Internet of Things core. We wired up a high-quality SiLabs CP2104 USB-Serial chip that can upload code at a blistering 921600 baud for fast development time. It also has auto-reset so no noodling with pins and reset button pressings. The CP2104 has better driver support than the CH340 and can do very high speeds without stability issues.

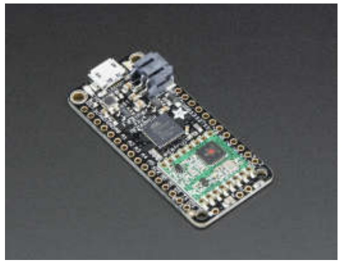

Figure 2.4: Adafruit Feather 32u4 Radio (RFM69HCW).

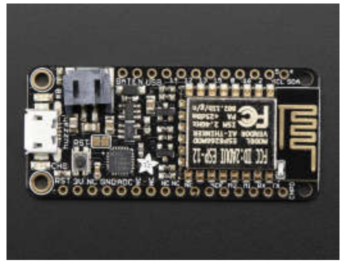

Figure 2.5: Adafruit Feather HUZZAH ESP8266.

Both Adafruit Feather modules (for sub-GHz and for WiFi) are designed for cheap and modular solutions.

2.3.5 ATxmega256A3U AT86RF233 ZigBit Module

http://www.atmel.com/pt/br/devices/ATxmega256A3U-and-AT86RF233-ZigBit-Wireless-Module.aspx

The Atmel ZigBit 2.4GHz ATZB-X0-256-3-0-C wireless system-on-module is designed to work with IEEE 802.15.4 and ZigBee WPAN communication protocols. The ZigBit module is compatible with a ZigBee stack that supports a self-healing, self-organizing mesh network, while optimizing network traffic and minimizing power consumption.

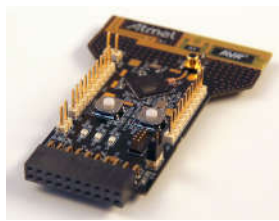

Figure 2.6: ATxmega256A3U AT86RF233 ZigBit Module.

2.3.6 CC1350 SimpleLink™ Ultra-Low Power Dual Band Wireless Microcontroller

http://www.ti.com/product/CC1350

The CC1350 is a member of the CC26xx and CC13xx family of cost-effective, ultra-low-power, 2.4-GHz and Sub-1 GHz RF devices from Texas Instruments™. Very low active RF and microcontroller (MCU) current consumption, in addition to flexible low-power modes, provide excellent battery lifetime and allow long-range operation on small coin-cell batteries and in energy-harvesting applications.

The CC1350 is the first device in the CC13xx and CC26xx family of cost-effective, ultra-low-power wireless MCUs capable of handling both Sub-1 GHz and 2.4-GHz RF frequencies. The CC1350 device combines a flexible, very low-power RF transceiver with a powerful 48-MHz ARM® Cortex®-M3 microcontroller in a platform supporting multiple physical layers and RF standards. A dedicated Radio Controller (Cortex®-M0) handles low-level RF protocol commands that are stored in ROM or RAM, thus ensuring ultra-low power and flexibility to handle both Sub-1 GHz protocols and 2.4 GHz protocols (for example Bluetooth® low energy). This enables the combination of a Sub-1 GHz communication solution that offers the best possible RF range together with a Bluetooth low energy smartphone connection that enables great user experience through a phone application. The Sub-1 GHz only device in this family is the CC1310.

This CC1350 adds the Bluetooth® low energy functionality to the CC1310 module with small increase on the cost of the solution.

2.4 Protocols and standards

In computer networks, a protocol is a set of rules that ensure a communication of specific set of information between two machines. A standard is a document that specifies several aspects of something that has the overwhelming agreement and support of a entity (the standards making body). In the networking area, several protocols are supported by standards. In this section is presented some of the protocols that ensure a coherent communication among the sensor networks.

2.4.1 IEEE 802.15

The standard family defines the topologies and network roles. In particular, it defines the physical (frequency and channels, spectrum handling, modulation and bit rate) and MAC (packet formats, operational modes, timing aspects, topologies) layers of the OSI model (Hackmann (2006)).

Based on figure 2.7, the 802.15.4 is the standard that defines the PHY and MAC layers for low rate wireless personal area networks. It supports **full-function devices** (device capable of being the network coordinator or simple node and can have implemented complex network functionalities) and **reduced-function device** (limited devices with low-bandwidth limitations and limited or no-network intelligence). The possible network topologies are the following:

Star — Each device in the network communicates with the full-function device network coordinator;

Peer-to-peer — All devices communicate with each others (if they are in the communication range). Sufficiently flexible to implement more complex topologies such as multi-hoping, cluster trees and mesh topologies;

Standard	Description	Initial Release / Revision Date	Amendments
IEEE 802.15.1 (Bluetooth)	MAC and PHY Layer Specifications for Wireless Personal Area Networks (WPANs)	2002 / 2005	Bluetooth Core Configuration v4.0 and Bluetooth Low Energy (2009)
IEEE 802.15.2	Coexistence of Wireless Personal Area Networks With Other Wireless Devices Operating in Unlicensed Frequency Bands	2003	In hibernation since 2011.
IEEE 802.15.3	MAC and PHY Layer Specifications for High Rate Wireless Personal Area Networks (HR-WPANs)	2003	802.15.3b (2006): Amendment to MAC Sublayer 802.15.3c (2009): Millimeter-wave-based Alternative Physical Layer Extension
IEEE 802.15.4	MAC and PHY Layer Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)	2003 /2006/ 2011	802.15.4.a (2007): PHY Layer Extension to Chirp Spectrum Techniques and UWB systems 802.15.4c (2009): Alternative PHY Extension to support one or more of the Chinese 314-316 MHz, 430-434 MHz, and 779-787 MHz bands 802.15.4d (2009): Alternative PHY Layer Extension to support the Japanese 950 MHz bands 802.15.4e (2012): Amendment 1: MAC sub-layer 802.15.4f (2012): Active Radio Frequency Identification (RFID) System PHY 802.15.4j (2013) – Alternative PHY Extension to support Medical Body Area Network (MBAN) services operating in the 2360-2400 MHz band
IEEE 802.15.5	Mesh Topology Capability in Wireless Personal Area Networks	2009	-
IEEE 802.15.6	Wireless Body Area Networks	2012	-

Figure 2.7: Members of the 802.15 family. Adapted from Panousopoulou (2014) lecture presentation slides.

Multi-hopping — This is a technique that allows the usage of two or more wireless nodes to convey data from a source to a destination;

Cluster trees Topology to reduce the routing complexity where each node knows its parent node and all it's child nodes. It has always only one single path between two nodes.

Wireless mesh This technique allows data to be propagated along a path by hopping from node to node until it reaches its destination.

2.4.2 802.15.4-based wireless standards

Radmand et al. (2010) presents a comparison of wireless sensor standards for industrial applications. In figure 2.8 is present the overall schema of the wireless standards.

2.5 Communication KPI's

According to Radmand et al. (2010), it is identified the following "Industrial Requirements" for the WSN's:

Reliability — Reliability is a measurement of the transmission accuracy, in percentage, that evaluates the amount of data that reach it's destination. This measurement uses the properties of data communication, acknowledge-based usually.

Latency — Latency is the measurement of the time delay and is defined as the time that a data packet takes to be transmited from the source to the destination. The latency is directly related to the link quality and a high latency link is result of a link with high signal-to-noise ratio.

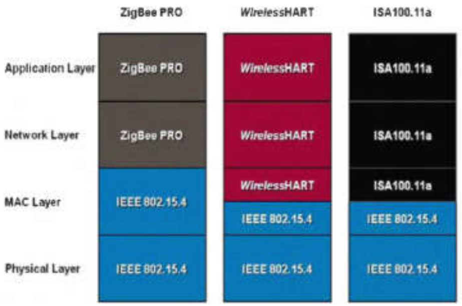

Figure 2.8: Overall schema of wireless standards. Adapted from Radmand et al. (2010).

Sensor Data Update Rates — This KPI is not directly related with the communication link. However the update rate of the sensor data affects the power consumption due to the increase of the processing effort. In a SYNC-based update rate, this KPI is related to the frequency of the SYNC event.

Wireless Transmission Range — This KPI is the the maximum distance that a communication link supports the data transfer with a given reliability and in specific conditions (indoor/outdoor; line-of-sight or LOS).

Power consumption — The power consumption is a measurement of the combination of the computational effort of the nodes and the transmission effort. It is directly related with the update rate as well as with the link quality and, if it exists, the routing activity in each node.

3 Development of Wireless Monitoring System

In this chapter is presented the development of the wireless monitoring system, following the specifications and requirements raised in the chapter 2. This chapter is divided in four parts, starting with the description of the selected wireless technology. In 3.2 and 3.3 is presented the hardware and software architecture of the system. Communication results and KPI metrics are presented in section 3.4. In section ?? is made the discussion of the results.

3.1 Description of the selected wireless technology

The CC1350 platform was selected to fulfill the wireless requirements. The availability of Sub-1 GHz and Bluetooth technologies in the same device allows enough flexibility in terms of possible functionalities to be implemented. The powerful 32-bit ARM Cortex-M3 allows the implementation of a Real-time Operating System, capable of handling several tasks.

3.2 Hardware architecture

The hardware architecture depends on serial communication between the power converter and the wireless node. Complementary, it depends on serial communication between the concentrator and the end user applications (serial monitor, Raspberry Pi and concentrator LCD). Figure 3.1 presents the hardware architecture.

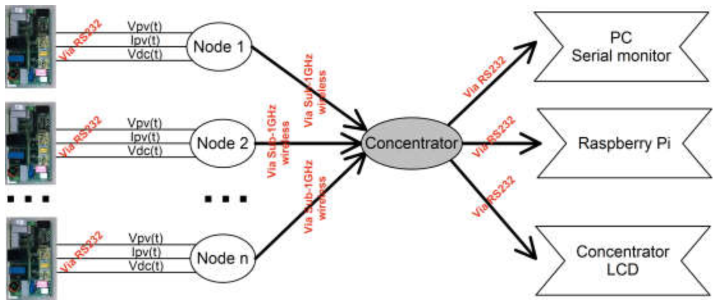

Figure 3.1: Hardware architecture.

The communication interface between node and power converter must support different voltage levels (in particular 3.3V from CC1350 node and 5V from power converter). This way, an electronic board (PCB) was developed to support this constraint. Complementary, this PCB allows a robust mechanical interface between the wireless node and the power converter, without extending the dimensions defined in the SRS. This PCB integration with wireless node and the power converter is presented in the figure 3.2.

Figure 3.2: PCB integration with wireless node and the power converter.

On the concentrator side, the CC1350 development board has available the USB serial communication as well as the LCD as shown in figure 3.3.

Figure 3.3: Concentrator connected to RPI.

3.3 Software Architecture

As proposed in the SRS, figure 3.4 presents the domain model of the software to be implemented in the concentrator and nodes.

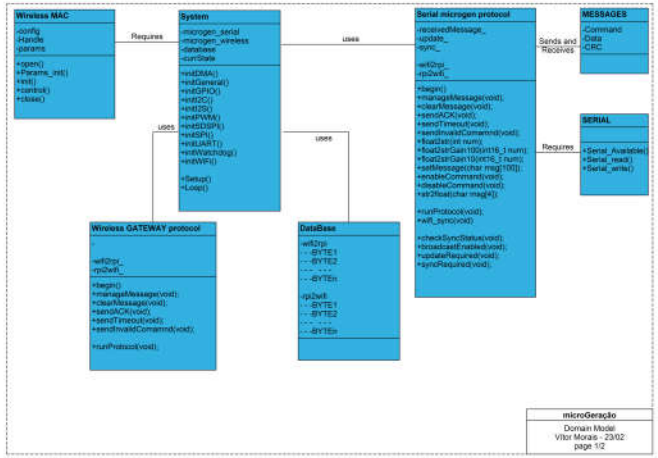

Figure 3.4: Domain Model Diagram.

The software architecture was based on a proprietary implementation of a WSN by the manufacturer of the CC1350 (Texas Instruments). In the power converter side, a serial request-response protocol was implemented. In addition, the database was constructed based on flowchart of figure 3.5.

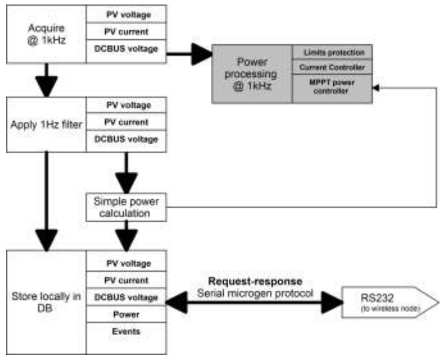

Figure 3.5: PV power converter implemented software.

The power converter acts as a communication slave that responds upon wireless node requests. The following list presents the data exchange between both devices:

#VPV#03# Request for panel voltage, with 0,1V precision;
#IPV#03# Request for panel current, with 0,01A precision;
#VDC#03# Request for DC Bus voltage, with 1V precision;
#PWR#03# Request for PV power, with 1W precision;
#EVE#03# Request for PV power converter events;
#WHOIS#05# Request for board identification.
#SYNC#04# Request for Database synchronization.

The remote node will request for the values in the PV power converter database. At a 1 second period, the data is sent to the data concentrator.

3.4 Communication results

In figure 3.6 and 3.7 is presented the pretended test-bench for the wireless nodes.

Figure 3.6: Back view of microgeneration system.

Figure 3.7: Detail of wireless module

3.4.1 Validating the electric measurements

The first results collected by the wireless node are presented in figure 3.8. Identified in red in the graph are presented the three electric tests: a) increase of the DC_bus voltage with a voltage controlled source; b)increase of the DC current in the PV current transducer, with a current controlled source; c) Increase of the PV DC voltage, with a voltage controlled source. As a consequence of the power converter topology, the DC_bus voltage increases due to a diode between two sides of the converter.

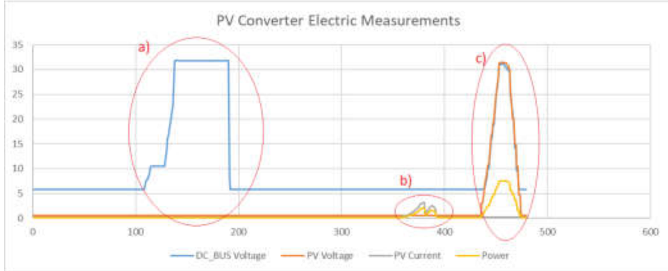

Figure 3.8: PV power converter electric measurements. (horizontal axis in seconds)

3.4.2 Validating the wireless communication

The Texas Instruments WSN implementation used evaluates the wireless strength of the received data. In figure 3.9 is presented the Received Signal Strength Indication (RSSI), as a measurement of the power present in a received radio signal.

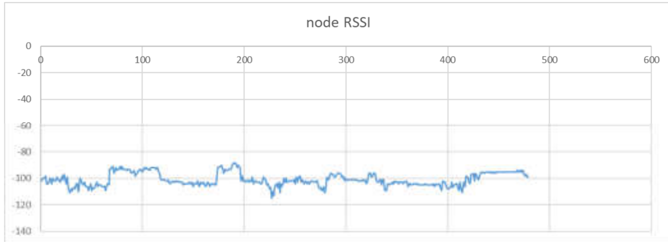

Figure 3.9: PV power converter electric measurements. (horizontal axis in seconds)

Complementary, the existence of multiple nodes was validated, as presented in the raw data of the concentrator verified in figure 3.10.

Waiting for nodes...							
0x0e	739	0	-101	0	0	0	0
0x0e	761	0	-102	58	6	2	1
0x0e	759	0	-102	58	6	2	1
0x0e	759	0	-102	58	6	2	1
0xf0	448	0	-111	0	0	0	0
0x0e	759	0	-102	58	6	2	1
0xf0	448	0	-106	0	0	0	0
0x0e	756	0	-103	58	6	2	1
0xf0	448	0	-106	0	0	0	0
0x0e	756	0	-103	58	6	2	1
0xf0	445	0	-97	0	0	0	0
0x0e	757	0	-103	58	6	2	1

Figure 3.10: Concentrator raw data received.

4 Conclusions and Future Work

With this work, we propose and implement a solution for the wireless monitoring of power converters. The main challenge of this wireless monitoring is to obtain energy data of a system in a harsh environment. The motivation for this work is to study the implementation of a wireless monitoring system in railway environment, based on the outcomes of the implementation of such monitoring system in a renewable energy generation system.

The system specification was defined, with the construction of a System Requirement Specification (SRS) document as the main outcome. In addition, it was performed an overview on existing wireless communication systems, a market survey on available technologies, and the protocols, standards and communication KPI's was raised.

A specific technology was selected, on the family of wireless MCU's. The implementation stage complies with the definition of the hardware and software architecture. The communication results validates the acquisition of electric measurements from multiple PV power converters.

The lack of data results is clear. Any of the communication KPI's was not evaluated due to the need of further development. This further development depends on a new solution for the interface between the power converter and the wireless node, since the communication link is highly affected by the noise of power converter.

For future work is clear the need of evaluating all the proposed communication KPI's. This task requires a new electronic board to interface the remote node. Complementary, the data concentrator should be improved to implement a local database and a serial request-response protocol to exchange data with the microgeneration system master.

We conclude that the methodology followed and the proposed solution validates the objective of this work, which is the wireless monitoring of a power converter.

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Attachment 1 — Overview of communication systems for Smart Grids

Study of communication systems for smart grids

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Supervisor: António Pina Martins

June 14, 2017

Contents

Chapter 1

Communication systems

This chapter presents the relevant communication approaches used in Metering Systems. In first section the reader is introduced to the subject. The topologies and requirements of communications in metering systems are presented. Then, divided between the communications in Automatic Meter Readers (AMR) and in Smart Metering (SM) systems, are presented each technologies with all the important features, benefits and constrains. Standardization procedures are presented starting with the standards in Europe and ending with a brief coverage on the worldwide standardization methodologies. In the last section is intended to present the research opportunities in smart metering communication.

1.1 Introduction

The innovation and evolution in the communications gives a considerable credit for the practical accomplishment of the important features of the Smart Grid (SG). The advance development in the wired and wireless, as well as the opportunity to use of low cost interoperable devices are the main points for this increase in the innovation and evolution in the communications, [1].

The need for having an improved employment of power generation sources, expanded productivity, adherence to regulatory constrains, enhanced costumer experience and low carbon fuel dependence are the motivation for the Smart Grids and one of their crucial parts, the smart meters, [2].

Currently, the existent electrical utility systems have a hybrid combination of communication technologies. This technologies support a vast range of applications like as SCADA/EMS, distribution feeder automation, generating plant automation and physical security, [1].

Being the renewable energy power grids a distributed system with multiple networks, energy sources and loads, there is a need to have an effective communication and coordination to monitor, analyse and stabilize the grid at various hierarchical levels, [2].

1.2 Topologies of Metering

In this chapter there are evaluated two topologies of metering, the systems based on automatic meter reading devices and the smart metering systems.

A substantial part of an AMR based system is based on a unidirectional communication connecting the meter to the data concentrator. For AMR communication networks, four important technologies are considered: first, Power Line Communications (PLC) allows communication over the existing energy line, in second, telephone/Internet lines that uses the telephone infrastructure for a wired connection, in third, the cellular network that allows wireless communication over a long distance and finally, short range radio frequency for low distances, [3].

Smart Metering Systems use some of the same means of communication of AMR. However the bidirectional communication is inherent to Smart Metering Systems. Even if there are considered a wide range of topologies and architectures to be used in Smart Grids, the most common is a topology where the Smart Meter collects data from several devices, in a Home Area Network (HAN), mostly in the wireless domain, and sends the collected energy data to a data concentrator that connects several Smart Meters in a distributed Metropolitan Area Network (MAN). A central command center receives the data from all data concentrators and in this command center resides the data storing, the servers and the processing facilities, including the management and billing applications, [4].

1.3 Requirements of Communication

1.3.1 AMR technical requirements and performance metrics

Certain quality requirements should be met by an AMR network. In a new design of a AMR network, those quality requirements are given by the following quality metrics, [3].

Reliability: A major requirement of the AMR network is the insurance and guarantee that all meter readings are received as well as all utility server control packets. A fair assessment of the given network is made by performance metrics such as the success rate and the loss rate.

Scalability: It is mandatory to made the assessment of a designed network focusing on the ability of providing support to several meters that ate placed in a large geographical area. Moreover, this scalability metrics is also related to the frequency of the readings.

Real time communication: The data transfer between the energy meter and the data storage unit is required to arrive within a given amount of time. Therefore, a performance metric evaluating the end-to-end delay is required.

Order: Each packed received is required to be identified with the time of the measurement, to ensure that, at the receiving station, the packet ordering is guaranteed.

Security: The security in communication is required to be guaranteed. Having this on mind, the level of the security implemented in a meter-station communication is expressed in terms of the implemented cryptographic tools used in the different protocol stack layers and the number of the bits used. Usually, at lower layers the implemented security is hop-to-hop and between both ends of the AMR application is implemented a end-to-end security.

On the field of Data Collection Mechanism, to accomplish large varieties of data with a high bandwidth, the devices must support three modes of communication: fixed scheduling (where the acquired data is reported at fixed intervals), event-driven (where the data are generated and transmitted due to events on meters) and demand-driven (where the data packets are transmitted upon a request made by the data collection center), [3].

1.3.2 Smart Metering Systems requirements

A bidirectional communication is essential for Smart Metering Systems. The ability of sending the acquired data to the analyzing computer as well as receiving service commands from operation center is a major requirement. A standard communication is a necessary part of the AMI and a highly reliable communication network is mandatory for communicating with high volume of data, [4]. The following requirements are essential to design and select an appropriate communication network, [5]:

- Large quantity of information transferred;
- Implementation of restrictions to access the data;
- Ensuring the confidentiality of critical data;
- The complete information of customer's consumption has to be represented;
- Displaying of the relevant information on the status of grid;
- Ensure the authenticity and the precision of information in the communications with final device;
- Promotion of cost effective solutions;
- Have the potentiality of hosting advanced features beyond AMI requirements.
- Support a possible future expansion.

1.4 Communication Systems in AMR

In this section is covered the communication in AMR based systems. Unidirectional communication devices are extremely cost effective and simple to use. The usage of such devices in a metering infrastructure allows the consumption measurement in order to implement Demand Response (DR) programs. Those communication devices allow utilities to alert program applicants and/or the appliance directly about a DR event, [6].

Considering a meter device functionality as a sensor node providing energy consumption measures, the number of metering devices can increase up to thousands, [3].

Starting from the wired technologies and then covering the wireless ones, the communication technologies in AMR are the following:

- Power Line Communication - Narrowband;
- Power Line Communication - Broadband;
- Telephone lines;
- Messaging over GSM network;
- Short Range RF communication.

1.4.1 Power Line Communication

Transmitting the data over the voltage distribution lines (electrical power), Power Line Communication is a communication technique to transmit data signals from one device to another, [3; 2].

Similarly to wireless communication in a certain way, it has the advantage of not requiring extra cabling. However, this technology depends on several factors (such as the speed of propagation, the chosen frequency, the voltage level carried, the distance that separates two communicating devices and the presence of transformers), affecting the PLC propertiessuch as limited bandwidth, [3].

PLC Narrowband Topology

The PLC Narrowband topology has a limited bandwidth at low frequency with low attenuation (very few dB per kilometer), limited bitrate and long packet dimension. It has an operating range of 3–500 kHz including CENELEC, ARIB and FCC specified bands, [6; 1]. It is distinguished between High and Low data rate narrowband PLC, depending if it uses a single carrier or multi-carrier.

In most recent advances of this technology using multi-carrier based technology and mainly based on orthogonal frequency division multiplexing (OFDM), This technology can achieve data rates up to 1Mbps. However, in order to guarantee a quality of service (QoS) level that is suitable for SG control, robust coding techniques are required and consequently the available rate, at the physical layer, should not exceed 50 kbps, [6; 1].

PLC Broadband Topology

The Broadband PLC technology operates in a range between 2 MHz and 250 MHz having data rates achieving several hundred Mbps. This technology is suitable for in-home communications, where the low coverage is only up to few hundreds of meters (due to the high attenuation), [6; 1].

Despite the coverage area limit on this technology, applying this technology to SG is possible, by limiting the available bitrate (to 3.8 Mbps, by setting modulation parameters to robust mode choices). This technology allows short packet durations (much less shorter than the 20 ms electrical cycle), which are well suitable to guarantee optimal operation of real-time algorithms, [6].

Comparison of topologies: PLC Broadband vs PLC Narrowband

Both technologies are of extreme importance on the development of smart grid solutions, due to its advantages. The PLC Narrowband is more appropriate to the data acquisition and communication objectives in Smart Grid. The additions to Smart Grid Applications on the field of End User Internet applications are one field where PLC Broadband is more suitable, [1].

1.4.2 Telephone Lines

Invented by Alexander Graham Bell in 1876, the telephone has been an important mean of communication. In 1958 data transfer was added over telephone lines to fulfill the desire of transferring data between remote machines, [7].

With the increase of bandwidth needs, Asymmetric Digital Subscriber Line (ADSL) technologies extended the signaling to upper frequencies (up to 1.1 MHz in ADSL1 and ADSL2, and up to 2.2 MHz in ADSL2plus). Standardized in 2003, ADSL2plus is one of the most widely used broadband technologies that are currently available, [7].

Telephone lines are preferable and they offer high reliability with relative lower costs, and its operation is straightforward. An AMR system can achieve the inbound, outbound, or bidirectional communication functionality using telephone lines, [3].

However, the availability of having telephone lines covering each automatic meter is a constraint since it is not always satisfied, [3].

1.4.3 Messaging over GSM Network

On the wireless side, the communication technologies used in AMR are Messaging over GSM Network and Short range RF communication. Starting with Messaging over GSM Network, one important service is the Short Message Service (SMS) that has turned into a communication protocol that allows devices to transfer delay-tolerant messages, [3].

Different standards supports SMS technology, namely Global System for Mobile communications (GSM), Digital Advanced Mobile Phone Service (D-AMPS) and Code-Division Multiple Access (CDMA2000). Researchers has been attracted to use SMS service due to his recognition and broad coverage of GSM networks. However, latency increases starting on several minutes to hours and failure rate is considerable, [3].

1.4.4 Short Range Radio Frequency

The second wireless technology considered in AMR systems is the Short range Radio Frequency (RF). This technology deals with low-power RF equipments at the customer site and several solutions are classified covered by RF: Bluetooth, WiFi, Zigbee, where they are dependent of the frequency bandwidth and the signal power, [3].

A few solutions presented in [3] propose the usage of short range RF as a part of data communication between AMR and a data concentrator. In next section some of the technologies used in the past to collect data from AMR's has been intensively used in smart metering systems.

1.5 Communications in Smart Metering Systems

It is considered that smart meters acts as the access points. The data collected is transmitted from smart meters to aggregation points. By having short distances between nodes, technological solutions having low power consumption and transmission based on wireless are preferable and the dominant solutions for the lower level networks. These wireless networks includes HomePlug, 2.4GHz Wifi, ZigBee and 802.11 wireless networking protocol, [4; 8].

At the aggregation points, backup power is required since it is considered a critical level subsystem. on the lower level, considering the smart meters as a non-critical device, backup power is not needed, [4].

1.5.1 PLC in Smart Metering Systems

Similarly to the AMR communications, The PLC is an available technology for in-home communication and it's advantages are the low cost and easy access to expand and penetrate in the utility provider's territory. However, their disadvantages includes their reduced bandwidth (maximum of 20 Kbps) and decrease of reliability near the transformers due to the data distortion. In remote locations PLC is valuable duo to the lack of coverage of wireless networks to cover a low number of nodes, [4].

1.5.2 Wireless in Smart Metering Systems

The following sections will cover the wireless communications in smart metering systems, starting with the low-rate and low-power communications applied around the smart meters and ending with the high-rate communications (and consequently higher costs and power than low rate communications). With the increasing on demand for higher bandwidth, broadband technologies such as mobile WiMAX, IEEE 802.16e and broadband PLC are expected to be considered and used in newer installations, [4].

IEEE 802.15.4 (ZigBee)

The standard IEEE 802.15.4 imposes conditions in the physical layer and media access control focusing on low-rate (up to 300 kHz) wireless personal area networks. Developed by the Zigbee Alliance and covering the specifications of the IEEE 802.15.4 on the physical layer and the medium access control, Zigbee is a commonly used for low power wireless communication technology. It operates on the ISM bands of 868 MHz, 915 MHz and 2.4 GHz adopting direct sequence spread spectrum (DSSS), [1].

DASH7

On the low-rate field of research, an alternative to Zigbee is the DASH7. Using the ISO/IEC 18000-7 standard to support this wireless sensor network technology, DASH7 is developed to reach active Radio Frequency Identification Devices (RFIDs) and operates at 433MHz band. The advantage is the typical range of 250m (could achieve 5 km) and has a typical and maximum data rates of 28 kbps and 200 kbps, being in this specifically designed for Smart Grid and for applications in Smart Energy.

IEEE 802.11 (Wireless LAN (WLAN) or Wi-Fi)

IEEE 802.11 is the standard for the information exchange between systems and for the telecommunications. The coverage area of this technology is on local and metropolitan area networks (LANs and MANs). The specific requirements are on the Medium Access Control and on Physical Layer. The most popular versions of this standard is the IEEE 802.11b and IEEE 802.11g, that differs in the modulation technique (Direct Sequence Spread Spectrum (DSSS) technique versus Orthogonal Frequency Division Multiplexing (OFDM) modulation technique). The data rates are, respectively, 11 Mbps and 54 Mbps, [1; 9].

IEEE 802.16 (WiMAX)

On the field of the broadband wireless communication there is the Worldwide Interoperability for Microwave Access (WiMAX) under the IEEE 802.16 standard. It is specifically developed aiming the point-to-multipoint communications being applied in fixed and mobile applications and it has data rates up to 70 Mbps over a distance of 50 km. Framed into the smart grid systems, this communication technology is considered as a solution for high data rate communication link to be applied at the backbone of the utilities, [1].

GSM and GPRS

Operating at 900 MHz and 1800 MHz, the Global System for Mobile communications (GSM) is the most used cellular network all over the world. The modulation technique is the Gaussian Minimum Shift Keying (GMSK) and it achieves transfer rates up to 270 kbps. Its architecture consists of four components: the Operation Support Substation, the Network Switching Substation, the Base Station Subsystem and the Mobile handset. Due to its level of development around the world being present in remote locations, this advantage makes this an interesting technology to be applied in Smart Grid applications, [1].

LTE/LTE-Advanced

Long Term Evolution (LTE) is a recent standard for wireless technology that allows high data rates with high capacity and low latency and with a good Quality of Service (QoS). The improved version of this technology, the LTE-Advanced, admit higher capacity with expanded peak data rate of 1 Gbps for the downlink and 500 Mbps for the uplink, obtained on the increase of the spectral efficiency, higher number of active subscribers connected at the same time, and better performance at cell edges, [4]. This technology, for the Smart Metering environment where the high bandwidth and good QoS are mandatory at some communication points.

1.6 Smart Metering Standards

This section will cover the standardization process that has been done in the field of communications in smart metering systems. Several work has been done to gather all players together in order to reach the requirement for communication within a network (the usage of agreed standards and a universal language). On the field of

AMR the following protocols has been proposed: ZigBee, Modbus, M-Bus, DLMS/IEC62056, IEC61107 and ANSI C.12.18, [4].

1.6.1 Smart Metering Standardization Activities in Europe

Framed in 2009/72/EC Directive, to accomplish the vision of smart grid being supported by the technologies referred above, it is mandatory to follow industrial standards in order to ensure reliability and interoperability, [10].

The benefits of Smart Meters are well known and presented previously in this article. Despite there is an interest to implement those technologies across the world, the adopted communications, regulation, standardization and technologies may vary depending on economical, political, geographical, and social factors. These systems are, therefore, highly complex due to the large number of stakeholders involved with direct interest in the process, [10].

The harmonize process of smart metering/grid standards has been done. Besides this clear effort within Europe of harmonization, there is also an effort to have a single establishment of European standards that will be widely used. The focus of this harmonization in on communications, architectures and solutions, [10].

1.6.2 Communication Standardization in Europe

Having standards on metering systems is an activity established either in international and European levels of standardization CENELEC/CEN and ETSI). Starting from the European level, three bodies has a prime objective issued by the Mandate M/441 EN "...to create European standards that will enable interoperability of utility meters which can then improve the means by which customers' awareness of actual consumption can be raised in order to allow timely adaptation to their demands (commonly referred to as smart metering)", [11].

This way five Standardization Technical Committees has been created for the aforementioned purposes.

Smart Meters Coordination Group (SM-CG)

This Technical Committee was setup as a Joint Advisory Group between CENELEC, CEN and ETSI for the establishment of European standards focusing an open architecture to be implemented in utility meters that enables interoperability and improvement of customer awareness on their energy consumption. It target three specific standardization: the electricity meters, the non-electricity meters (gas, water and heat) and the home automation. On the field of functionalities, it has the following points, [10]:

- Promote the remote reading of all metrological data and ensure the provision of these measurements to appropriate market organizations,
- Bidirectional communication between the metering system and designated market organizations,
- The support of advanced billing and tariffying systems,
- The meter is allowed to disable and enable loads or power sources,
- The communication between meters and individual devices within the home/building,
- The meter provides the information via a portal/gateway to an in-home/building display or to other auxiliary equipment.

CENELEC TC 13

Another technical committee is the CENELEC TC 13 with the scope of preparing European Standards (without discarding the utilization of IEC standards) for the measurement of electrical energy and for the controlling of the load on electrical equipments. The activities of TC 13 are related to the development of a common language in AMR/AMI for participating partners, being defined in the IEC 62056 DLMS/COSEM, [10].

Device Language Message Specification (DLMS) is the specification of an application layer, being a widely used concept for the abstract modelling of communication entities. Companion Specification for Energy Metering (COSEM) is a specification applying object oriented models of meters. COSEM provides a view of their functions being based on the available standards for exchanging data between energy meters. A list of roles and functionalities of DLMS/COSEM are presented in , [4; 3].

The role and function of DLMS/COSEM can be defined as, [4]:

- An object model specification of the functionality of the meter as seen from its interface(s).
- An identification system to be applied on every measured data.
- A messaging method that communicates with the model and to converts the data to a frame (a series of bytes).
- A message transport method to exchange the information from the metering device to the data collection system.

CEN TC 294

CEN TC 294 focus his work on the standardization procedures of communication systems to be applied on meters and on their remote reading functionality. The activities of this technical committee arte in the development of the EN13757, covering the standards for all the Meter-bus (M-BUS) and wireless M-BUS, [10].

CENELEC TC 205

This TC focus his work on preparing the standards to cover home and building electronic systems, using Information and Communication Technology. It has also to guarantee the integration of several control and management applications used in homes and buildings. The activities of this TC are the coverage of the deployment of the EN50090 and the EN50491 standards, creating regulations in Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS), [10].

ETSI M2M

The purpose of this TC is to develop standards to be applied in Machine-to-Machine (M2M) communications. The activities of this group are on Next Generation Networks as well as on the 3GPP standards initiative for mobile communication technologies, [10].

1.6.3 World wide standardization

Similarly, the same standardization approach has been applied all over the world. In USA, there is the IEEE P2030, the ANSI, the US NIST and the future Internet Protocol for smart grids in the IETF. Furthermore, the standardization in China is driven by the State Grid Corporation of China (SGCC). Moreover, in India the IEEE Standards Association (IEEE-SA) brought in two new standards, IEEE 1701 and IEEE 1702, focusing on the creation of a multi-source plug-and-play communications environment to be applied in varied smart metering devices, [10].

1.7 Research opportunities and challenges

In this section, a small overview on research opportunities and challenges is presented. This is of particular importance in a primordial research stage. It is divided in four parts: the interoperability of multiple communication technologies, the scalability of solutions, a self-organizing network on existent infrastructure and the approach used in home networking research to smart metering systems.

Interoperability

A relevant feature of smart grids is the interconnection of several energy distribution networks as well as several power generating sources and consumers. This interconnection depends on a communication network that is not influenced by the physical medium used does not depend of the manufacturers and the type of devices. It is suggested generic application interfaces (APIs) and middlware as a interesting improvement for the devices used in smart metering, the systems and the communication networks that contributes for the implementation of smart grids, [10].

Inserted in the railway smart metering environment and framed in the Shift2Rail European Commission program, [12], this research trend has an added value on achieving the goals of interconnecting several devices (independent of the manufacturers and type of devices).

Scalable internetworking solutions

In the field of Wireless Sensor Networks (WSN), the research has the possibility to be extended to smart grid and smart metering systems. Therefore, the global M2M communication infrastructure topology, the service requirements and the device functionalities has the opportunity to be detailed. As previously refered, ETSI has a technical committee towards solving the M2M issues, [10]. On the railway environment, due to the dispersion of the railway system across a large area, the usage of WSN on Smart Metering technical demonstrators is desirable, [12].

Self-organizing overlay networks

With the scale of smart grids and their deployment complexity, telecommunication network systems that supports smart grids are pushed to rely and depend on the existing public networks. A self-organizing network that is upon an existing infrastructure is an approach to contribute to the science on smart grid systems, [10].

Home networking challenges

Framed on the paradigm of the research on home networking, where the developed systems are focused on providing multimedia applications having increased Quality of Service (QoS), as well as zero-configuration of the devices and uninterrupted connectivity to home users, the smart metering systems has an interesting possibility of inheriting these features, [10].

1.8 Synthesis

Several authors cover the communication in smart and non-smart metering systems as a part of the whole infrastructure. Event if it was not followed a specific structure observed in the literature review, the structure of this chapter was based on the work of [4], [3] and [2] where they propose similar coverages to review this thematic.

Based on their work, a literature review was made divided in three stages. In first stage, the requirements of communications in smart and non-smart metering systems was covered as a starting point to have a good overview of the features that communications has to be according with.

In second stage the past, current (and future) technologies in communication are presented, describing theirs benefits and drawbacks and, if possible, the possible integration of those technologies in smart (and non-smart) metering infrastructure.

In the third stage, the standards and directives that regulates those technologies are presented following the work on literature review made by [10].

This three-stage structure (requirements - presentation of technologies - standards) was followed either for smart and non-smart metering systems. Despite the several approaches in the literature to present this thematic, the followed structure presents in advance what is the goal of the communication on those systems before presenting the communication technologies itself and their own standards and regulations around the world.

The last part of this chapter present a brief work of [10] on evaluating the current research opportunities on this field of science. On smart grid systems there is several work that can be performed to contribute to this field. However, the most of those research opportunities on the usage of new communication technologies that are inserted on the development of standards.

For the future work, this following on studying the research opportunities should be continued, not only on the railway environment - where it will be the focus of the future work - but in the smart grid development.

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ATTACHMENT 2 — SYSTEM REQUIREMENTS SPECIFICATION

System Requirements Specification (SRS)

PV wireless monitoring

Using this Document – System Integration Benefits

The System Requirements Specification (SRS) document describes all data, functional and behavioral requirements of the hardware and software under production or development.

Table of Contents

1. INTRODUCTION

This section presents an overview of the SRS to help the reader understand how the document is organized and how to read and interpret it. The System Requirements Specification (SRS) document describes all data, functional and behavioral requirements of the hardware and software.

Renewable Energy System development are inherent to the power electronics development. In the scope of the microgeneration project of SYSTEC-ENERGY Research Unit – Smart Energy Systems and Technologies – a distributed PV harvesting with multiple power converters is in development. Despite of the standalone behavior of the PV power converters, a monitoring subsystem is expected to be implemented.

1.1. Purpose

The purpose of this document is to describe the specific requirements for the Wireless PV monitoring system. This document is intended to provide an unambiguous, concise, and complete list of requirements to help design the Gateway and the nodes attached to each PV power converter. This document will include constraints and show how to use the system.

1.2. Scope

The Wireless PV monitoring system is a system intended to acquire the data and behavior status of each PV power converter.

1.3. Context

Place the software in a business or product line context with the aim for the reader to understand the 'big picture'. Strategic issues relevant to context are discussed.

This work is inserted in the scope of a microgeneration project of the SYSTEC-ENERGY Research Unit. Figure 1 presents the main architecture of this project. Currently, several work has been done in this project to implement a monitoring subsystem. This work focuses on data collection from each power converter and also on its control by sending references and actions. At the moment of this proposal, no work has been done to implement the monitoring feature in the PV converters. This way, a wireless network implementation is proposed to monitor the PV power converters.

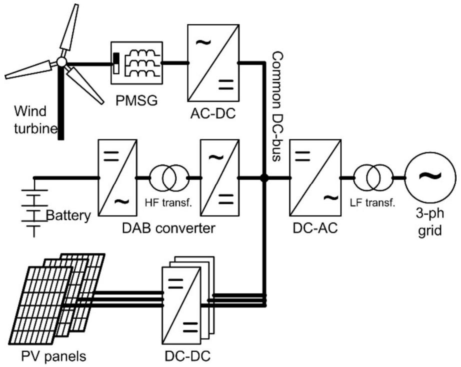

Figure 1 - Main architecture of microgeneration project.

The PV converter uses a non-isolated high gain DC/DC topology and has a PIC32 microcontroller which implements a MPPT algorithm in the control loop. It is currently possible to connect a device with wireless capabilities to the PV power converter. The converter is able to provide power and data. The data collected from the monitoring device is sent to an aggregator node for post processing and data storage. Currently, several work has already been done to have a reliable wired data aggregator/concentrator. This subsystem is also responsible for sending user commands to the power converters and presenting the user interface in a webpage remotely accessed via a web browser.

1.4. Organization

The rest of the document is broken down into seven sections.

Section 2 contains the overall description. In this section, the document will provide information about the system functions. Also included in this section is a description of the constraints needed for safety, as well as any assumptions made in the user characteristics and dependencies.

Section 3 has a hierarchical enumerated list of the requirements the system must fulfill.

Section 4 contains various models that specify the bridge between application domain and machine domain. In this section, UML diagrams and their respective detailed explanations are used to visualize and demonstrate the expected behavior of the system.

Section 5 gives an overview of the prototype, describes how to access it and run it, as well as examples of sample scenarios.

Section 6 gives a list of all the references used to compile this document.

Section 7 gives a point of contact if more information is required.

2. OVERALL DESCRIPTION

Present here a high-level overview of the product being specified and the environment in which it will be used, the anticipated users of the product, and the known constraints, assumptions, and dependencies.

The system to be developed is a wireless monitoring system capable of acquiring data from several PV converters, supporting the mechanical and EMI influences from the environment and being integrated to the current monitoring infrastructure.

2.1. Product perspective

Describe the context and origin of the product being specified in this SRS. For example, state whether this product is a follow-on member of a product family, a replacement for certain existing systems, or a new, self-contained product. If the SRS defines a component of a larger system, relate the requirements of the larger system to the functionality of this software and identify interfaces between the two. A simple diagram that shows the major components of the overall system, subsystem interconnections, and external interfaces can be helpful.

The wireless feature is intended to be added to the monitoring infrastructure supported in a System-on-Chip computer – namely a Raspberry Pi 2 – and the PV power converters.

The diagram in the following figure presents the overall perspective of the development expected by this SRS

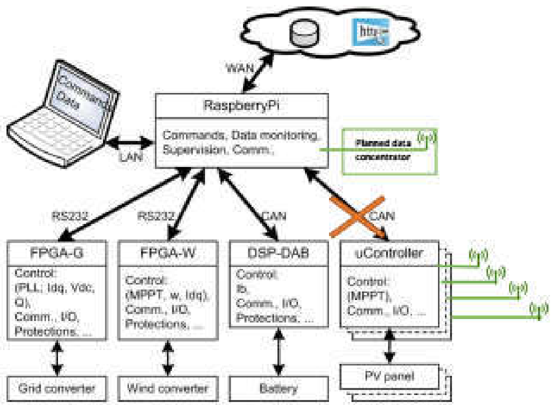

Figure 2 - Communication's architecture of microgeneration project.

The major requirements of the microgeneration monitoring system are the data acquisition and storage, having a website interface that might be easily accessed from the internet (with all the security constrains guaranteed). The relevant data must be identified, collected and transmitted using regular communication channels (RS232, SPI, CAN, etc).

2.2. Product features

Summarize the major features the product contains or the significant functions that it performs or lets the user perform. Details will be provided in Section 3, so only a high level summary is needed here. Organize the functions to make them understandable to any reader of the SRS. A picture of the major groups of related requirements and how they relate, such as a top level data flow diagram or a class diagram, is often effective.

This addition to the microgeneration project has two main objectives:

1. Extend the monitoring feature to the PV power converters
2. Implement and demonstrate a feasible wireless communication between the PV power converters and the head of the system

2.3. User classes and characteristics

Identify the various user classes that you anticipate will use this product. User classes may be differentiated based on frequency of use, subset of product functions used, technical expertise, security or privilege levels, educational level, or experience. Describe the pertinent characteristics of each user class. Certain requirements may pertain only to certain user classes. Distinguish the favored user classes from those who are less important to satisfy.

No user classes are expected in this communication module. The user interaction is defined by the upper layer of this system.

2.4. Operating environment

Describe the environment in which the software will operate, including the hardware platform, operating system and versions, and any other software components or applications with which it must peacefully coexist.

This system will be implemented in a cabinet with EMI constrains caused by the power converters. This SRS will include the specification of the hardware platform.

2.5. Design and implementation constraints

Describe any items or issues that will limit the options available to the developers. These might include: corporate or regulatory policies; hardware limitations (timing requirements, memory requirements); interfaces to other applications; specific technologies, tools, and databases to be used; parallel operations; language requirements; communications protocols; security considerations; design conventions or programming standards (for example, if the customer's organization will be responsible for maintaining the delivered software).

The wireless monitoring module to be placed in each PV converter should be attached mechanically and electrically. The figure 3 presents the PV power converter in question.

A design constraint concerns the space in the cabinet, where the PV power converters will be placed in a vertical orientation. The maximum space between boards must be no longer than 11cm (currently each board requires 8,5cm of free space). No extra space is allowed bigger than the PCB.

Figure 3 - PV power converter.

2.6. User documentation requirements

List the user documentation components (such as user manuals, on-line help, and tutorials) that will be delivered along with the software. Identify any known user documentation delivery formats or standards.

Complementary to this SRS document, a brief description of the hardware and software should be developed. This description will support the integration of this monitoring system onto the main system.

2.7. Assumptions and dependencies

List any assumed factors (as opposed to known facts) that could affect the requirements stated in the SRS. These could include third-party or commercial components that you plan to use, issues around the development or operating environment, or constraints. The project could be affected if these assumptions are incorrect, are not shared, or change.

Also identify any dependencies the project has on external factors, such as software components that you intend to reuse from another project, unless they are already documented elsewhere (for example, in the vision and scope document or the project plan).

It is expected that the final solution depends on software developed by the manufacturers for the wireless modules. No extensive analysis and code review is expected to be made upon that software.

2.8. Minimum system requirements

Describe the minimum system requirements for this product (e.g. platform version, disk space, RAM, etc.)

The minimum system requirements is not applicable due to the need for the final solution to select the platform and/or the hardware needed.

3. SPECIFIC REQUIREMENTS

3.1. Operations

3.1.1. The system must collect data from more than 1 PV converter (up to 10 PV converters)

3.1.2. Each wireless node should be powered by 5V

3.1.3. The wireless concentrator should be powered by USB (5V)

3.1.4. The system concentrator node must have an accessible broadcast mode that provides the received raw data from remote nodes.

3.2. Communication

3.2.1. Each wireless node should have a serial communication

3.2.2. The wireless concentrator should have a serial communication

3.2.3. The wireless concentrator should implement the microgen serial protocol

3.2.4. A wireless concentrator must collect data from all the nodes in less than 10 seg

3.2.5. All wireless nodes must send data to the wireless concentrator upon a request.

3.3. Safety/reliability

3.3.1. All data shall be sampled and hold upon a SYNC command.

4. DATA MODEL AND DESCRIPTION

This section presents various UML diagram to help showcase the functions of this PV wireless monitoring.

4.1. Use Case Diagram

A Use Case Diagram visually captures functions of the system. It shows the interactions between external actors on internal functions of the system. The system boundary helps to define the external actors and the internal functions. The extends signify another use case that is similar, with added functionality. Moreover, use case templates are provided to give detailed information for each use case of the system in the diagram. These templates show which actors are involved for a specific use case and shows the system requirement it satisfies.

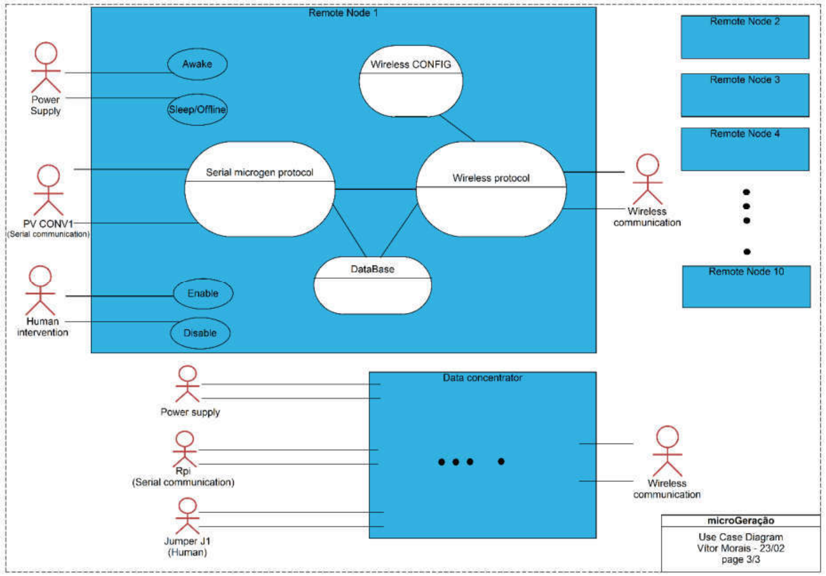

Figure 4 - Use Case Diagram – node

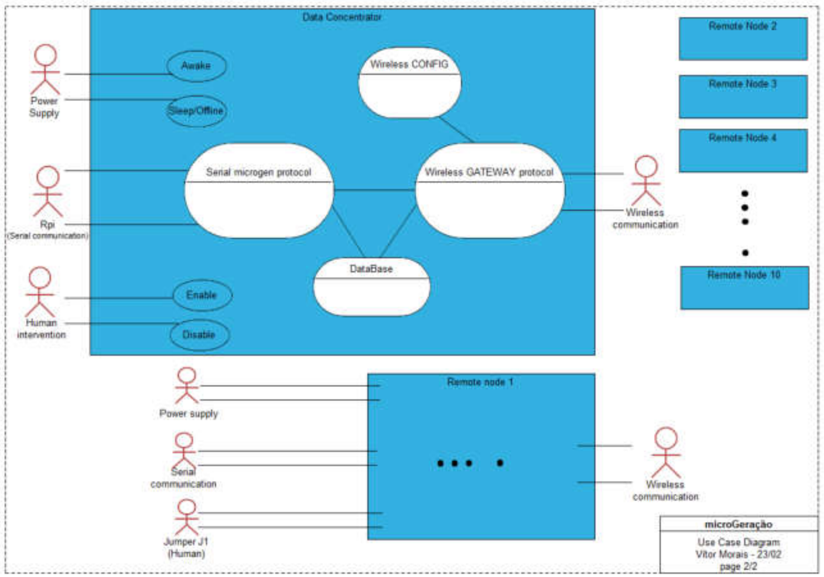

Figure 5 - Use Case Diagram - Data Concentrator

Use case	Awake
Actors	Power Supply
Description	The system should start up when the system voltage threshold is above 4.5 volts.
Type	Primary
Cross-Refs	
Use Cases	All

Use case	Sleep/Offline
Actors	Power Supply
Description	The system should go into sleep mode or offline mode when the system voltage threshold is below 3 volts.
Type	Primary
Cross-Refs	
Use Cases	All but awake

Use case	Enable
Actors	Human Intervention
Description	The system should restart and go to enable mode when the user presses a button (or jumper)
Type	Optional
Cross-Refs	
Use Cases	All but disable

Use case	Disable
Actors	Human Intervention
Description	The system should restart and go to disable mode when the user presses a button (or jumper)
Type	Optional
Cross-Refs	
Use Cases	All but enable

Use case	Serial microgen protocol
Actors	Rpi (serial communication)
Description	The system should execute the serial microgen protocol
Type	Essential
Cross-Refs	
Use Cases	All

Use case	DataBase
Actors	
Description	The system should stores the data and command between serial and wireless
Type	Essential
Cross-Refs	
Use Cases	All

Use case	Wireless CONFIG
Actors	
Description	The system should have stored all the configuration of remote nodes
Type	Primary
Cross-Refs	
Use Cases	All but disable

Use case	Wireless GATEWAY protocol
Actors	Wireless communication (with nodes)
Description	The system should send a SYNC signal to remote nodes; The system should receive all data from remote nodes
Type	Primary
Cross-Refs	
Use Cases	All but disable

Use case	Wireless protocol
Actors	Wireless communication (with concentrator)
Description	The node should broadcast all data to concentrator upon a SYNC command
Type	Primary
Cross-Refs	
Use Cases	All but disable

4.2. Domain Model

The following section contains a domain model and a data dictionary for the system.

In the domain model, boxes represent logical objects within the system. Within the boxes, lines preceded with a "-" represent individual pieces of information that that particular object knows, and lines preceded with a "+" indicate actions a given object can perform. Lines connecting the objects show relationships among the boxes, and include a descriptive name and numbers representing how many of each object is involved.

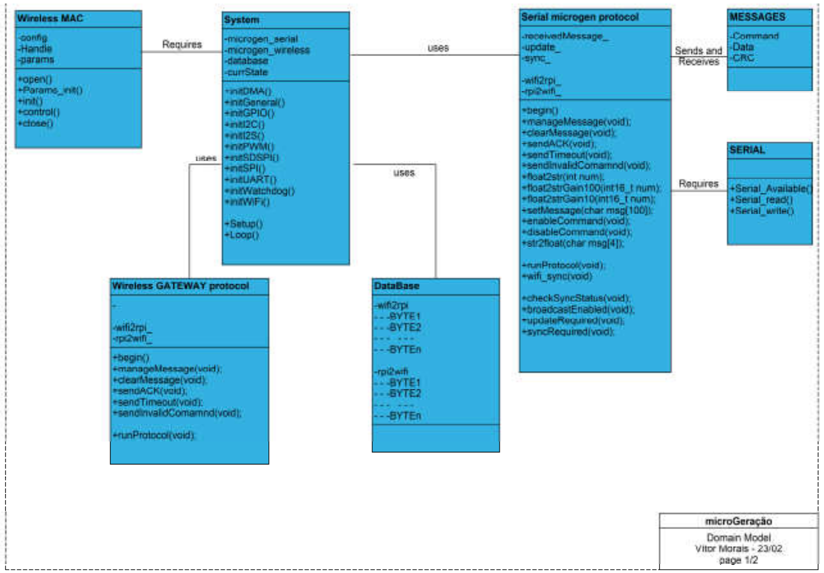

Figure 6 - Domain model diagram – Concentrator

Data dictionary

The data dictionary provides additional detail for every element in the domain model.

Element Name		Description
System		Contains the core functionality of the wireless concentrator node such as programming, protocol dependencies, peripheral and communication ports
Attributes		
	currState	Current state of the system: setup, loop_waitForSerial, loop_waitForWifi, loop_updateDB
	microgen_serial	Object of serial communication protocol between the data concentrator and the raspberry pi
	microgen_wireless	Object of wireless communication protocol between data concentrator and wifi nodes
	Database	Object of data storage
Operations		
	+initDMA()	Initialize board specific DMA settings
	+initGeneral()	This function initializes the general board specific settings.
	+initGPIO()	Initialize board specific GPIO settings

	+initI2C()	Initialize board specific I2C settings
	+initI2S()	Initialize board specific I2S settings
	+initPWM()	Initialize board specific PWM settings
	+initSDSPI()	Initialize board specific SDSPI settings
	+initSPI()	Initialize board specific SPI settings
	+initUART()	Initialize board specific UART settings
	+initWatchdog()	Initialize board specific Watchdog settings
	+initWiFi()	Initialize board specific WiFi settings
	+Setup()	General setup of the system
	+Loop()	General loop of the system

Element Name		**Description**
DataBase		Contains the data to be exchanged between serial and wireless
Attributes		
	wifi2rpi : struct	Data exchanged from wifi nodes to rpi
	rpi2wifi : struct	Data exchanged from rpi to wifi nodes
Operations		

Element Name		**Description**
SERIAL		Contains the serial Hardware layer (HAL)
Attributes		
Operations		
	Serial_Available()	Checks if serial read buffer is available
	Serial_read()	Reads incoming byte
	Serial_write()	Writes message to serial port
Element Name		**Description**
Serial microgen protocol		Contains the class description of the serial protocol implemented in the microgen project
Attributes		
	currState	Current state of the protocol: setup, run
	receivedMessage: array	Stores temporarily the received message
	update : boolean	Flag: if enabled then updates the database for the new data
	sync : boolean	Flag: if enabled then ask device for new messages
	wifi2rpi_	Database: stores the data received via wifi to be sent to rpi
	rpi2wifi_	Database: stores the data (commands) sent by rpi to the wifi
Attributes		
	begin()	Initializes the protocol
	+manageMessage(void);	Processes the received message
	+clearMessage(void);	Clears the received message
	+sendACK(void);	Sends via serial a ACK message
	+sendTimeout(void);	Sends via serial a TIMEOUT message

	+sendInvalidComamnd(void);	Sends via serial a INVALID message
	+float2str(int num);	Converts a number to ASCII and sends it via serial
	+float2strGain100(int16_t num);	Converts a number with 2 decimals to ASCII and sends it via serial
	+float2strGain10(int16_t num);	Converts a number with 1 decimals to ASCII and sends it via serial
	+setMessage(char msg[100]);	Sets message of receivedMessage array
	+enableCommand(void);	Sets command flag to COMMAND_ENA
	+disableCommand(void);	Sets command flag to COMMAND_DIS
	+str2float(char msg[4]);	Converts a received command value from ASCII to float
	+runProtocol(void);	Waits and receives serial message
	+wifi_sync(void)	Enables system for SYNC (or broadcast with remote nodes)
	+checkSyncStatus(void);	Disables Sync flag; returns SYNC flag status
	+broadcastEnabled(void);	Broadcasts all received raw data through the serial port
	+updateRequired(void);	Disables UPDATE flag; returns UPDATE flag status

Element Name		**Description**
Messages		Data structure of the exchanged serial messages: #DATA#CRC#
Attributes		
	Data	Data exchanged
	CRC	Number of bytes of DATA
	Command	Optional: it assumes the format {COMMANDVALUE} with 4 ASCII number bytes for COMMAND and 4 ASCII number bytes for data
Operations		

Element Name		Description
Wireless GATEWAY protocol		Contains the class description of the wireless protocol to be implemented
Attributes		
	currState	Current state of the protocol: setup, run
	wifi2rpi_	Database: stores the data received via wifi to be sent to rpi
	rpi2wifi_	Database: stores the data (commands) sent by rpi to the wifi
Attributes		
	begin()	Initializes the protocol
	+manageMessage(void);	Processes the received wifi message
	+clearMessage(void);	Clears the received message
	+sendACK(void);	Sends via wifi to a node a ACK message
	+sendTimeout(void);	Sends via wifi to a node a TIMEOUT message
	+sendInvalidComamnd(void);	Sends via wifi to a node a INVALID message
	+runProtocol(void);	Waits and receives serial message

Element Name		Description
Wireless MAC		Contains the wifi Hardware layer (HAL)
Attributes		
	config	Configuration parameters
	Handle	Object handler
	Params	Object parameters
Attributes		
	+open()	Function to initialize a given WiFi peripheral
	+Params_init()	Function to initialize the WiFi_Params structure to its defaults
	+init()	Function to initialize the WiFi module
	+control()	Function performs implementation specific features on a given WiFi_Handle.
	+close()	Function to close a WiFi peripheral specified by the WiFi handle

Remote node vs data concentrator

The code implemented in each remote node should be similar to the data concentrator. On the serial communication, the microgen protocol should be implemented in both the PV converter and the remote node. On the wifi communication, the remote node must implement a Medium Access Control similar based on a producer-consumer mesh network.

4.3. Sequence Diagrams

The following section contains the sequence diagrams. These diagrams pretends to evaluate the data exchange between the modules of the system. The diagrams are an hypothesis that may vary depending on the system architecture used and it is not binding.

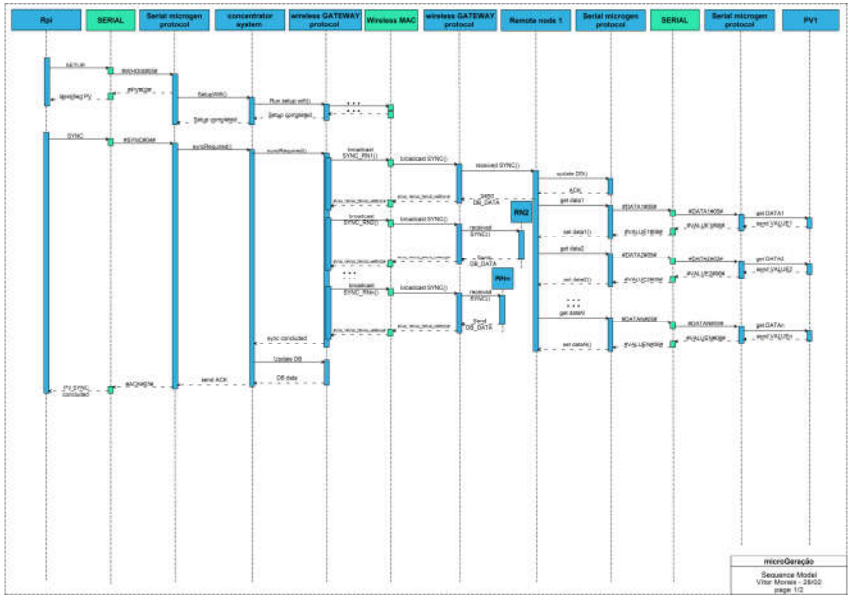

Figure 7 - Sequence diagram for SETUP and SYNC.

Figure 5 is intended to present the SETUP and SYNC sequences. Setup is a Raspberry routine intended to identify the devices connected itself. Sync routine provides a signal to all devices in order to hold the current variables in memory (dataBase). The signal SYNC must be broadcasted to devices at the same time, with a **maximum jitter of 10ms**.

The routine in the data concentrator device collects all data from remote nodes after a SYNC signal. The data collection from remote nodes should include the serial microgen protocol in both the remote node and the PV power converter.

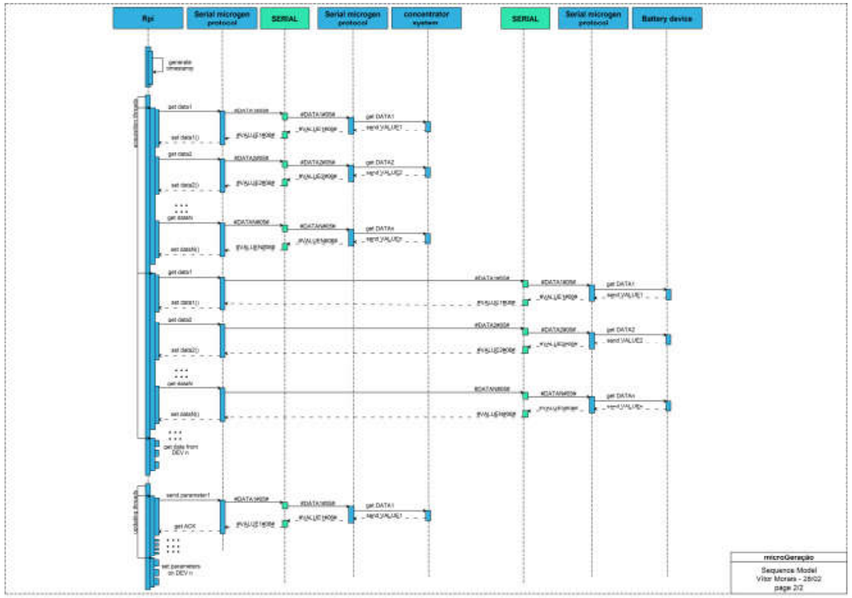

Figure 8 - Sequence diagram for timestamp, acquisition and updating.

After the last SYNC signal acknowledge received, the master should hold the current timestamp.

The acquisition of the data from each device should be processed simultaneously. From the point of view of the PV data concentrator device, all data should be transmitted using the serial microgen protocol.

The commands and references must be sent to devices after the acquisition. The same protocol should be used to send the data from the master to the data concentrator of the PV power converters.

4.4. State Diagram

The state diagram pretends to illustrate the possible states and transitions that may occur in the system. The proposed diagram may vary depending on the platform used and it is not binding.

The figure 7 shows all possible states and transitions for the PV wireless monitoring. States are marked using a round-edged box with a short description of the state. State transitions are signified using arrows with text descriptions. These descriptions generally consist of a function call and any constraints that need to be met before the transition is made. Constraints are indicated using brackets. The starting state of a diagram is indicated using a black dot pointing to a state.

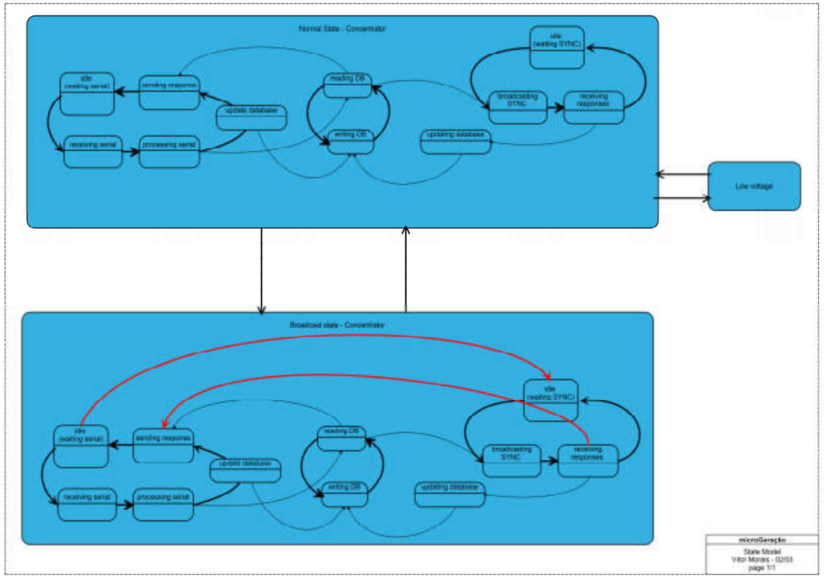

Figure 9 - State diagram for the PV wireless monitoring subsystem.

4.5. Prototype

The following section will describe the prototype behavior in different scenarios. The prototype may depend on the platform and the proposed prototype operations are not binding.

The prototype visually simulates what happens on the system in different scenarios.

Prototype Operation

The main result of the PV wireless monitoring subsystem is accessible with a browser through the raspberry pi master interface.

A alternative result will be the access to the remote node using other mean of data presentation such as the serial port or an LCD.

5. REFERENCES

- The template used for this SRS is based on Generic Ethernet Gateway (GWAY) from Chrysler Group LLC (available at http://www.cse.msu.edu/~cse435/Projects/F2013/Groups/GWAY/Docs/GWAY_SRS_V3.pdf)
- Please check microgen.fe.up.pt for more information on the project publications.