European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality (ICREPQ'11)
Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011

An integral and flexible wireless power monitoring system

S. Blanc[1], P. Yuste[1], A. Lorente[1], J.J. Serrano[1]

[1] Department of Computer Engineering
Universitat Politècnica de València
Camino de Vera S/N 46022 Valencia (Spain)
Phone:+34 963877000, e-mail: sablacla@disca.upv.es, pyuste@disca.upv.es, allomar1@itaca.upv.es, jserrano@itaca.upv.es

Abstract. This paper describes the main and fundamental aspects of a power monitoring system, with good adaptation possibilities that ease its use in both PV power production plants and home or building electrical grids.
It makes a smart metering solution which integrates several acquisition modules for electrical energy production and consumption monitoring, analysis and control management. The system is flexible in its configuration, easy to install and maintain and allows data transmission to a remote server by Ethernet, Wifi or GPRS/GSM or to a local server through a simple USB cable.

Key words

Wireless, monitoring, Smart metering

1. Introduction

In the past few years wireless sensor networks (WSN) have evolved considerably. The aim of these networks is to provide solutions which are low cost but reliable acquiring data from the environment in real time and ensuring loss free transmission to their final destination. WSN are especially well suited to acquiring data in power plants where production is distributed over a large area. If we compare wired and wireless infrastructures we can see that a wireless connection has a lower installation and physical maintenance cost, it can be used for integral data acquisition, transporting heterogeneous data from power production, consumption or smart metering on the same network. A WSN also has a lower development cost, as it is a generic system that can be used for many applications. Implementation is specific for each plant, varying the following parameters: type and number of nodes, distribution of nodes in the plant and distance to the central node.
An example of existing systems is Siemens PV plant monitoring solution [1]. This system monitors the performance and yield of the plant. Our system presents the following advantages: Measures not only power generated but also power consumption of the plant itself, what is very useful in small plants and home plants; It is wireless, what reduces installation and maintenance costs and can be used with a variety of sensing modules to adapt to the needs of different installations. This modularity eases its use in different applications, such as energy audits, as in [2] with the added advantage of being an integral measuring system. It also adds in flexibility, as the sink node can send information to the database through a number of different networks, such as Ethernet, Wifi, USB or GPRS/GSM.
This paper presents the system developed. Section 2 describes system topology and nodes already designed. Section 3 some functional aspects of the network and section 4 presents conclusions and future work.

2. System description

Topology:

As figure 1 shows, the monitoring system is made of two subsystems: The measurements acquisition system and the data analysis system.

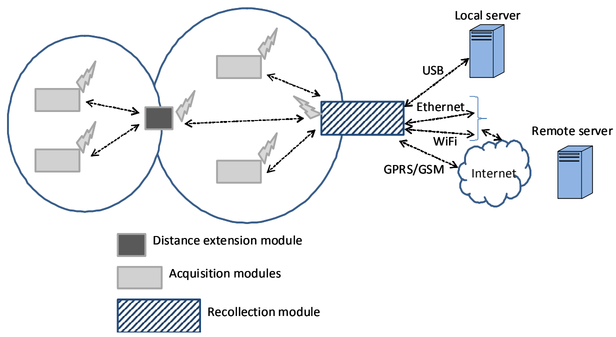

Figure 1: Wireless network and database topology

The measurements acquisition system is composed of wireless nodes. These measurement nodes can be powered by batteries or solar cells. The network topology is a star, where all acquired data are centralized in a sink node committed to generating a bridge between the acquisition system and the analysis system. The network can be set to different frequencies, but currently is operating at 868.3 MHz (In Europe), it uses a GFSK modulation and a bit rate of 38.4 Kbps, medium access is CCA (Clear Channel Assessment). The architecture of the nodes is modular, with a basic core component in all nodes. Measurement nodes are instrumented according to the type of acquisition to be performed. They can be in one of four types:

PHV V&I Power Strings Analyzer

This module is instrumented to measure DC current and voltage in PHV panels. The module needs to be installed only in a PHV panel per power string. This connection allows the module to measure both DC current and voltage per string. In [3] a circuit for DC V&I in PV panels is described. It does not integrate a wireless connection, but it is a good example of the analogical part of the circuit.

As well as Power Inverters used in DC/AC conversion, the module includes instant power displaying, total energy produced calculation, and some additional measurements. However the advantage of the PHV V&I Power Strings Analyzer is to get better precision, troubleshooting individually per string, and pinpoint damaged solar PHV panels.

Moreover, the whole system also allows improving maintenance tasks with on-line detection of efficiency losses due to dirty panels, or comparing panel efficiency with different elevations. Generally speaking, data obtained are very useful for efficiency evaluation, prediction, and maintenance.

V&I AC Power Line Analyzer

This module design is based on a power metering IC to obtain faster analogical to digital conversions, allowing a deep analysis of current and voltage waveforms, including, for example the 20 first Fourier series components of the signals if required. Moreover, the module includes a relay that can cut off the power line, and additionally, the module can include a temperature measuring sensor.

The device can be used to monitor instantaneous power, peak power, total energy consumption, power fails or line over voltages. Generally speaking, data obtained are very useful for energy consumption analysis, efficiency loss detection, maintenance task and power saving techniques implementation. The monitoring system in [4], can measure solar radiance, temperature, panel DC current/voltage, together with measured inverter data. But together with energy production measurements, energy consumption measurements should be also included. It is possible with the V&I AC Power Line Analyzer.

Meteo R&T

This module incorporates instrumentation to connect a solar radiation sensor in the [0..100mV] range, and two temperature sensors (PT1000) in the [-20º..80º] range.

Serial data monitoring

The module incorporates a RS232 and a RS485 serial instrumented channels. It can be used for smart metering following CEI 60870-5 international standard.

Moreover, the RS232 channel has been designed for on-plant serial number programming of the associated electric power devices.

Additionally with these four modules, some others have already been developed, to increase the range of measurable parameters such as CO2, or humidity.

The sink node also contains a basic core, and its instrumentation depends on the desired type of data retransmission: Ethernet, USB, GSM or Wifi.

The web or data servers monitoring systems have been proved to be a smart tool for real-time analyzing [5,6], prediction algorithms, and besides, for system control management. However, many systems still need a local server for data recollection, as not all plants have availability for internet access. The incorporation of different recollection alternatives solves many problems. In our system, flexibility is given by a collection of four different modules to recollect data. The GPRS/GSM recollection module is very suitable for plants with access difficulties or without internet access possibilities. The USB simple recollection module is easily adapted to home plants. The Ethernet modules is useful for building installations; and finally, the WiFi recollection module, combined with current commercial routers, is the future for any type of installation.

The analysis system is based in database management, allowing hosting. Data received from measurement nodes are calibrated, stored and managed for analysis in this subsystem. The aim is, on the one hand, to eliminate specific processing in measurement nodes, such as calibration. On the other hand, to allow possible updates or changes in data analysis without affecting measurement nodes maintenance.

Digital signal conversion: Each basic core has different channels allowing digital signal conversion through AD/DA converters. As no module uses all available channels, the remaining can be used for possible extensions of the module or for measurement redundancy in data acquisition.

Installation and maintenance: The integration of different acquisition measures is essential to perform a reliable analysis. But the installation and maintenance must be also easy, objective which can be reached with wireless modules.

Standard compatibility: Currently, the RF communication protocol uses the SimpliciTI compliant protocol stack [7].

Energy efficiency: One of the challenges of wireless sensor networks is achieving low power consumption. For this reason, most architectures usually include specific processors or controllers that allow the system to be set in a low power mode (sleeping state). Likewise, the basic core component used in our system is tiny in size and it is based on a commercial communications module [8] including a CC1110F32 microcontroller from Texas Instruments [9]. This basic communications module allows a direct connection to some measurement elements, but it is more common to fit it over an instrumented extension. The nodes are powered at 3V. Power consumption in the basic communication module is 16mA transmitting at 10mW, 18mA receiving and 0.3 µA in sleep mode. Reception range is 290m in open field.

3. Functional Aspects

Functional aspects in a measurement system refer to measurement points, measurement transmission mechanisms from the measurement point to the database, and measurement analysis and management mechanisms. We will consider the following features:

3.1. Measurement types:

It is a physically heterogeneous system, with different measurement modules, as it has been described in section 2. However, the advantage of an integral system is that it does not need different communication channels, but allows for the concurrence of modules with different features, such as measurement magnitude, sampling frequency, data resolution or data transmission frequency. Besides, nodes are capable of processing, what improves system performance. Firstly because the nodes can pre-process the acquired signals, as well as filter and compress data. Secondly, because it allows us to reduce network traffic making transmission frequency lower than sampling frequency; for instance, in the R&T module radiation sampling frequency is higher than 64 samples per second. However transmission frequency can be as low as 1 message per minute with the averaged value. Third, this processing capability can be used for any actuation, such as alarm activation. It is the case of V&I modules, allowing string disconnection.

3.2. Communication types:

The system allows for bidirectional communication between measurement nodes and a sink. According to the measurement point, the transmission types the system allows are:

Periodic transmission requested by measurement point.
This is the most frequent transmission in ambient parameter monitoring and energy measurement points. In a periodic basis, the measurement point transmits a data packet to the sink node. This transmission requires mechanisms to detect communication errors and assure a high minimum coverage. Implemented mechanisms are basically two: Transmission with acknowledge and maximum number of retransmissions per frame. A frame not acknowledged by the sink before a pre set timeout, will be retransmitted but not indefinitely for thee reasons: firstly, because it can be due to a temporal or permanent node isolation, so it would only result in more power consumed; secondly, because it can be due to a high network traffic, and a temporal delay would be more efficient than a immediate retransmission; and thirdly, because data can have a timing deadline.

Master-Slave transmission. In some modules measurements have to be taken in a time known and guided by a Real Time Clock (RTC). These are of the "serial data monitoring" type. For instance, timed counter values in power meters must be acquired and read synchronously with the zone time. To synchronize all modules connected to meters, either through RS485 or individually, a query is sent from the sink to the measurement node, as a token to start read and data transmission. Moreover, modules contain a RTC in their hardware, that in some cases can be used to determine connection times and intervals that can be used to set the node in a low power state, known as sleep mode. This advantage is especially useful in those nodes powered by batteries.

Emergency transmission: These are transmissions from the sink to one of the nodes or broadcasted to all of them pointing emergency events.

3.3. Network capacity:

The number and distribution of sensors depends on the PHV plant (or home) requirements. There is no limitation regarding the number of network connections. The limitations come from three factors: traffic generated for time unit, connection distance and message processing in the sink.

Concerning generated traffic an example has been implemented with a heavy traffic (stress workload), where there is no coordination in transmissions. They are, therefore, asynchronous transmissions, where each node sends a packet periodically with a CCA (Clear Channel Assessment) as the only reliability mechanism. The example system is made by 22 nodes transmitting between 43 and 286 bytes per second with sleep intervals of 3 seconds. As we can see from the results (figure 2) despite protocol limitations system response is good. Considering simulated traffic is atypical, and above estimated, and additional coordination techniques are implemented in transmissions, in all cases where the system has been tested the coverage established in the system requirements has been granted.

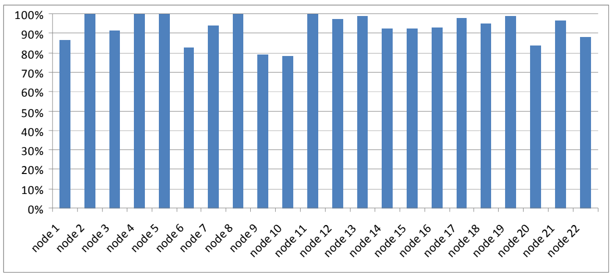

Figure 2: Transmission success per node

Regarding connection distance, nodes can be as far as 290 meters from each other. However, it is possible to raise this distance using retransmission nodes with a selective wake-up mechanism. This mechanism lengthens the life of these retransmission nodes even if they are powered with batteries. Retransmission from the nodes to the sink is made with a deterministic master-slave transmission schedule.

Lastly, message processing in the sink node is reduced when using this node as a bridge, leaving data management to the analysis system.

3.4. Dependability mechanisms:

Transmission failure detection can be done at three levels: physical, data link level and application level. *Physical level* can be redundant, either at reading level, at node level or at network level. Redundancy at reading level means obtaining a number of readings of the signal per time unit. This allows filtering for out of range readings, averaged data or even more complex algorithms. Redundancy at node level means there is more than one instrumented channel in the node for data acquisition from the same sensor or identical sensors (i.e. TMR techniques). To ease channel traffic voting is also done at node level, reducing the total number of sent frames. Redundancy at network level means there is more than one acquisition node placed in the same measurement point. Generally speaking, we must consider this choice raises the economical cost of the system even more than node level redundancy, implies more network traffic and implies the sink or the management and analysis system processes these redundant frames to take decisions. However it would be justified as a preventive mechanism in case of node decease or critical connection loss in any of the redundant nodes.

At *data link level* techniques improving received message rate are implemented, obtaining efficient power consumption.

At *application level*, as with previous levels, filtering and availability or link-loss alarms can be implemented and managed.

3.5. Security mechanisms:

Nodes include an embedded AES (Advanced Encryption Standard) coprocessor capable of working with 128 bit keys. With this coprocessor all communications can be encrypted and decrypted for maximum security with a minimal impact on the activity of the node.

4. Conclusions

In this paper, a wireless sensor network based architecture for monitoring PV power plants has been presented. Several nodes have been implemented measuring the most important parameters, such as AC and DC power, weather and serial inputs from smart meters. The system is flexible enough to be adapted to different other measurement scenarios, such as home power consumption monitoring, energy audits, and many more. The main advantages of this system are: Ease and low cost to deploy and maintain, flexibility and integration ability.

For future applications work is being done in extending the number of different sensing nodes. Also as many times wireless nodes are used in battery powered applications, we are studying transmission protocols in order to make them more efficient and safe without decreasing battery life.

References

[1]http://www.automation.siemens.com/mcms/solar-inverter/en/solar-inverters-sinvert/pv-monitoring/Pages/communication.aspx

[2] C. Yongpan, M. Xianmin, Z Jili, L. Zhen, "Development of Monitoring System of Building Energy Consumption", in Proc. 2009 International Forum on Computer Science-Technology and Applications, pp. 363-366

[3] V. Leite, F. Chenlo. "An Improved Electronic Circuit for Tracing the I-V Characteristics of PV Modules and Strigs." In *International Conference on Renewable Energies and Power Quality* (ICREPQ'10) Granada (Spain), 23th to 25th March, 2010

[4] A. Craciunescu, M. Predescu, M. Grottke, M.O. Popescu, C.L. Popescu, G. Ciumbulea, A. Nedelcu, O. Mitroi, A. Bejunariu. "Monitoring Results of the 30kWp PV grid-connected power system installed at the Unv. Politehnica of Bucharest" In ICREPQ (2009).

[5] F. Fioretti, S. Pasqualini, A. Andreoli, P. Pierleoni. Permanent Switchboard Monitoring using Embedded Web Server. International Conference on Renewable Energies and Power Quality (2009)

[6] G. Escrivá, M. Alcázar, C. Alvarez. Integral Management System for the energy efficiency improvement in comercial facilities: Application to the Polytechnic University of Valencia. ICREPQ (2009).

[7] http://focus.ti.com/docs/toolsw/folders/print/simpliciti.html

[8] Available in www.wsnval.com

[9] http://www.ti.com