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# Distributed Smart Metering by using Power Electronics Systems

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**Abstract.** The main objective of this paper is to develop a monitor system implemented in existing power electronics equipment. The proposed algorithm is integrated in a previously developed Photovoltaic Array Emulator with the principal aim of monitoring important quality parameters that will be sent to a central repository (by using UDP protocol), where they will be available as Open data.

**Keywords:** Smart Metering, Power Quality, UDP Protocol and Open data.

## 1 Introduction

Historically, the electrical grid has been a “broadcast” grid, where generators cover the demand in a country or region. Whereas this model has served its purpose for the last century to some extent, the smartgrid [1] concept appears due to the growing need to reform the world’s electrical grid and systems to address new societal challenges:

- The world is considering being more economical and environmentally friendly, and therefore the electrical grid is becoming more complex with the introduction of power electronics systems present in renewable energy generators.
- In a society where information and data are becoming increasingly important, information and communication technologies carry the conception of open data. Open data [2] refers to the notion that certain data should be unreservedly available to everyone for using and republishing as wished, free from restrictions imposed by copyright, patents or other mechanisms of control.

The European Platform Technology Smartgrids published 19 June 2013 The Summary of Priorities for Smartgrids Research Topics [3]. Specifically in D section with a priority 1 the sub-topic cluster Modelling Power System and ICT together is found.

In order to fulfill the research topic, we use the actual power electronic systems in order to be the host of the corresponding algorithms, able to get quality parameters on the base of the IEEE Standard 1459-2010 [4] and send it over the internet to an open grid of data, where everybody would be able to use the producer and consumer data

for their work, as could be researching, madding statistical studies, matching generation and consumption as part of the grid control and so on.

The developed algorithm needs to be adaptable and embedded for every power electronics system, taking advantage of the electrical parameters already measured by these types of systems.

Therefore, our paper is built upon the development of the aforementioned algorithm and inclusion in a real system to prove its correct operation with the rapid prototyping tool based on xPC Target. We send over Internet to an open repository quality parameters calculated by an algorithm implemented in a photovoltaic array emulator connected to a commercial inverter.

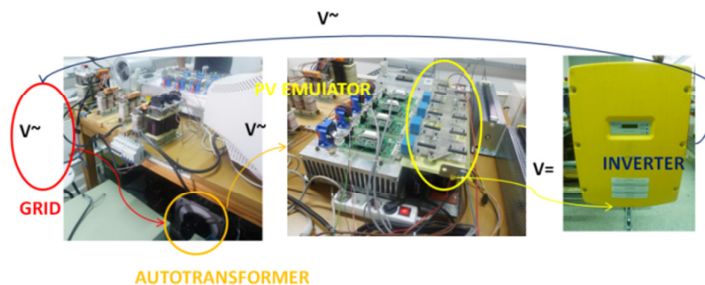
## 2 Relationship to Collective Awareness

In order to contribute to collective awareness, the developed algorithm has the ability to send power quality data to a common repository, where they will be available as open data for other researchers that would be able to use them to develop advance strategies in order to operate the electric grid, for instance.

Besides in a vision of future, this kind of algorithms will avail of the increasing use of power electronics systems (for example, the converters used in distributed generators mainly based in renewable resources). These systems usually have electric sensors which the algorithm could use for monitoring the system, and enough resources for running the algorithm. Taking this into account, the power electronic systems will convert into sources of pre-processed data that can be used in high level intelligent systems that will optimize the operation of the grid.

## 3 System's Physical Description

The system is composed by a PV array emulator, an electronic converter working as a synchronous rectifier, which constitutes the interface circuit between the electrical grid by means of an autotransformer and the inverter. The real system is a SEMISTACK SKS 230F B8CI 190 V12 inverter by Semikron. We see the system's scheme in Fig. 1.



**Fig. 1.** Real Scheme of the System.

The inverter, which returns the power, once reconverted to AC, to the grid, is a SMA sunny minicentral 6000A inverter.

Thus, we have a close-loop system consisting of a Photovoltaic array emulator controlled by Simulink (where we can control parameters, such as irradiance curve, DC voltage, number of panels in series and parallel, etc [5]), taking energy from the grid, and connect to a SMA, which returns it to the same point.

The system has a measurement conditioning board with a total of 10 Hall-effect sensors with the main characteristics shown in Table 1.

**Table 1.** Sensor characteristics.

| Magnitude | Sensor          | Number of Sensors           |
|-----------|-----------------|-----------------------------|
| Voltage   | LV 25-P by LEM  | 5 (Vsa, Vsb, Vsc, Vdc, Vga) |
| Current   | LA 25-NP by LEM | 5 (Isa, Isb, Isc, Idc, Iga) |

#### 4 Quality Parameters defined on the base IEEE Standard 1459-2010

Our system takes measurements in three different points:

1. Autotransformer to Emulator.
2. Emulator to Inverter.
3. Inverter to Grid.

In each one of these point, as if it is a single-phase system, only one voltage and current are measured thanks to a measurement board.

In single phase systems, the calculation of the root mean square (RMS) fundamental voltage  $U_1$  and current  $I_1$  is based on the instantaneous measured components voltage  $u(k)$  and current  $i(k)$ . By getting the RMS fundamental magnitudes, the harmonic ones,  $U_H$  and  $I_H$ , can be obtained, since  $U^2 = U_1^2 + U_H^2$  and  $I^2 = I_1^2 + I_H^2$ , where  $U$  and  $I$  are the RMS values of  $u$  and  $i$ , respectively.

The apparent power  $S$  is expressed as:

$$S^2 = (UI)^2 = S_1^2 + S_N^2 \tag{1}$$

The active power  $P$  can be calculated as the mean value of the power product of the instantaneous voltage and current. Afterwards, the non-active power is defined as:

$$N^2 = S^2 - P^2 \tag{2}$$

Other important quality rates measured are the total harmonic distortion of voltage  $THD_U$  and current  $THD_I$ :

$$THD_U = \frac{U_H}{U_1}, THD_I = \frac{I_H}{I_1} \tag{3}$$

Finally, the last parameters obtained are the power factor  $P/S$  at points 1 and 3, and the DC power at point 2.

Note that we get in our measurement block the three-phase values of power at the beginning and ending points thanks to three times the equivalent single-phase power.

Now, the measurement technique used in this work is based on the single phase Quality Meter proposed in [6]. Fig. 2 shows us the quality parameters algorithm.

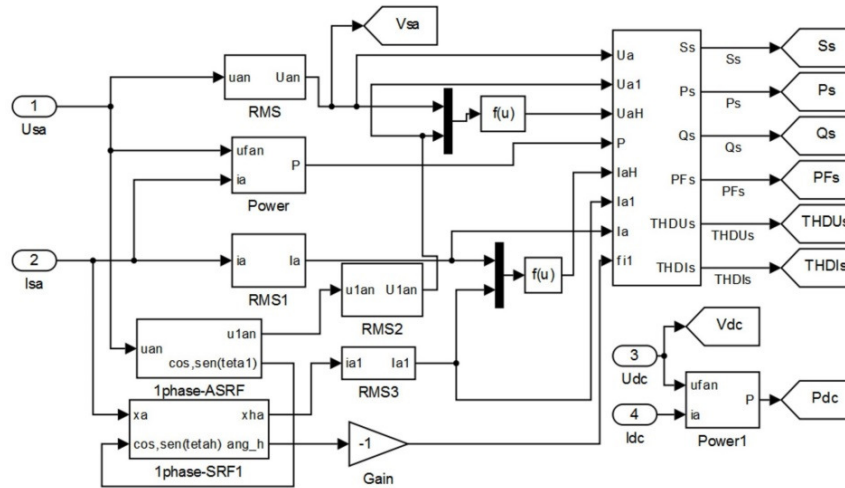


Fig. 2. Quality Parameters Algorithm (Points 1 and 2).

## 5 Creating a Real Time Quality Metering

### 5.1 Implementation Stages

The proposed algorithm will be implemented in two stages. First stage, that is the one described in following sections, is a Proof-of-the-concept. The second stage will be a real application implementation that will be done in future works. The resources needed for each step are:

- Proof-of-the-concept stage: A prototype of proof for the first implementation of the algorithm (mode used in the present paper). We establish a system structure based on three different PC's:
  - Host PC, used for the compilation of the algorithm to control the PV emulator and to calculate the required parameters.
  - Target PC, which executes in real time the code generated by the host PC to control the system.
  - Server PC, which receives the data from the target PC and sends them to an Open data.
- Real application stage: In this operation mode the Host PC is no longer needed, and only the control platform or PC, where the smart metering and power electronic controls are running, and the WebServer, where the Open data are available (that is a share PC for multiple services), are operating.

### 5.2 Quality Parameters Algorithm and Communication Implementation

The PV emulator was developed in the host PC with its corresponding control [5]; now to get the smart metering, the quality parameters algorithm is implemented inside of this model too, taking advantage of the inputs needed in the previous project.

Thus, once the host and target are connected via TCP/IP, inputs coming from the data acquisition target go through our measurement block, to get the desired quality parameters.

These parameters now have to end in the server computer for the data logging, being the chosen communication the UDP protocol [7].

The communication has been added to the host Simulink model, with the UDP send block and the previous pack block. The UDP send block needs the IP address to send to (server IP: 158.49.55.93), the IP port to send to (1992) and the sample time. We use an enabled subsystem, controlled by triggered function, which activates what is inside (UDP send Block, Pack and discrete function) every 5 seconds during the sample time. Before the pack block, data are treated by a discrete transfer function to calculate the average value of the five previous values and send it through the UDP send block. We can see this configuration in the Fig. 3.

The pack block is used to convert the Simulink signal of double type to a single vector of uint8 as required by the send block.

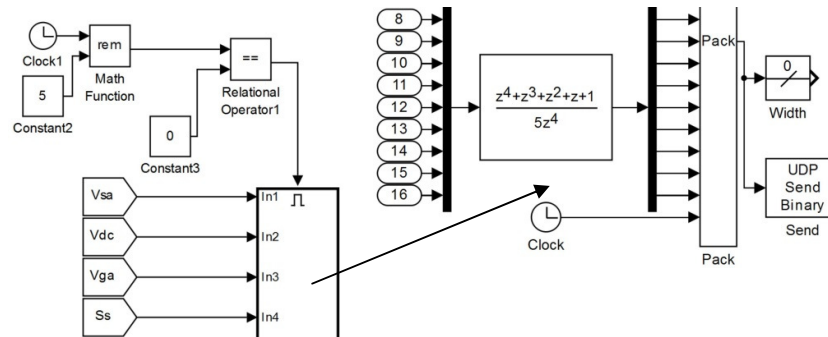


Fig. 3. UDP Send Scheme.

Once the data has been sent, we need to receive it in the server PC. A simulink model with a UDP receive block and unpack has been created. The UDP receive block needs IP address to receive from (0.0.0.0 for accepting all) and the IP port to receive from (1992). Another important data is the output port width, known thanks to the width block. The Unpack Block changes again the uint8 data to the original state.

Therefore, we have to treat the data. We have configured an S- function to get the values of these data and write them in an array, which goes to a text format file. The S-function is inside of an enabled subsystem activated each 5 seconds (systems are synchronized). We can see the receive scheme in Fig. 4.

At the end, we obtain in our server PC a text format file with all the read quality parameters, ready to be uploaded to the Open data. The chosen format for this open data is an XML file [8], which is a widely used format for data exchange because it gives good opportunities to keep the structure of the data obtained from our original

system (in our case text format file with the data array structure). In this way, new data could be added to the text file at the same time the XML format file is updated. In Fig. 5 we have a scheme of the communication system.

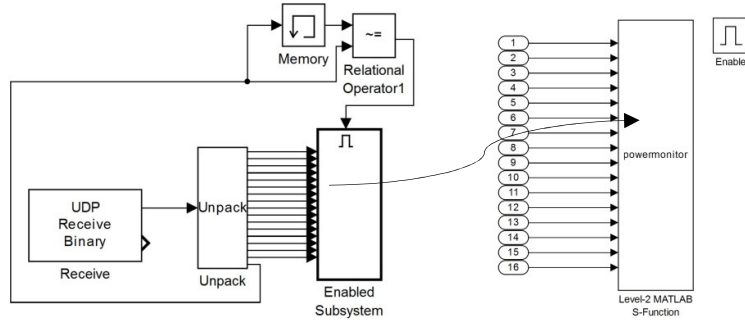


Fig. 4. Receive scheme.

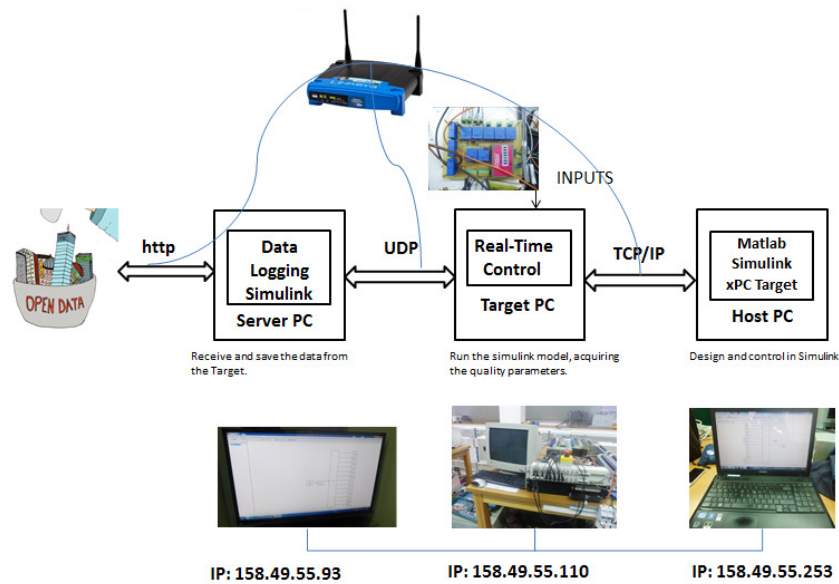


Fig. 5. Communication System Scheme.

### 5.3 Real Time Guarantee

The real time behavior of the system is guaranteed because we only execute the S-function, which contains a clock function to write the current time and date to the corresponding data, comparing the mark of real time received from the target with the previous value, activating the function when they are different. This is because the

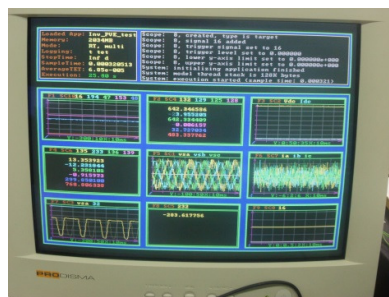
clock block in charge of getting the real time is inside of an enabled subsystem activated each 5 seconds, so when a new data is received is because the time have changed from 5 to 10, for example.

### 6 Experimental Results

In table 2 the experimental test parameters are shown. The data obtained from an experimental test are shown in xPC target environment (Fig. 6a) and they can be accessed by conventional web navigator form in its corresponding repository (<http://peandes.unex.es/powermonitor/>) as it can be seen in Fig. 6b.

Table 2. Experimental Test Parameters.

| Parameter                    | Value     |
|------------------------------|-----------|
| Kind of Solution             | Euler     |
| Simulation Step              | 1/3120    |
| Basis Irradiance             | 1000 W/m2 |
| Number of panels in series   | 8         |
| Number of panels in parallel | 1         |
| V <sub>DC</sub>              | 272V      |
| V <sub>Supply</sub>          | 75V       |



(a)

### PE&S Power Monitor

Filter:  all registered data  Apply

| Time              | Vdc            | Vdc           | Vpa           | Is            | Is            | Qc            | Pfs           |
|-------------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 21/10/13 18:12:05 | 7.64520000e+01 | 2.8900000e+02 | 2.3800000e+02 | 3.1000000e+01 | 3.1000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:10 | 7.58560000e+01 | 2.8500000e+02 | 2.3200000e+02 | 2.9540000e+01 | 2.9540000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:15 | 7.49650000e+01 | 2.8450000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:20 | 7.49620000e+01 | 2.8000000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:25 | 7.49500000e+01 | 2.7900000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:30 | 7.49490000e+01 | 2.7800000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:35 | 7.49480000e+01 | 2.7200000e+02 | 2.3000000e+02 | 2.8000000e+01 | 2.8000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:40 | 7.49470000e+01 | 2.7200000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:45 | 7.49470000e+01 | 2.7200000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:50 | 7.49470000e+01 | 2.7200000e+02 | 2.3000000e+02 | 2.9000000e+01 | 2.9000000e+01 | 0.0000000e+00 | 1.0000000e+00 |
| 21/10/13 18:12:55 | 7.64520000e+01 | 2.8900000e+02 | 2.3800000e+02 | 3.1000000e+01 | 3.1000000e+01 | 0.0000000e+00 | 1.0000000e+00 |

(b)

Fig. 6. (a) xPC Target Environment. (b) Data Repository.

With the experimental case we advise how the performance of the system has decreased. Note that after including the proposed algorithm in the initial power electronic system, the sample and switching frequency has been decreased from 8 to 3,120 kHz. Otherwise, the system will be stuck.

### 7 Conclusion and Future Works

A smart metering system able to generate Open data accessible in a central repository has been developed and tested using xPC Target. It has been used to get quality



parameters from a system, which consists of a photovoltaic array emulator and a commercial inverter, saving them in an Open data in real time.

With this experiment we have proved how the metering algorithm could be implemented in an existing power electronics system. The inclusion of the proposed algorithm in the power electronics system causes the decrease of the sample frequency from 8 to 3,120 kHz. In the future, when we afford the real application stage, the metering algorithm will be included as a different execution tier to prevent affecting the original control algorithm. We consider that is possible to include these smart metering functions in the next generation of power electronics systems, which in some cases will required only the change of systems' firmware.

Besides other interesting work would be to develop a virtual lab [9] with the system, what would be meaningful and very popular in distance education. We will have with this proposal to implement the control in the opposite way, through the open data network to the real system. It will allow the students to see how the real system reacts when they change the control parameters.

To conclude, in the future we pretend to integrate the Open data generated by our algorithms in existing projects as Green Button Developer [10]. It will have to be done according to the ESPI scheme (Energy Services Provider Interface), which provides a way for Energy Usage Information (EUI) to be shared, in a controlled manner, between participants in the energy services markets.

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