ENERGY SAVING SMART METER USING LOW COST ARM PROCESSOR

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Abstract: In this paper a low cost real-time ARM-based energy management system is proposed. It is conceived as part of a distributed system that measures the main power system quantities and give the possibility to manage the whole power plant. An integrated Web Server allows to collect the statistics of power consumptions, power quality and is able to interface devices for load displacement. The device is characterized by easy access to the information and the combination of a smart meter and data communication capability allow local and remote access. In this way it is possible to manage the power consumption of the power system leading to an overall reduction in consumption and costs.

Key words: Power meter, Web server management, Smart Grids, Demand Side Management.

1. INTRODUCTION

A smart grid is an upgraded electricity network to which two-way digital communication between supplier and consumer, intelligent metering and monitoring systems have been added. Smart metering is an integral part of a smart grid. It consists of an electricity meter that records consumption of electric energy and communicates that information to the grid operator and energy supplier for monitoring and billing purposes. With this information consumers are able to directly control and manage their individual consumption[1].

Moreover, the grid operators can better plan the use of infrastructure and balance the system. Smart grids are expected to: i) reduce greenhouse gas emissions, ii) increase the share of renewable energy and distributed generation, iii) give the consumer the ability to adapt his consumption to benefit from the lowest prices offered during the day and iv) enhance energy efficiency. In this way the consumers can follow their actual electricity consumption. This provides them strong incentives for energy saving and then optimize management of the electricity grid.

Smart grids should integrate the actions of all energy suppliers and consumers connected to the grid and feature an smart energy measurement system to track electricity flows in all directions.

With this aim a low-cost smart energy meter is proposed. it is mainly a smart device with communication capability and shows a software architecture based on web-technology. In this paper, we present a smart energy meter with a web portal where customers will be able to see how much they paid for electricity last year, the amount of energy consumed on the same day, and the comparison with the cost of electricity consumption in the same day last year[2]. An annual report identifies the months when more electricity is consumed, and a daily report identifies the peak hours.

2. SMART POWER METER

The metering unit tracks the customer's utility usage and process the billing. The communication unit enables two way digital communication with the utility company. The start/stop unit starts and shut down the utility supply. The measurement unit consists of: i) an acquisition section that acquires the output of current and voltage transducers, ii) a microcontroller section that process the acquired samples to obtaining the desired quantities, iii) a display section that shows status and other useful information and iv) a memory section which store for the billing the obtained values in EEPROM. The power meter is able to measure the electric power consumed by each appliance during time periods. Furthermore, it is possible also send data via Ethernet to Web Server. We propose a power /energy meter that measures, in a given period of time, the following parameters: i) Voltage and Current RMS values, ii) Active Power (P) and Power Factor (PF), iii) Energy consumption, iv) Frequency v) Voltage and Current Total Harmonic Distortion (THDV and THDI), vi) Power Quality, and vii) Power consumption profile[3].

2.1. Hardware Architecture

The hardware implementation is built around a STM32F107xxx microcontroller [4], [5].

The STM32 is based on the Cortex-M3 profile, which is specifically designed for high system performance combined with low power consumption. The STM32 is composed of the Cortex core which is connected to the FLASH memory by the dedicated Instruction bus. The Cortex Data and System buses are connected to a matrix of ARM Advanced High Speed Buses (AHB). The internal SRAM is connected directly to the AHB bus matrix, as is the DMA unit. The peripherals are located on two ARM Advanced Peripheral Buses (APB). Every APB is bridged onto the AHB bus matrix. The AHB bus matrix is clocked at the same speed as the Cortex core. Furthermore it include two synchronizers ADC capable of 12 bit 1 MHz.

2.2. Architecture Distribuited System

The general architecture of the distributed smart metering system is shown in Fig. 1. It uses Gnutella network to route request from a server dedicated to receive request based on Web service (Gnutella Web Service) to an embedded client on which a light Gnutella client is developed to access to Gnutella network (Gnutella Embedded client) in which each node is a smart meter [6].

The specialized architecture for electrical energy, gas and water measurement is depicted in Fig.2 where the meters can communicate between them at the same level and with the concentrator. The communication is bidirectional: in this way, it is possible to exchange information between the various meters[7].

The Figure 2 shows the schematic of the developed smart metering system. Each household has an information display, and smart meter to acquire and store information regarding power consumption[8]. Every group of households it is installed a data aggregator, which communicates with components in the household group[peer]. Information display, smart meter and data aggregator communicate with each other through the power line. Additionally PLC repeater can be installed if the distance between households and data concentrator is excessive or there is a physical problem that makes the communication difficult, (not necessary for normal apartment building). These equipments can be installed anywhere and in several types of configurations as shown in Fig. 1. Also a Web Server (installed in data aggregator) can provide internet communication to provide power consumption statistics for a single household or for a group of household. STM32F107xxx is used as core of the hardware platform in this paper [9], [10].

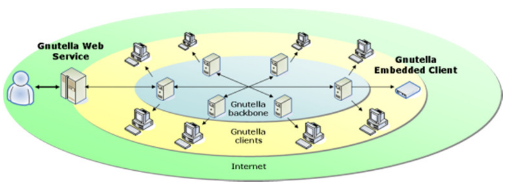

Figure 1. Architecture of the proposed distributed Smart Metering system

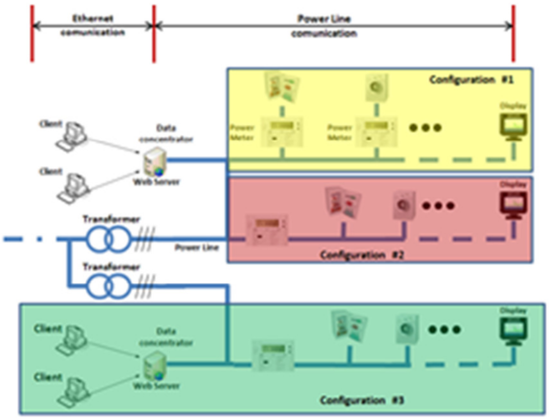

Figure 2: Configuration types of smart metering system with communication components

2.3. Distributed System Communication

Automatic Meter Reading (AMR) is the process of reading meters remotely without needing to be physically at the meter. PLC AMR systems use power line communications (PLC) technology to provide comprehensive two-way communications over the existing electricity supply network. This system allows utility implement low-cost AMR solution [11]. Advanced Meter Infrastructure (AMI) is an increasingly used term in the industry. It refers to a system which is capable of collecting and managing data from smart meters at real time via a two way communications link. Utilities use the data to provide consumers with new and enhanced products in real time and to ensure a seamless service experience. AMI is often used to describe both current-generation AMR systems that have been available on the market for a number of years, as well as new-generation systems providing more advanced architecture and capabilities. "Smart Meters" refers to the meters installed on such AMI systems.

The Power Line AMI/AMR System:

- A Power Line Communication (PLC) AMI/AMR is a method in which electronic data is transmitted over power lines back to the substation, then relayed to a central computer in the utility's main office. This would be considered a type of fixed network system -- the network being the distribution network which the utility has built and maintains to deliver electric power. Such systems are primarily used for electric meter reading. Some providers have interfaced gas and water meters to feed into a PLC type system.
- The Power Line AMI/AMR system remotely reads customer meters at real time and then transfers the data into the billing system.
- AMI/AMR will reduce the need for meter readers to collect meter readings manually utility of each month.

2.4. Software implementation

In the "Fig. 4", the real time software instrument implementation is shown. Referring to the standard IEC 61000-4-30 [12], the power quality parameters considered are: supply voltage dips and swells, voltage interruptions, voltage transients, fundamental frequency, supply voltage, power factor, magnitude of the supply voltage, flicker, voltage and current harmonics and interharmonics. From Channel in, the samples are acquired with a sampling frequency of 1MS/s. These samples are processed with a low-pass filter with 10 kHz cut-off frequency (Section A-B), averaged and decimated in order to increase the resolution for the following analyses which require 9kHz frequency band at least. Then, the samples are buffered (Section C). We adopted a double buffering technique in order to perform continuous analysis without loosing samples. When the first buffer is full, there is an interrupt to CPU. The ISR, as first task, change in DMA address so that samples start to fill the other buffer. In this way, the system respects precise timing constraints and avoids overflows. The block D is used to estimate the actual fondamental frequency in order to perform synchronized analyses. The section E looks for dips through rms continuos processing. In the section F, a digital flickmeter is implemented. In the block G, a digital re-sampling is made to obtain in exactly ten cycles of the fundamental a number of samples that is a power of two. The result of all the measurement sections are validated using flag control: flagged results are not accounted for subsequent analisys, not flagged data are grouped with reference to absolute time in order to obtain measurement with 10 min clock boundary [13].

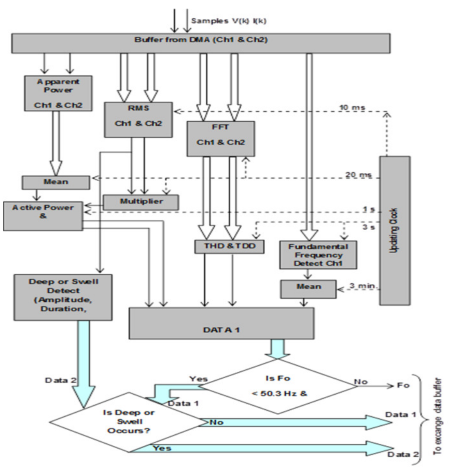

Figure 3: Software architecture

2.5 Measurement Algorithm

In the Fig.4 the measurement algorithm is shown. The frequency is measured evaluating zero crossing of voltage signal, after that the DC component, added by conditioning stage, has been cancelled. THDV and THDI [14] are evaluated from Fast Fourier Transform (FFT) of voltage and current signals, after that they are resampled to analyze a number of samples equal to 256, i.e. a power of four

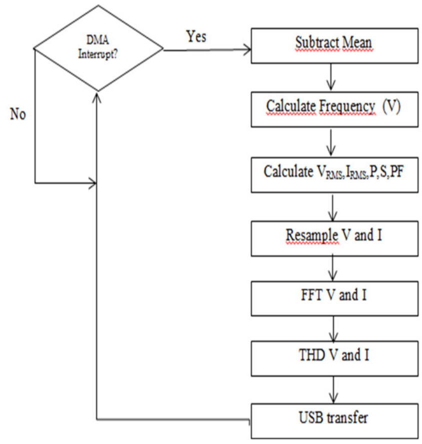

Figure 4: Flow chart (measurement algorithm)

3. WEB SERVER MANAGEMENT

Distributed energy meters transfer measurement results to the data aggregator through Power line. In the data aggregator a web server collects the statistics of each household and other advanced information is extracted. A client can connect to the server to analyze household group energy consumption. In Figure 5 Web Server work process is shown [15].

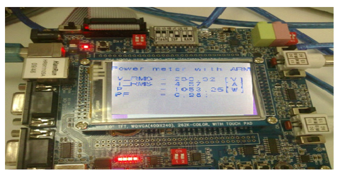

Figure 5: Web Server work process

In the development of Web Server application HTML protocol is used to provide static web pages to the client.
Concrete steps are as follow:

- Users, in the client browser, make a request to the Web Server.
- Web Server will make a judgment on the request.
- Web server will transfer file directly to the client browser.

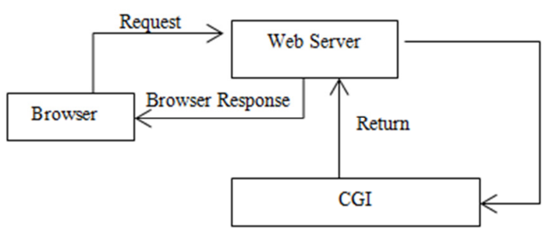

Figure 6: Software architecture

The webpage address is composed by an ip address (192.168.5.25), followed by a password (123456). The webpage is divided in two parts:

- The header part contains the title of the website and several links to view other pages
- The latter contains the linked pages

3.1. Experimental result

In order to prove reliability of the implemented instrument, a metrological characterization has been performed. In sinusoidal conditions have been performed varying input parameters around rated values; in particular, Fundamental frequency (50 +/- 15%), input voltage (50% to 100%), input current (50% to 100%) and phase displacement between - π/4 to π/2). For each test, some quantities have been measured and they are: frequency, voltage and current r.m.s. values, phase angle, active, reactive, non-active and apparent powers and power .Regarding the tests in non-sinusoidal conditions, for each test five harmonic components spanning between 3 and 39 (with a THD fixed to 10% for has been added to voltage and current waveforms, and its order has been varied in according to 0.The obtained results are summarized in Table I , reporting the uncertainty obtained for each measured quantity.

These preliminary tests have been carried out without sensing and conditioning sections, using as reference values the measurement results of a PXI platform with high performance data acquisition system (Fig.7).

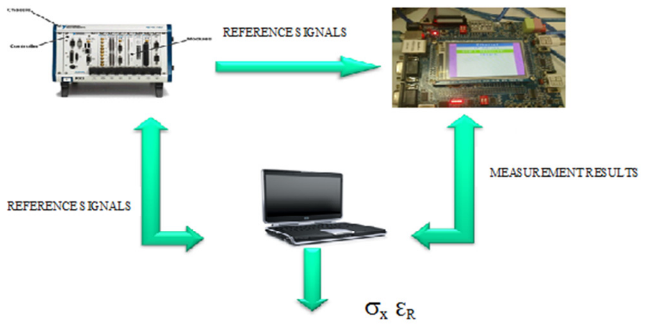

Fig. 7 : Data acquisition system

Further tests have been performed in order to evaluate the effect of frequency and phase angle variations on active and reactive power using test protocol reported in[17] both in sinusoidal and non-sinusoidal conditions.

Quantity	Uncertainty (sinusoidal tests)	Uncertainty (non-sinusoidal tests)	Units
Voltage (r.m.s.)	0.03	0.04	[%]
Current (r.m.s.)	0.03	0.04	[%]
Frequency	0.67	0.67	[mHz]
Active Power	0.043	0.061	[%]
Apparent Power	0.13	0.15	[%]
Power Factor (conventional)	0.002	0.002	[p.u.]
Non Active Power	0.60	0.62	[%]
Voltage THD	———	0.072	[%.]
Current THD	———	0.070	[%]

Table I: Values of the mean squared errors in the sinuoidal and non-sinusoidal test

In Fig. 8 absolute values of the errors, respectively on active power (a) and reactive power (b) versus the phase angle and the frequency, averaging on voltage and current amplitudes, are reported

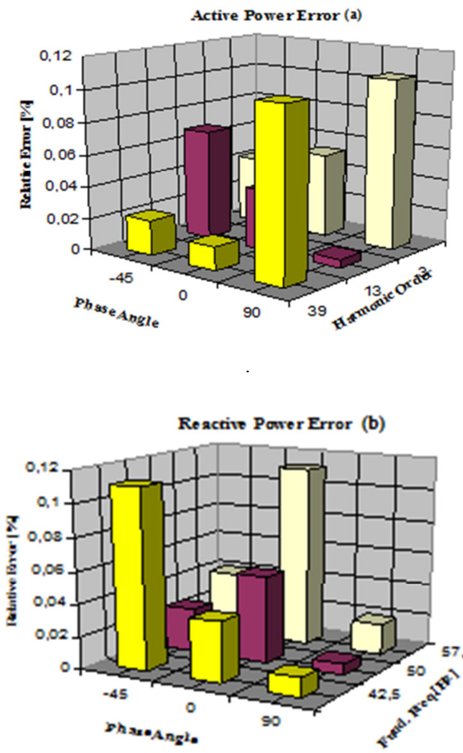

Fig. 8 Active (a) and Reactive Power (b) relative error in sinusoidal tests.

In Fig. 8 absolute errors, in non-sinusoidal conditions, respectively on active power (a) and non-active power (b) versus the fundamental phase angle and the harmonic order, averaging on the other parameters, are reported.

The experimental test have shown that the realized equipment is able to perform, power and energy measurement and can acts also as class A PQ measurement instrument.

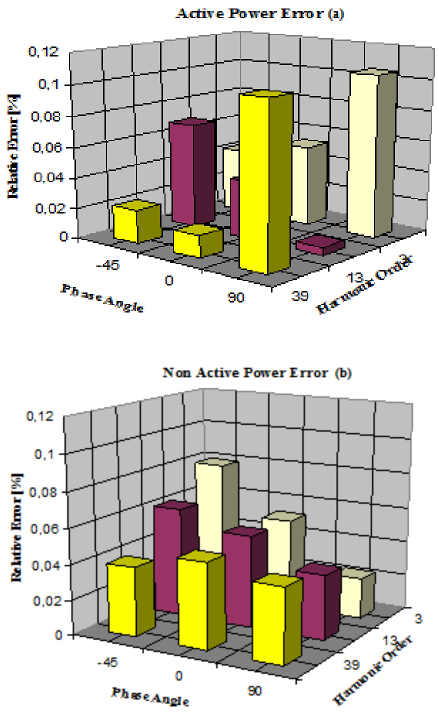

Fig. 9. Active and Non Active Power relative error in non-sinusoidal tests.

In addition a typical daily power consumption in a generic household is shown in Fig. 11. The peak value of the consumption is in the central hours of the day as shown in the figure.

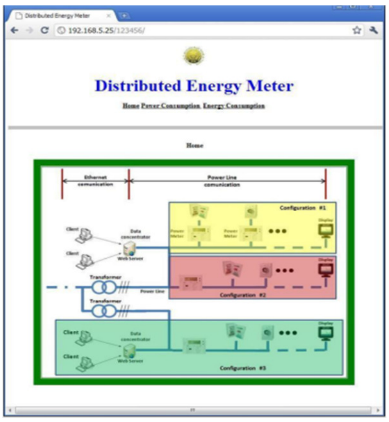

Figure 10. Home page of the website

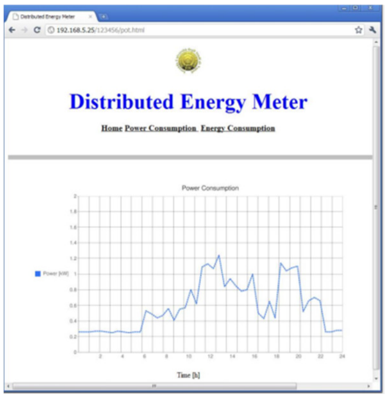

Figure 11. Daily power consumption in a generic house

4. CONCLUSIONS

In this paper a smart energy meter is proposed with the aim to obtain a low-cost device for a sustainable use of electrical energy. Consumers can monitor their actual electricity consumption. This provides strong incentives to save energy. It is mainly composed of energy meter with a web-based user interface (UI) and network capabilities which allow to interact with the power plant both locally or remotely, using public communication network.

The UI gives graphical information on instantaneous consumptions, on the effect of single burden on load shape and suggests the appropriate strategy for demand site management. In this way gives the consumer the ability to adapt his consumption to benefit from the lowest prices offered during the day and enhance energy efficiency.

Energy Management System using Smart Meter and Web Server was developed. Not only measurements regarding the amount of electricity used, but also allows the customer to control the maximum consumption using internet communication. In this way the combination of such a smart meter with an appropriate communication infrastructure could provide remote access and facilitate planning.

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