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Proposal of a Communication Architecture for the Configuration and Monitoring of an Electric Microgrid

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Abstract. This paper proposes the use and application of a wireless technology to create a communication architecture for the configuration and monitoring of an electric microgrid. The architecture uses a wireless sensors network with sensor nodes based on a digital signal controller, DSPIC30F4013, which have a unit to execute algorithms for digital signal processing and a 16-bit microcontroller with several peripherals. The sensor nodes have standard PMOD and MikroBus connectors for sensor interface and communication modules. The sensor nodes use a WIFI communication module which has a 32-bit embedded processor where the TCP/IP protocol stack is located. In the communication architecture, an embedded system based on an ARM Cortex A53 quad-core processor is used as a server. The server uses a client-server architecture using TCP sockets and a Linux custom kernel version created using Yocto Project.

Keywords: microgrid, Embedded system, Sensor network, Digital signal controller.

1 Introduction

During recent years, a great interest in renewable energy sources has presented. These sources do not disturb the environment like conventional, fossil fuel-based energy sources do. Several kinds of renewable energy sources exist, among which wind power and solar energy stand out. Nowadays, the production via renewable energy sources is a feasible option and its proposed to be used along with the existing generation and distribution schemes. By doing this, it is sought to promote and diversify the energy supply so that, in the future, they may play an important role in the new technological-environmental electric energy generation schemes [1]-[3].

An essential point to the use of renewable energy sources is the need to implement interfaces which allow these sources to connect to the electric network, as well as to feed electric loads directly. Such interfaces are known as microgrids [4]. Another important point to consider in this new generation scheme is the flexibility and autonomy these microgrids work with. Namely, in case of failures on the distribution net, they can provide power directly to the user, achieving a higher flexibility than current distribution schemes. This new generation scheme is known as Distributed Generation (DG) [5]. Wired and wireless communication technologies can be used in microgrids [6]. The most popular wired technologies used in power systems are the RS-

232/422/485 serial communication nets with bus technologies (like Modbus, Profibus and CANbus) [7], the power line communication [8] and Ethernet [7], [9]. On the other hand, the most popular wireless technologies used in power systems are the Global System for Mobile Communication (GSM) [7], WIFI [11], [12], WiMax [8], ZigBee [6], [13]-[15], Bluetooth[14], radiofrequency [14] and Microwave [16].

Wired technologies have large bandwidth for data transfer and are more dependable than wireless technologies, however the installation cost is relatively high. Whereas wireless technologies have low installation cost and are better suited to remote areas. Furthermore, they are better suited to future expansions.

A comparison between different wireless transmission technologies is done in [6] showing that WIFI uses the highest data transfer rate at 54Mbps, however the initial cost is modest compared to other technologies. Nowadays, this cost has considerably decreased in such a way that is considered to be low. The ESP8266EX [17] is a System On Chip with efficient energy consumption handling, compact design and a dependable performance on Internet of Things (IoT) applications. It has a WIFI controller, with a 32-bit processor where the TCP/IP protocol stack is located, embedded on the same integrated circuit. Also, it has SPI, UART and I2C communication interfaces to operate with any given microcontroller. This SoC is used on Wireless Sensor Networks for control and monitoring. A WSN is a wireless network made up of autonomous sensors that are implemented in areas of interest and have common features such as: data processing, storage capacity, wireless communication interfaces and limited power consumption. These networks are used to control and monitor several application types on different environments [18].

In this work, the use of wireless technology is proposed to create a communication architecture that uses a WSN based on a DSPIC30F4013 [19] Digital Signal Controller (DSC) to process the control algorithms used during the operation of monophasic inverters on island mode [20] and on a ESP8266EX SoC to communicate with a WIFI network. The SoC configuration is done through AT commands using the UART interface of the DSC. The data is sent to a central controller that is located on an embedded system based on a quad-core ARM Cortex A53 processor, RaspberryPi 3. The server which receives the data from the WSN is located on this embedded system.

1.1 Microgrid Communication Architecture

The microgrid communication architecture is shown in Fig. 1. This architecture is constituted by three modules:

- Sensor Node
- Communication Module
- Server Module

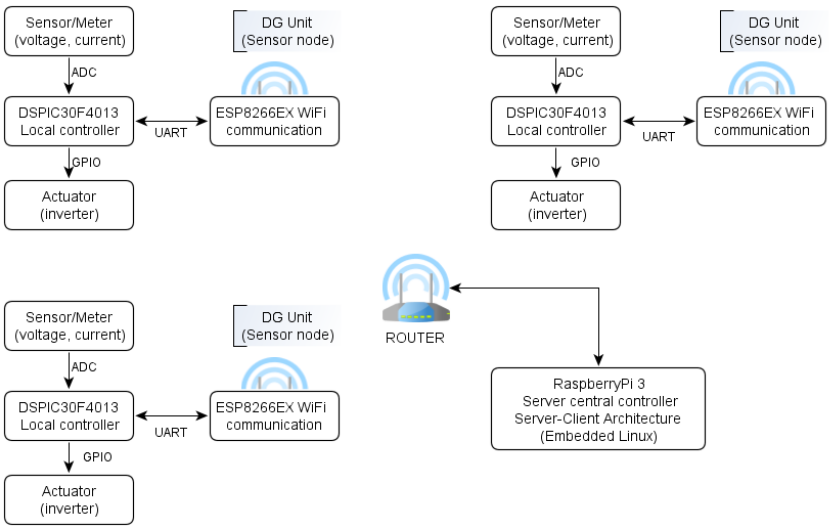

Fig. 1.¡Error! Secuencia no especificada. Proposal of a Communication Architecture for a Microgrid.

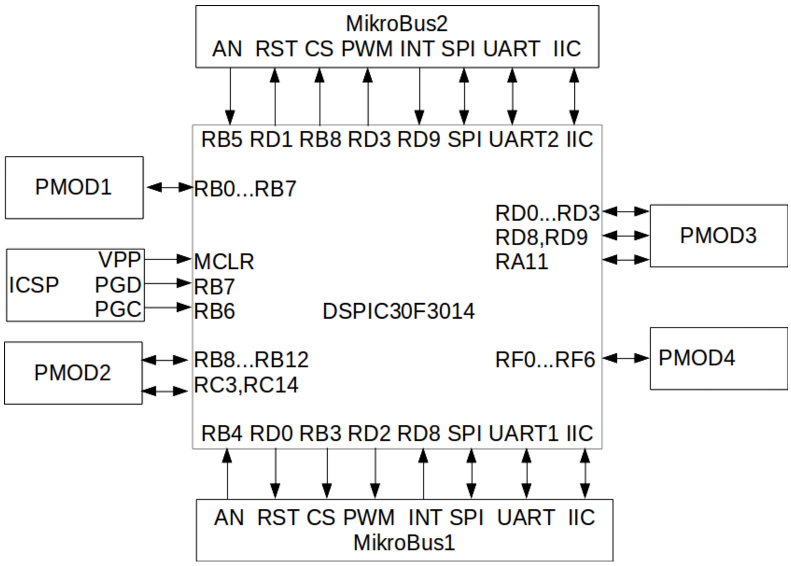

Fig. 2. Sensor Node.

1.2 Sensor Node

This sensor node (SN) is based on the DSPIC30F4013. Among its peripherals, this DSC has [19]: 2 UART, 1 SPI, 1 I2C, 5 TIMERS, 4 PWM, 1 CAN, 1 DCI, 48Kbytes of program memory and 2Kbytes of data memory. The DSC has a 16-bit RISC architecture. The SN uses two connectors based on the MikroBus standard [21] and four connectors based on the PMOD interface specification [22] to smoothly adapt peripheral modules. A 14745600 Hz crystal is used on the SN, with which 29.4912 MIPS are reached. Additionally, the In-Circuit Serial Programming (ICSP) connector and its 5V and 3.3V power source are owned. The MikroBus standard essentially convers the SPI, UART and I2C communication interfaces while the PMOD handles every input-ouput terminal.

The SN node performs the processing of the control algorithms used in the operation of monophasic inverters on island mode as part of a microgrid. The monitoring of different variables and parameters is also performed for this mode of operation such as: voltage, current and harmonic measurement. The voltage is 127V and the current is 3.4A for a 400W inverter [20]. The SN interconnection architecture is shown in Fig. 2.

1.3 Communication Module

The communication module is based on a ESP8266EX SoC that uses a UART interface to communicate with the DSC. The SoC has a 9,600 bauds rate configured by default with a minimal frame composed of one start bit, one stop bit and 8 bits per data with no parity bit used. That is 10 bits per frame. The transfer rate is given by (1):

$$bytes_{transfer} = \frac{BaudRate}{BitsPerFrame}. \tag{1}$$

Given a 9,600 bauds rate, the transfer rate is 960 bytes per second. The sampling frequency used in the control of the operation of the monophasic invertors on island mode is 40 KHz with a resolution of 16 bits per data. Given this sampling frequency and a word size of 16 bits, a transfer rate of 40,000 words per second is needed to send samples of the input variables in real time. With a rate of 921600 bauds, a transfer rate of 92160 bps is attained, namely, 46,080 words per second. Using this speed, the samples can be sent in real time.

To configure the UART of the DSC to a speed of 921,600 bauds, we use equation (2) in order to find the right value to use in the UxBRG register:

$$UxBRG = \frac{FCY}{16 * BaudRate} - 1. \tag{2}$$

With the 14,745,600 Hz crystal located in the SN, a 8-bit PLL is configured so that FCY is 29.4912 MHz. Given this value for FCY, we get UxBRG = 1. Using this crystal value, the desired baud rate is achieved. The DSC communicates with the Wi-Fi SoC via AT commands using the UART1 interface with an initial rate of 9,600 bauds. To receive the command response, the UART1 receiving interruption is enabled. The commands used on this application are shown in Table 1.

To debug the command execution between the DSC and the Wi-Fi SoC, the UART2 interface is used to send every response from each command through a FT232 serial-USB converter. The UART2 is configures at a rate of 9,600 bauds. On the computer, the response acquisition is done by programming the UART through the File Hierarchy System (FHS) using a program written in C language. The architecture of the proposed test application is shown in Fig. 3.

Table 1. AT Commands for configuring ESP8266EX.

Function	AT Commands	Response
Restart	AT+RST	OK [System Ready, vendor:www.ai-thinker.com]
WiFi Mode	AT+CWMODE? AT+CWMODE=1 AT+CWMODE=2 AT+CWMODE=3	Query STA Mode AP Mode Both
TCP/UDP Conections	AT+ CIPMUX? AT+ CIPMUX=0 AT+ CIPMUX=1	Query Single Multiple
JoinAccess Point	AT+CWJAP? AT+CWJAP= "SSID","Password"	Query AT+CWJAP?+CWJAP: "Router" OK
Get IP Address	AT+CIFSR	AT+CIFSR 192.168.0.105, OK
Set up TCP/UDP conection	AT+CIPSTART=? (CIPMUX=0) AT+CIPSTART = <type>,<addr>,<port> (CIPMUX=1) AT+CIPSTART = <id><type>,<addr>, <port>	Query id = 0-4, type = TCP/UDP, addr = IP address, port= port
Set Buffer Size	AT+CIPSEND=N	N, Number of bytes to send
Baud Rate	AT+UART=BAUDRATE	

The whole application is developed in a C language interface for embedded systems and the assembly language of the DSC. The flowchart of the proposed system for the Wi-Fi module in shown in Fig. 4 (a).

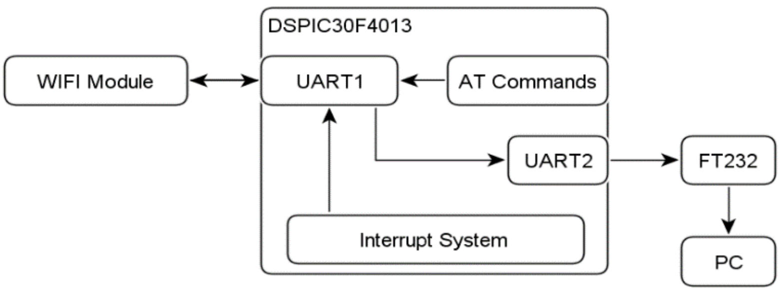

Fig. 3. Testing Unit for the Sensor Node.

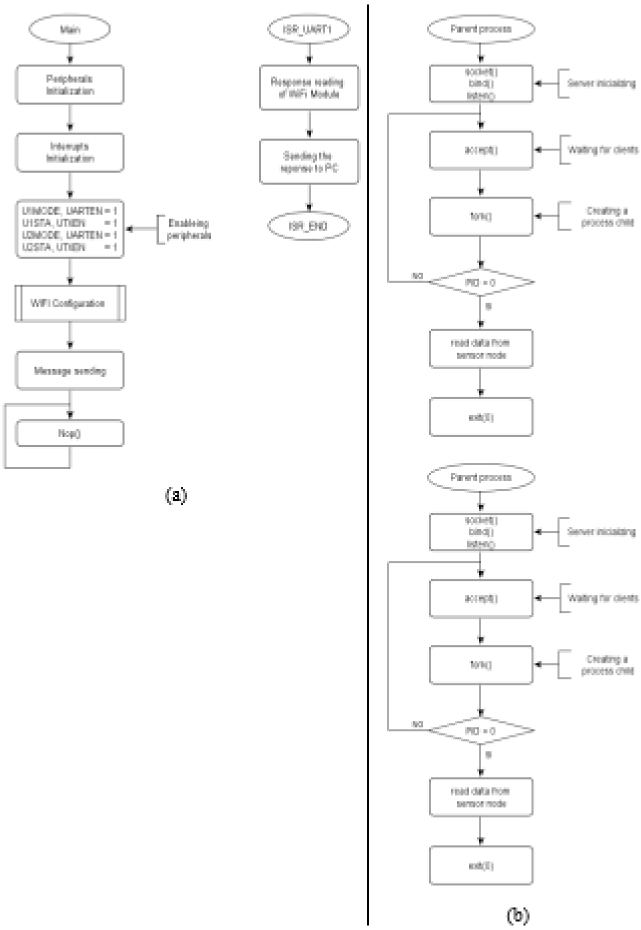

Fig. 4. (a) Flowchart for WiFi Module testing, (b) Flowchart for Server Application.

1.4 Server Module

The server module is implemented on the development board RaspberryPi 3, whose main characteristics are [24]:

- 1.2 GHz quad-core Cortex A53 processor with dedicated 512Kbyte L2 cache in BCM2837 SoC.
- 1GB RAM
- VideoCore IV 3D graphics core.

The operating system used with the development system is a personalized version, called rpi-basic-image, generated in Yocto Project [25]. This version has the hardware configuration needed to initialize the Linux kernel on the RaspberryPi with some additional features using only 180Mb. The kernel version used is 4.4.32. The boot system used for the server application daemon is System D. The server application is programmed in C language and uses Berkeley TCP sockets in a client-server architecture. The application uses the fork() system call to create a process for every client that requests a connection to the server, allowing process-level parallelism. The flowchart for the server application is shown in Fig. 4 (b).

2 Testing and Results

A sensor node was designed, fabricated and assembled with a DSPIC30F4013 DSC to implement local control and to configure the ESP8266EX Wi-Fi SoC. A Wi-Fi 3 Click module from Mikroelektronika vendor was used. Fig. 5 shows the sensor node working with the SoC. This figure also shows the responses to the AT configuration commands.

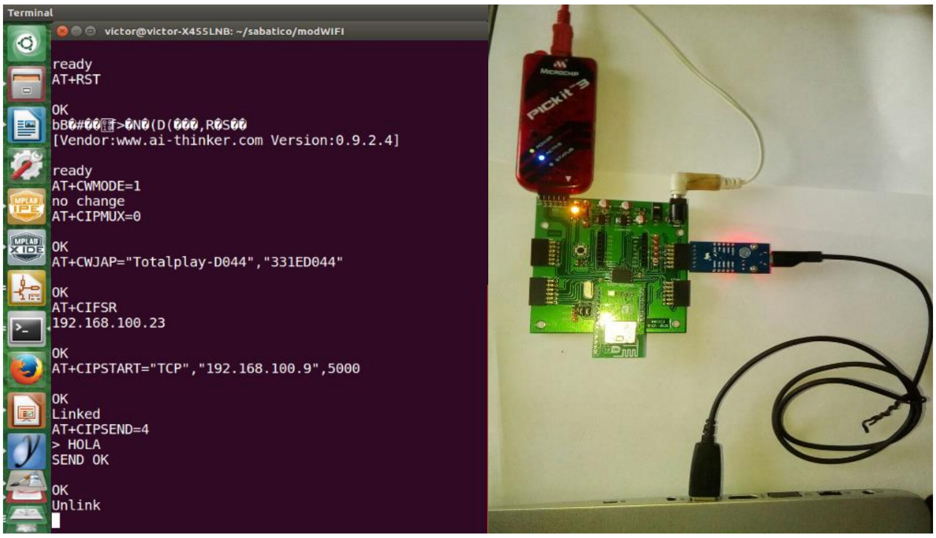

Fig. 5. Sensor node in operation with ESP8266EX.

To verify the proper operation of the server on the embedded RaspberryPi 3, system tests were carried out by connecting from 1 to 30 clients on the server simultaneously. Each client sent a buffer of 100,000 64.bit integer data at different frequencies, variating from 1KHz to 40KHz, with increments of 5KHz. The obtained results are shown in Table 2.

In Table 2, the first column shows the frequency at which each client sent the data. The second column shows the number of clients connected to the server. The third and fourth columns show the time the server took to receive all the client data and the last column shows the number of buffers received from the clients on the server.

The obtained results show that from 15 simultaneously connected clients, deconnections may occur and data buffered may get lost. Fig. 6 shows the execution of the server.

Table 2. Results of system tests of the server application.

Frequency (khz)	Clients	t (m)	t (s)	BUFFERS	Frequency (khz)	Clients	t (m)	t (s)	BUFFERS	Frequency (khz)	Clients	t (m)	t (s)	BUFFERS
1	1	1	59.7	1	15	1	0	8	1	30	1	0	5.411	1
	5	2	45.6	5		5	0	8.77	5		5	0	4.75	5
	10	3	41.04	10		10	0	10.66	10		10	0	5.39	10
	15	4	52.48	13		15	0	14.43	13		15	0	8.138	15
	20	8	15	20		20	0	21.549	17		20	0	8.35	17
	25	8	37.2	21		25	0	26.21	21		25	0	12.72	21
	30	10	13.59	25		30	0	35.614	26		30	0	18.35	27
5	1	0	30.94	1	20	1	0	6.13	1	35	1	0	4.17	1
	5	0	26.37	5		5	0	6.68	5		5	0	4.59	5
	10	0	35.89	10		10	0	9	10		10	0	5.8	10
	15	0	42.31	12		15	0	12.65	15		15	0	6.33	13
	20	1	5.48	20		20	0	14.7	17		20	0	9.22	19
	25	1	26.4	22		25	0	19.25	21		25	0	10.66	20
	30	1	45.31	25		30	0	20.5	23		30	0	16.32	29
10	1	0	12.29	1	25	1	0	4.84	1	40	1	0	3.7	1
	5	0	13.44	5		5	0	5.76	5		5	0	3.5	5
	10	0	14.48	8		10	0	6.65	9		10	0	3.96	10
	15	0	24.4	14		15	0	8.92	12		15	0	4.41	12
	20	0	34.9	18		20	0	11.35	17		20	0	8.54	20
	25	0	46.25	22		25	0	16.38	24		25	0	11.66	22
	30	1	51	24		30	0	19.34	27		30	0	10	27

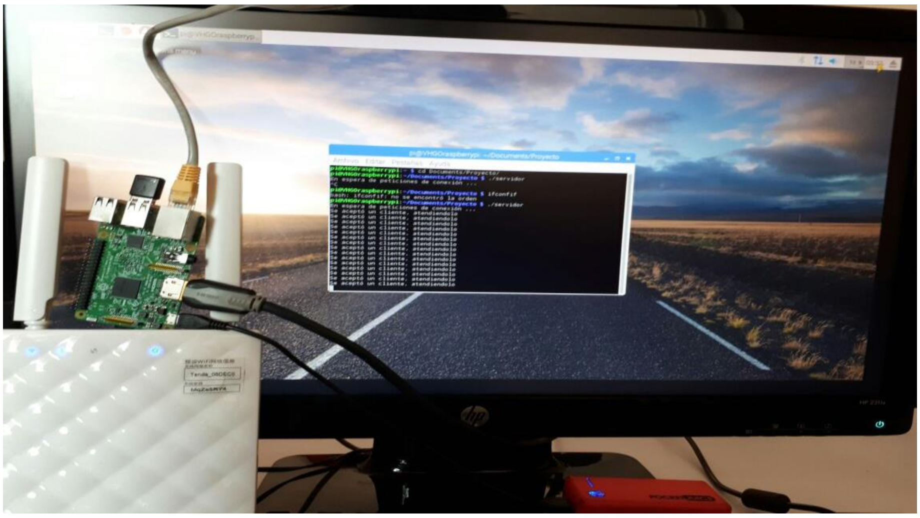

Fig. 6. Server in operation.

3 Conclusions and Future Work

The sensor node designed with the DSPIC30F4013 can process up to 29.4912 million instructions per second with the 14.7456 oscillator selected for the SN with a PLL of 8, this data is provided by the manufacturer. This oscillator value was selected in order to reach a 921600 baud rate on the UART with 0% configuration error. Given this transfer rate for the UART, transfer rate of over 40KHz can be reached. This node can process the control algorithms used on the GD inverters since it contains a DSP on the DSC. Furthermore, on the DSC the module ESP8266EX is configurated to gain connectivity to the wireless sensor network with a data rate of 54 Mbps. This data rate is higher that the data rate presented with GSM [7], WiMax [8], ZigBee [6], [13] – [15], Bluetooth

[14] and radiofrequency [14]. Furthermore, the module ESP8266EX presents a low cost nowadays.

The microgrid server is located on a quad-core ARM Cortex A53 based embedded system and a personalized linux version created using Yocto project for improve the memory space. This linux version occupies only 180Mb and allows only for the required processes for the server application to be running.

Using the DSC and the server embedded system, a low cost, robust communication architecture is obtained. This architecture uses only two communication layers. The first layer contains the sensor nodes and the second layer contains the embedded server. This architecture avoids the need to use multiple communication layers in microgrids as described in [6], [13] – [15].

This communication architecture can be used for processing control algorithms used in the operation of monophasic inverters on island mode as part of a microgrid.

Furthermore, this architecture allows to measure the phase of different inverters with the purpose to connect them in parallel and feed a greater load.

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