Metrologia
Fortaleza - CE 2017

Case analysis: An IoT energy monitoring system for a PV connected residence

Marcus André P. Oliveira, [1], **Wendell E. Moura Costa**[1], **Maxwell Moura Costa** [1],

[1] IFTO Campus Palmas

marcusandre@ifto.edu.br , wendell@ifto.edu.br , maxwell@ifto.edu.br

Abstract: In this paper is presented some measurements made by an IoT platform developed to register electrical parameters of domestic or industrial loads/circuits. The behavior of power, voltage and current can be verified through graphs and reports, to identify and prevent electrical energy waste and to analyze energy quality as well. With minor modifications, this system can be adapted to interact with the loads, to turn on/off or more complex actions like parameters sent by IR transmitters. Some particularities were implemented in hardware, embedded software, database and Web platform, to achieve a high personalized scenario.

Keywords: IoT, isolated sensors, energy measurement, energy quality, PV generation.

1. INTRODUCTION

IoT is the new opportunity of business in the information age. As the demand for new tools to transportation, work and leisure grows, energy demand increases as well. A big challenge, besides to increase the energy generation capacity, is to minimize the waste of power in his different formats (oil, gas, electric energy, etc.).

In addition to the increase in energy demand, there is also a very significant growth in the exchange of information, through data networks. The main example is the Internet, available to more than 43% of world population [1] (87% in some countries). After the first (“communication age”) and second stages (“social age”), the “Internet of Things” (IoT) stage is being stablished [2]. Devices, or “things” like domestic appliances, vehicles and herds can exchange some kind of information with or without human intervention.

The number of connected devices increase very fast. Since 2008, non-human devices generating net traffic surpassed PC`s and mobile phones, together [3]. Estimated IoT turnover should exceed U$ 470 billion annually by 2020, building a market that will directly drive a total of up to U$ 6.2 trillion by 2025 [4].

Into this perspective, an IoT system is under development to generate information about energy consumption and quality. Next sections presents the main premises and experimental data collected from a residence, in different scenarios.

2. IMPLEMENTED IOT PLATFORM

The presented IoT platform is a complex set of hardware and dedicated software (embedded and remote). The actual configuration is the natural evolution of some preliminary circuits built to remote measurement of DC/AC voltages and currents in photovoltaic installations, which was later adapted monitor air conditioning units in a public educational institution (30 individually monitored at this stage). The system is focused on accurate measurement of electrical data, including technical variables related to energy quality, to identify points of installation with potential risk to equipment due to sags, swells and other bus voltage faults. In this way, is expected the reduction on the number of failures, increasing equipment life time and generating savings for the customer. In long-term measurements, the behavior of power over time and the total energy consumed in the equipment or circuit may help the customer to define routines for more efficient use of the element under monitoring.

The platform is composed by four parts: the hardware, embedded software, server side software/database and client side Web application, as further explained.

2.1. Hardware

The basic information about any electrical circuit are the voltage and current in a given point. In order to collect data signals with maximum quality, non-invasive Hall effect and isolated amplifiers are being used as current and voltage sensors, respectively. To complete the hardware, each unit has also a 32 bit MCU (12-bit SAR ADCs, 32-bit Timers, etc), an UART/802.11 b/g adaptor, voltage regulators, fuses and expansion terminals.

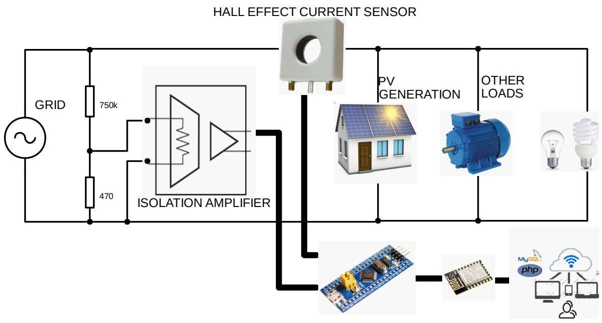


Figure 1. Isolated measurement of circuit.

Figure 1 shows the scheme for a single measurement in the whole residence. However, due the low cost of components and for more detailed analysis, several other measurement units were also installed.

Other important features of developed board are: low self-consumption, small network traffic and simple integration of other sensors for future usage such as: temperature sensors, luminosity, humidity, relays for triggering loads, parameter transmissions via IR transducers, etc..

2.2. Embedded software

The MCU requires an embedded software able to pre-processing signals from connected sensors. To make it possible, the following tasks are needed: 1 – acquire periodically a grid synchronized sample of voltage/current waveform; 2 – perform the A/D conversion; 3 – manage the connection with local router and with remote server; 4 – upload of collected data in required format (an HTTP GET or POST request). Up to the present moment, some basic commands sent from remote user to the board are also being successfully executed, performing on/off control on selected lamps/pumps when interfaced by relays. This bidirectional capability will be better explored in future releases of this platform.

2.3. Server-side software

The remote server contains PHP scripts which are called from each measurement unit, and receive data sent from GET or POST HTTP methods. In essence, the objective of this stage is: 1 – classify the raw values into the correct tables on a MySQL database; 2 – apply individual gains to each variable; 3 – perform error verification and correction, when applicable. In this datatable, is also stored user profiles, measured units characteristics and some other useful information for the correct visualization of graphs and reports, when required from client software.

2.4. Client-side software

The client application, actually hosted at www.simemap.com, is based on HTML and JavaSript functions for data visualization. At the moment, is already possible to analyse power, voltage and current profiles, individually or by groups. As the development grows, some premises are kept in mind: 1 – user access control according to profiles and privileges (total administration, local or visualization only); 2 – groupment of units by model, geografic position, measured values or others; 3 – choice of different variables combinations for graphs and reports; 4 – schedule of alarms and events for manual or pre-programmed remote interventions. In next section, some results extracted from such website is presented.

3. EXPERIMENTAL RESULTS

The author`s residence (here named "*Mapocasa*") was used as site to collect the experimental data in this paper. The main characteristics about this house are cited as follow:

- 3.12KWp grid connected PV system;
- Main loads: 2cv pool motor, 1cv irrigation motor pump, 3x 9000 btu air conditioning units, 2x 5000W (max) TRIAC controlled water heater, 1x refrigerator, 1x electric owen, several low power lamps and other minor loads.

Based on the elements above, figure 2 presents the IoT platform collected data for total power behavior in a 6-day period:

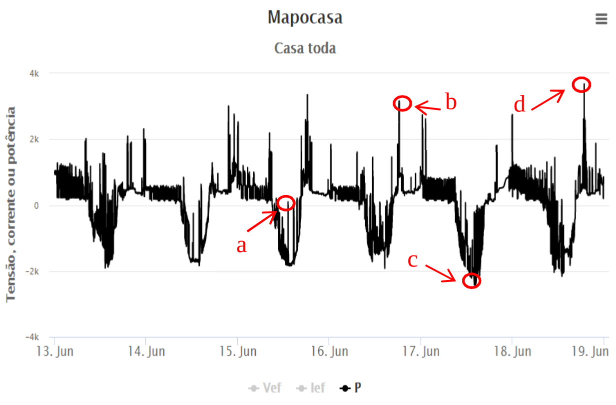


Figure 2. 6-day total consumption on residence.

From the data in figure 2, the system also prints some relevant informations:

- Maximum measured power: 3678.14 W
- Minimum measured power: -2440.39 W
- Energy balance: 1.73 KWh.

The existence of negative power values and a small total energy balance for the period is due the presence of the 3.12 KWp grid connected PV generator. Another IoT unit was installed to collect individual measurement for PV injected AC power, in same period, is shown in figure 3. If desired, AC voltage and current, as well DC power, voltage and current are also available to user in this same plot.

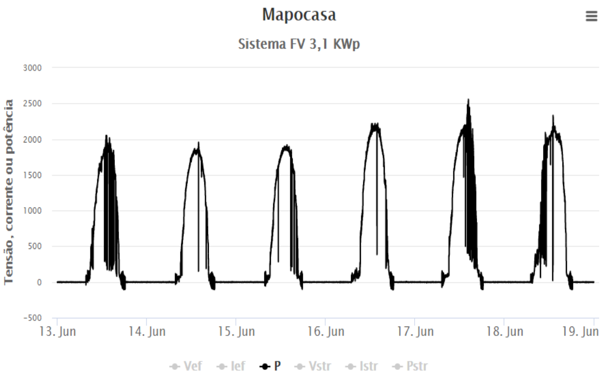
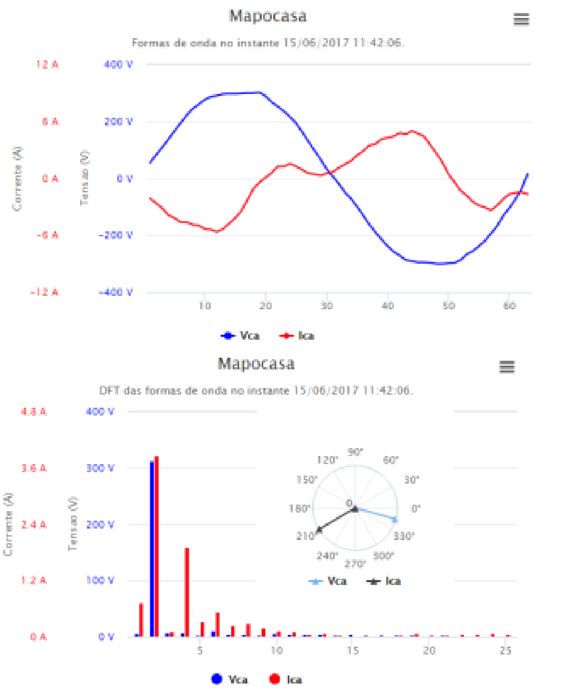


Figure 3. PV generation in analysed period.

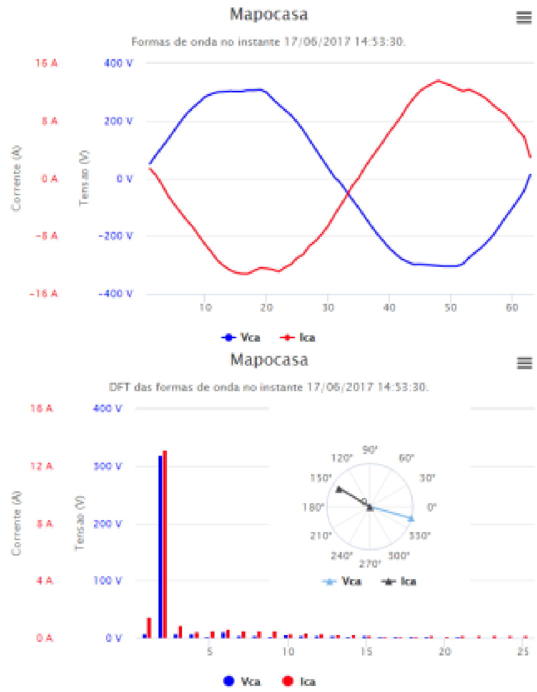
After third day, PV strings dust was removed, increasing generation. As in the previous case, some useful results can be extracted from these measured data:

- Maximum measured power: 2556.26 W
- Mean power: 439.1 W
- Energy generation: 67.48 KWh

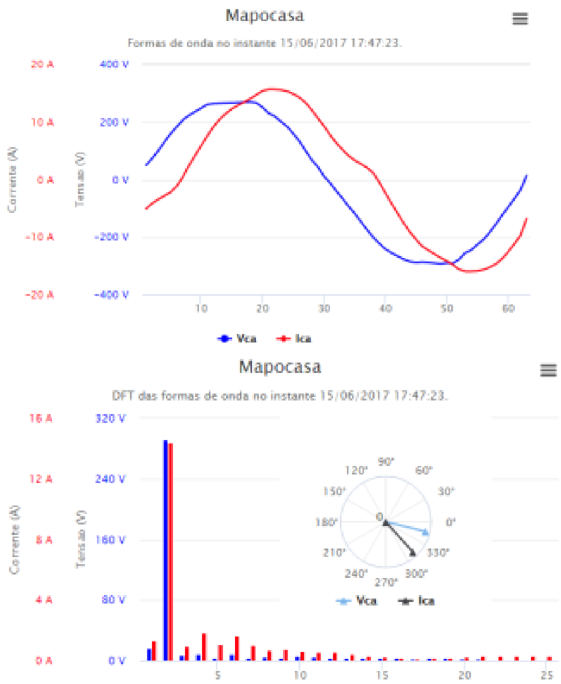
Voltage "*Vca*" and current "*Ica*" waveforms of points "*a*" to "*d*" selected on figure 2 are shown in figure 4, as well their harmonic contents and polar representation of fundamental component angle. This kind of results allows the analysis of energy quality parameters like power factor, total harmonic distortion on voltage and current (THD_V and THD_I respectively), glitches, notches and other disturbances with no hardware adaptations. With full-time diagnosis option enabled, even non-technical users can be alerted remotely if programed energy quality limits are exceeded.



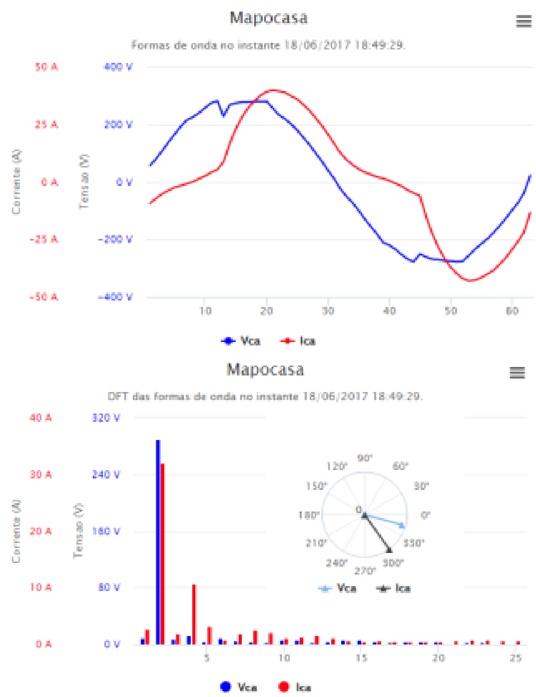
(a) PV generation, TRIAC switched water heater



(c) PV generation only



(b) No PV generation, 2 cv pool cleaning motor



(d) No PV generation, TRIAC switched heater,1 air conditioning unit, 1 refrigerator, some lamps

Figure 4. Residence "*Vca*" and "*Ica*" waveforms and harmonic contents.

Other available and useful option in this IoT system is the comparison between power consumption of two air conditioning units in same plot, as in figure 5. These equipments has similar characteristics (9000 btu, inverter split type, same room area), but were assembled by different companies.

The measurement made in this particular day resulted in:

- Maximum power (black unit): 875 W
- Energy consumption (black unit): 2,98 KWh
- Maximum power (blue unit): 752 W
- Energy consumption (blue unit): 3,04 KWh.

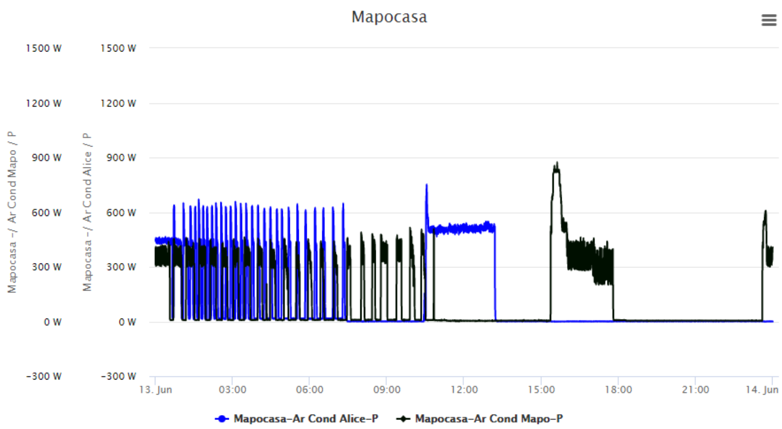


Figure 5. 1-day power comparison on 2 air conditioning units.

4. CONCLUSIONS

An IoT measurement system is a powerful tool to technical and non-technical users. The presented system was used to remote monitoring of electrical parameters voltage and current. With these basic values, power, energy, and some other statistic information can be also presented to customer, to support the creation of energy savings strategies. With the added capability to show individual waveforms in any individual measured unit, several power quality parameters can be also found. The presented results confirm the reliability of measurements, and a set of new features will be available on the commercial version, intended to be ready in a few months.

ACKNOWLEGMENTS

The authors thanks to IFTO by supporting this work with equipments and laboratories.

6. REFERENCES

[1] Internet.org by Facebook. **State of Connectivity 2015 - A Report on Global Internet Access**. Available in https://newsroom.fb.com/news/2016/02/state-of-connectivity-2015-a-report-on-global-internet-access/ . Acessed in 21/04/2017.

[2] LINS, Theo. **Internet das Coisas: coletando dados**. Available in http://www.decom.ufop.br/imobilis/iot-coletando-dados/ . Acessed in 21/04/2017.

[3] EVANS, Dave. **The Internet of Things: How the Next Evolution of the Internet Is Changing Everything**. Available in

http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf . Acessed in 21/04/2017.

[4] McKinsey & Company. **The IoT opportunity**. Hong Kong IoT Conference, 21/06/2016.