An Experimental Study on the Smart Home Concept with PV and Energy Management and Control Strategy Using an Open Source Platform

Adel Ghouari[1], *Chaâbane Hamouda, Abdelaziz Chaghi, Mohamed Chahdi*

ABSTRACT

The smart grid system is key to the new electrical network infrastructure. It takes into account the use of the new information and communication technologies (ITC) and the integration of the renewable energy power generation (photovoltaics PV, concentrated solar power CSP, wind, etc). The smart grid promises better management and control of energy sources. The application of the smart grid, especially, in Algeria allows the optimal control of the electricity demand since the latter keeps rising continuously. The use of smart grid allows the rationalization of the electricity consumption in smart homes through appliance automated control. Input energy savings result in the reduction of c emission. Herein, we present a new energy management strategy tested in an experimental smart home (SM). The implemented management approach was made possible by using a new electronic system that allowed the control of all appliances via the internet network. For this purpose, a dynamic monitoring web interface was developed under an open source platform in order to process the whole data delivered by the system. The final output of the system which consists of a balance between all types of energy involved, including CO_2 gas emission, is displayed. It is only then that the user can take adequate decision and establish the priorities for rational use of the energy available.

Keywords: Energy management system; smart home application; grid connected PV system; monitoring and Web technology; open source software.

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[1]Corresponding author: MSc. Adel Ghouari, adelghouari@hotmail.fr.

INTRODUCTION

The smart grid is the new energy management system, which is characterized by the multiplication of the energy sources between fossil and renewable energies [1]. In this context, the customer is given the possibility to manage the different sources (Gas turbine, PV, wind… etc) the energy price of which varies from one source to another [2], hence, the importance of the information and communication system tools (ICT) for the monitoring of the whole system to be implemented. This approach can be done with the electrical network decentralization configuration. However, in smart grid system the knowledge of the electricity information in the electrical network is very important, and this is possible with the use of the ICT [3,4].

The main advantage of the ICT utilities is the increase of the efficiency of the electrical network as well as the energy efficiency in homes; this can be achieved by involving all the components of the web services [5].

On other hand the smart grid energy management strategy deals with the optimization of the functioning process of electrical network, especially at the distribution level. In fact, the main reason for introducing the smart home concept is the optimization of the demand response between electrical network operator and customers [5]. The energy demand pattern and loads profile are the key information which is shared between them, taking into consideration the electricity costs. The fact to involve other energy source supplier, increases the complexity of the electrical network [6], especially those problems related to frequency. The integration of PVs systems becomes more required especially at low voltage [7-10] where the residential sector shows the greatest potential. In this approach, these types of systems are more interesting, and as such their performances must be analyzed for long periods under working climatic conditions.

New measures are needed that make the electrical network well protected and management system more reliable [11]. The application of the web-based management to the Algerian electrical network constitutes a big challenge, which could not be overcome without developing internet services. Moreover, smart grid components are becoming attractive because they enhance the reliability and the security of the electrical network [12]. All these aspects have to be considered carefully in order to define the platform which can match such a specific context of smart grid.

This work deals with the smart houses concept. A web server dedicated to the system management was designed and implemented. The control unit was connected to the internet network to check online the status of the system. The implemented system management ensures the interaction between the grid connected PV system (1.6 kWp), the household appliances, and the local electrical network.

THE ALGERIAN HOUSEHOLD ENERGY CONSUMPTION REVIEW

Energy Consumption

The energy balance shows that the final energy consumption is estimated at 42.46 MToe in 2015, this energy is shared between three main sectors. The industry with 8.8 MToe, the transport about 15.5 MToe and the household and others with the highest value which is about 18.1 MToe. The energy consumption in household and others sectors is dominated by the residential sector with 76.7%, however, the most important energy source used in this sector are the natural gas with 53.6% and electricity with 33.7% [12].

Algerian power demand analysis

Figure 1 illustrates the load curve taken in the summer of the year 2014 period, it showed a first load peak observed in the early afternoon period, and the corresponding value recorded was 10927MW. This huge power demand was caused mainly by the use of air conditioner devices.

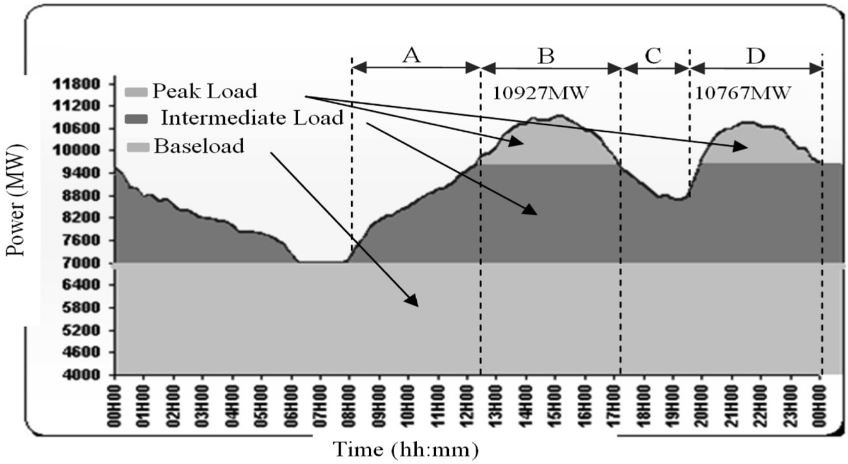


Figure 1. The Daily load curve in Algeria.

Table 1. The Algerian electricity network development and the relationship between electricity production and population 1962-2015.

electricity production and population 1962-2015.

year	1962	1966	1975	1985	1995	2005	2015
Population (million)	-	12.022	15.417	21.510	28.060	33.96	**39.50**
Power capacity (GW)	0.568	0.628	1.277	2.872	5.514	7.076	**15.163**
Electricity production (TWh)	1.124	1.094	2.122	11.221	19.261	27.322	**60.579**

The second load peak was observed in the evening period with the value of 10767MW. Moreover, the load curve showed an increase of electricity demand in the morning period (A), High demand (B, D) and a decrease of energy demand at the end of the afternoon period. The interesting feature of the curve was the solar radiation peak occurring during the period between 10 am and 17 pm. Subsequently, the high demand (B) can be supplied by the use of solar photovoltaic systems, knowing that the power demand in A, B and C has a similar trend as solar radiation. The objective was to reduce the use of natural gas and consequently the CO_2 gas emission [13–15].

The Electrical Network Characterization

The power capacity of the Algerian electrical network is about 15.8 GW as estimated in 2015 [13]. The natural gas is the main source of the electricity production. In fact the consumption of natural gas by the electricity companies was 13.895 Gm^3 to generate 60.5 TWh in 2015 [13]. However, a big issue becomes urgent to address as warned by the regulation commission for electricity and gas board (CREG), this related to the electricity network, In this, the losses occurring at the electricity distribution level show a significant part with 8878MW in 2015 [16]. The lack of control mechanisms and to some extent, the behavior of some customers (theft) do worsen the situation even more. As a result, the electricity demand is becoming more important. The power demand curve shows that the electricity demand has reached 10927 MW in 2014 [15], the demand for electricity will continue to rise in the future according to recent studies [13–17]. This is due to the population growth (Table 1) and also the technology development.

CO_2 Emission Review

The climate change and greenhouse effect are the main danger on the environment and earth pollution. Therefore, urgent measures have to be taken in order to keep the temperature level bellow 2°C. Unfortunately the temperature will continue to rise, for instance in 2013 it arose by 2.8°C [18]. The greenhouse effect is due mainly to human activities and is also the main source of CO_2 emission. CO_2 gas emission continues to rise at high rates which are becoming very dangerous, for example in 2011 this rate was 31.36 tCO_2 by fuel, China and OECD Countries are the main polluters their share part of pollution are 25.4% and 39.4% respectively [19]. For comparison, Algerian share part for gas emission is much lower, according to IEA (International Energy Agency) the total CO_2 emission by fuel in Algeria was 103.9$MtCO_2$ in 2011 [19]. In the Algerian case, no further information is available, since the only database released was in 2010 by the Ministry of Land-use Planning and environment, which gave the strategy adopted by the Algerian government.

In April 1993; Algeria adopted the United Nations Framework Conversion on Climate Change (UNFCCC), it consists of four main actions:

- Institutional strengthening;
- Adaptation to climate change;
- Limitation of gas emission and also to develop new management approach for energy use [20]. Thus the smart grid can lead to better results and it has a very promising potential in terms of reducing the greenhouse effect, especially when several sources of energy are integrated.

SMART HOME

The main application of SH is the energy supplied security, this is done by introducing new technologies that include intelligent software installed in the smart home. Thus, the energy efficiency factor becomes a new challenge. Improving efficiency, means reducing electricity consumption. Hence these concepts of energy security and efficiency can be achieved by new intelligent energy management systems. This approach can affect both the customer energy demand and the energy supplied by the electrical grid. Following this, the energy produced by the customer via the renewable energy sources (PV and thermal systems) and storage system become involved in the process [21–23].

This goal of energy management system is achieved by using the smart home components, such as the intelligent switchers, the smart meters, also the monitoring systems which play a key role in supervising household energy consumption, such as energy production by photovoltaic, wind, storage systems, etc. Moreover, they allow the communication with the electrical grid manager and customers via the Internet network. And also, the monitoring of energy prices [3].

EXPERIMENTAL SMART HOME

Grid Connected PV System Description

The smart home project installed at Batna University consisted of a PV generator, usual home loads (refrigerator, lights, PC and coffeemaker), these loads were supplied by the local electricity network (Figure 2), the electrical parameters of the loads were measured using the power meter LMG450. A control card which consists of a Raspberry PI and Arduino Ethernet cards was used to control the loads status via the internet network as shown in Figure 2. A grid connected PV system of 1.6 kWp (Ppv,nom) was installed to supply the local electrical network. The PV array consisted of 40 mono crystal modules (PHOTOWATT PWP 400 Type), it was inclined at an angle of 40° facing the south [17]. The connection of the modules was made in such a way to obtain an operating voltage ranging between 54 and 96 V. The inverter used in this experiment was the NEG 1600 Type with maximal power of 1600 Wdc with the maximal direct voltage of 110 V [24,25]. The parameters such as current, voltage, power, energy, frequency…etc were measured using a power meter (LMG 310 type). Next, temperature (Tm), the ambient temperature (Ta) and the solar irradiance (Gi) were measured using a pyranometer equipped with a solar integrator for recording the daily incident energy (HG).

PV Security System Description

The PV security system consisted of 20 modules of a maximal power of 800 W at standard conditions (1000 W/m², T=25°C). The system was connected to an inverter characterized by a maximal power of 900 W and a maximal operating voltage of 24 V. A set of 12 batteries of 2 V voltage connected in series, were used. The parameters of the set were

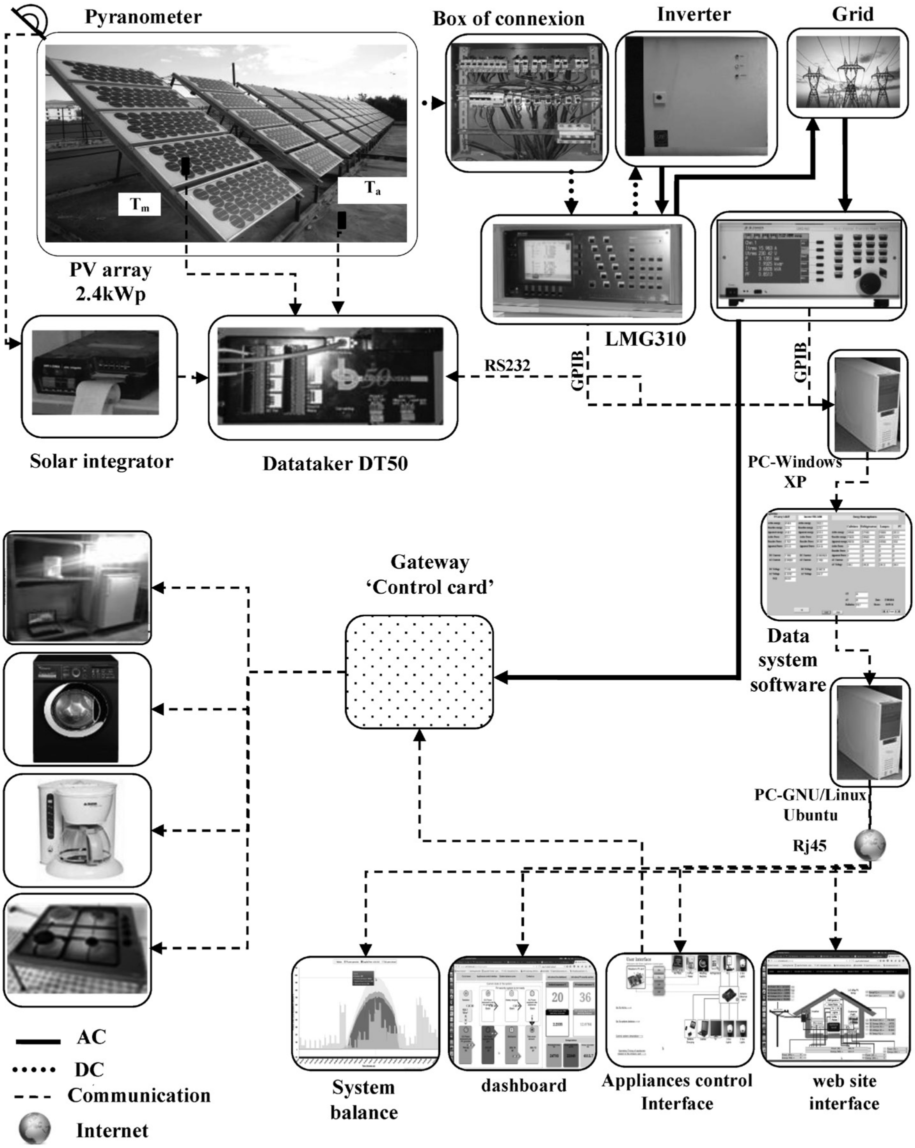


Figure 2. The architecture of the smart home system installed at Batna University The data acquisition unit (Datataker DT50 type) was used to read the PV module.

analyzed by the LMG450 meter. This system was designed to supply different electrical home loads (refrigerator, coffee maker, lamps…etc). Currently, the PV security system is in due course operation and no data are provided.

System Communication Architecture

The strategy of the energy management deals with the data processing of the grid connected PV system and weather parameters. The main goal is to analyze all data generated by the system during the functioning period. In fact, the architecture communication system provides the main factors to be processed such as energy, power, voltage, and other factors.

All the data recorded are sent to the PC via the RS232 and two GPIB protocols. The data processing and data saving are done using the software developed on Visual Basic 5 program named Data system software (Figure 2). Moreover, all the data are saved in the text files and sent via the TCP/IP protocol to the GNU-Linux PC in order to share the status of the system on the website.

Appliances Control System Description

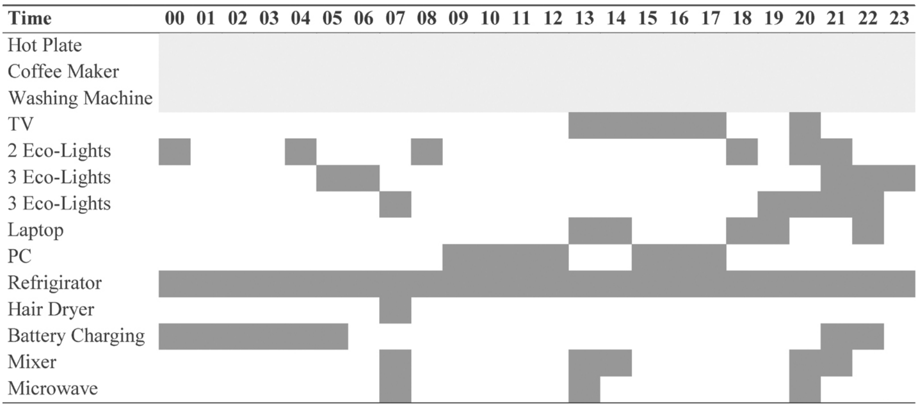
The solar laboratory of BATNA University provides all the facilities of a typical household appliances like refrigerator, washing machine, coffee-maker, desktop with printer, laptop and lights, the characteristics of which are summarized in the Table 2. The data of each load was monitored via the LMG450 discussed previously. The strategy used to control the household appliances lies on the open hardware and open software cards (Raspberry PI and Arduino Ethernet), the raspberry PI card control status of the washing machine, hot plate

Table 2. The electrical specifications of household appliances.

Appliances	Number	Rated Power (W)
Refrigerator	1	110
Hot plate	1	437
TV	1	86
PC + Printer	1	173
eco Light (18W)	2	36
eco Light (20W)	1	20
eco Light (12W)	2	24
Washing Machine	1	1100
economic Light (24W)	2	48
Coffee Maker	1	800

and coffee maker. The control status of the other appliance was done by an automatic code implemented into Arduino card. The timing of each appliance was recorded and illustrated in Table 3. The Arduino card was monitored using the Raspberry card, such that when it is turned off the appliances timing operation changes.

Table 3. The operation timing of household appliances implemented into Arduino card.



Open Source Platform

The main reason to choose the open source operating system for our installation is the security level and the concept of free software. Moreover, this procedure ensures high level of security for users, and improves security standards accordingly. Theses conditions were not satisfied with the previous closed systems and it is the users who usually undergo the side effect of the old methods [26]. It is also possible for open source users to develop their applications with a free software (Gambase, Lazarus, open office, Gummi, etc.). Given its powerful potential, the Raspberry PI type B card was used as the main tool for our investigation [27].

WEB PORTAL DESCRIPTION

System Website Server

A website was developed under open source platform. The role of the website was to check online the operating PV grid system including the PV module temperature, the data weather parameters (radiation and ambient temperature), and the consumption parameters of each load or the total and the local electrical parameters including the grid frequency (Figure 3). The system parameters can be checked on numerical or graphical mode. The parameters are measured and recorded on regular 24 hours period. Moreover, the visitors of the website can control the appliances status (On, Off) via the bottom "Control loads on/off." In fact, in order to have access to the appliances web interface the users need to be identified via the use of the username and password offered by the website administrator. On the website, a menu was developed to allow the user to check the performance of the system and also to get useful information about the main characteristics of the system. The website includes a menu named Archive. This menu was developed to enable the users to check the system data archive.

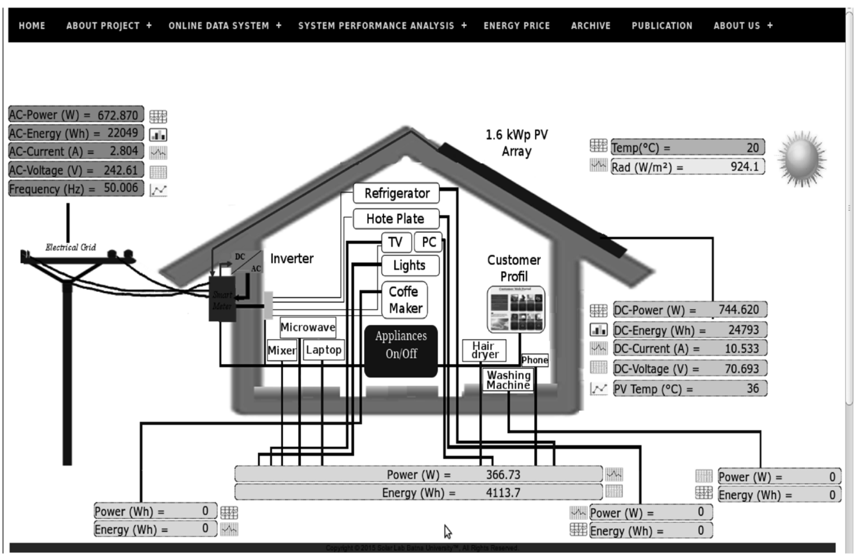


Figure 3. The view of the web site interface shows the parameters of the system in real time.

Appliances Control Web Interface

Figure 4 shows the web interface developed under PHP language, the household appliances control system is divided into two main subsystems. The first subsystem is the Raspberry PI card used to control the status of the hot plate, coffee maker, washing machine and Arduino

Ethernet card via the internet network. The second subsystem is intended to control the refrigerator, PC, 8 eco-lights, laptop, TV and the electronic devices charging. The control status is done with an automatic code incorporated into the Arduino card in adequation with Algerian household habits. The 8 eco-lights are assembled simultaneously on two eco-lights, 3 eco-lights and 3 eco-lights. On this interface the access on the system balance is possible via the link "Go To system balance."

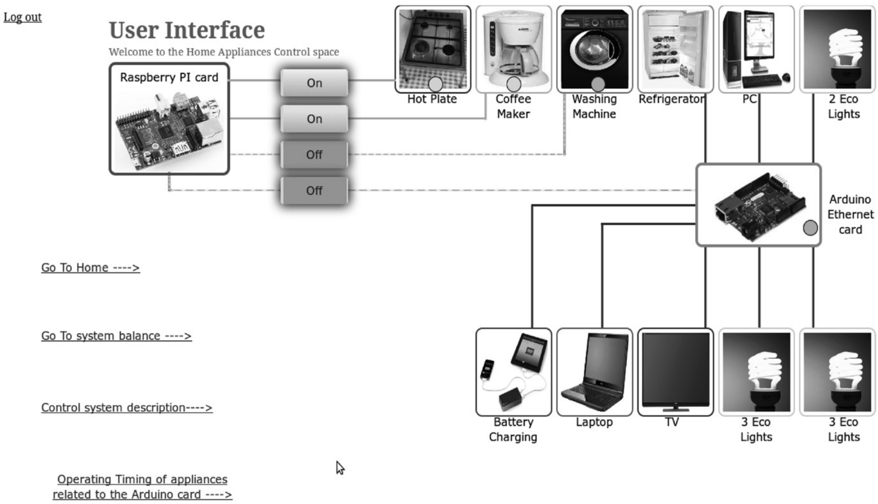


Figure 4. The view of the web interface household appliances control system.

System Balance Dashboard

The dashboard is introduced to show online the current status of the system balance during the functioning period (Figure 5). Most of the parameters of the system corresponding to the solar radiation, the DC power delivered by the PV generator, the power delivered by the inverter after conversion DC to AC, the power supplied to the grid and the total electricity demand by the household appliances they are all displayed presented in real time. Other parameters are shown in the dashboard like the PV module and ambient temperatures. The CO_2 gas emission can be avoided by the system and finally the energy balance of the system is given. The main indicator of the dashboard is the grid feed-in. When the grid feed-in indicator is in red this indicates that the power demand is higher than the power produced from the PV system which means that the customer is in worse off situation. In this case the customer can disconnect several appliances in order to minimize the energy consumption, especially when the PV system cannot satisfy the electricity demand. Alternatively when the indicator is in green mode which means that the customer is in better off situation then he can benefit from this advantage. Similarly, the electricity network control manager can check the electricity demand of their customers. It makes it also possible to control appliances taking into consideration priorities of appliances established by the customers. This application is introducing in order to reduce the electricity demand from the grid, particularly at the peak periods.

It is worth noticing that the data of the PV security system is not available at the moment wiring to some technical problem. Work is undertaken in order to complete dashboard as soon as possible.

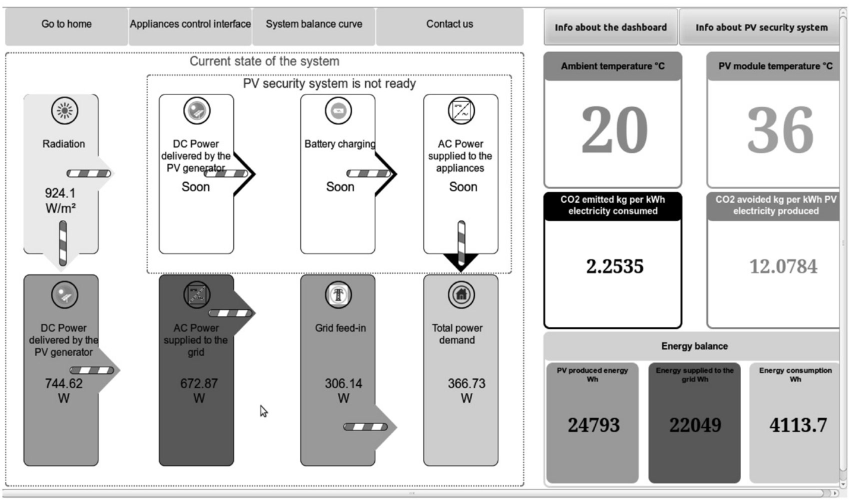


Figure 5. The View of the system balance dashboard.

RESULTS DISCUSSION

Solar Potential

The solar energy is to become the main source of the new electricity generation by the PV system. The average daily solar radiation measured since 2013 is about 5.21 kWh/m²/d. the annual value is about 1831 kWh/m², which seems to be a very important source to produce the electricity by the PV systems. In this region, the instantaneous radiation exceeds the value of 1000W/m² as shown in Figure 6. The same figure shows that the solar radiation is available during 4h30 at rate of 800W/m² corresponding to 3.6 kWh/m² during the same period. It is interesting to notice that during this period the demand for electricity from the electrical network is very important. It is then possible to use the PV system as an alternative to generate electricity need to satisfy the demand.

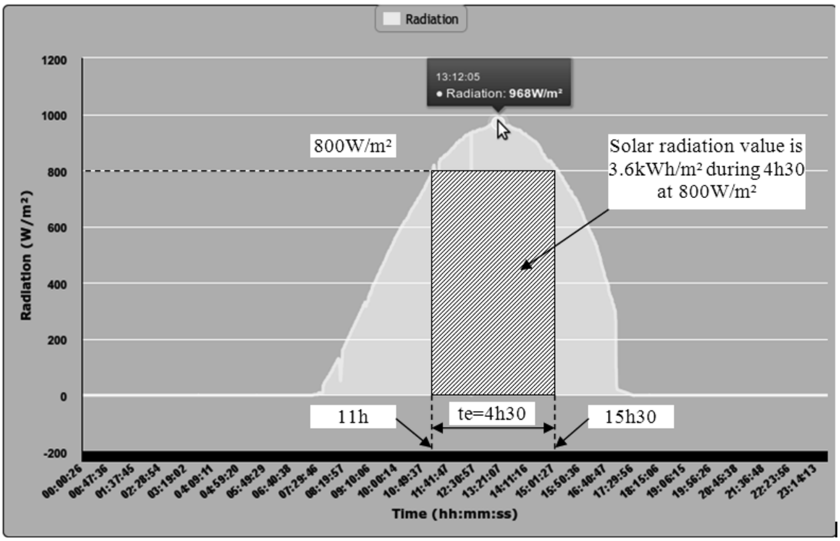


Figure 6. The evolution of the radiation during 31st October 2015 in Batna region.

Grid Connected PV System Energy Output

Figure 7 shows the DC power produced by the PV array (EDC), during the year 2013. The annual value was 1931.77 kWh. The daily average value (EDC,d) was 5.51 kWh/d with a variation between 4.35 (December) and 6.93 kWh/d (June). The annual value of the energy supplied to the grid (EAC) was 1705.032 kWh. The daily average value of the supplied energy EAC,d to the grid was 4.9 kWh/d.

Household Appliances Energy Consumption and Energy Balance Analysis

The monitoring system was adequate to determine the daily profile of the grid PV system, the electricity consumption and the self-consump-

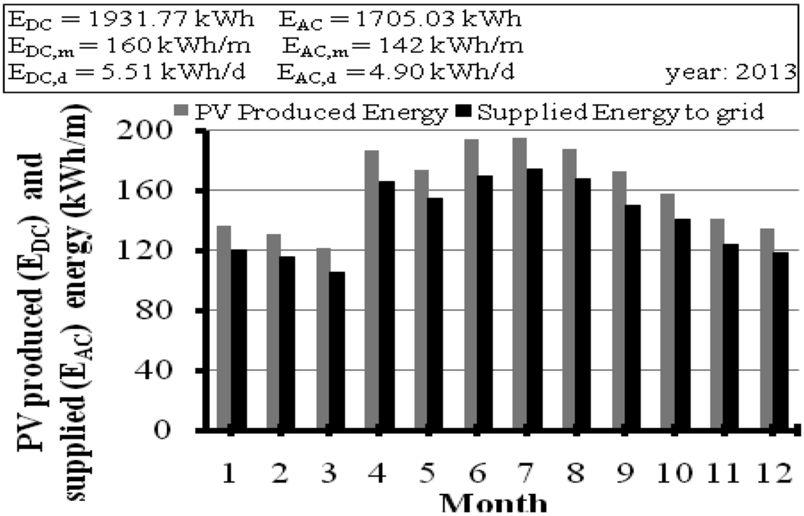


Figure 7. Monthly average PV produced and supplied energy to the grid for the year 2013 of 1.6kWp grid connected system at BATNA city.

tion. The Figure 8 describes the daily consumption profile (4) related to the appliances, it also shows the solar radiations (1) and both the DC power produced by the PV system (2). The same figure shows also the energy produced by the PV system which is injected into the grid (3) during the period from 8 am-5 pm when the contribution of the PV system is required. The remaining energy need is provided by the grid.

CONCLUSION AND FUTURE WORK

The main objective of this study was the application of the smart home concept, in order to determine its performance and to propose a new energy management system in household sector. It is based on the use of a web service via the monitoring interface. In fact, the incentive behind this study was to reduce the use of the electricity and natural gas consumption, while optimizing the electrical processes especially at the distribution level. This can be done with the use of the ICT utilities.

A new electronic card control system was realized. It consists of a new generation of open hardware card such as Raspberry PI and Arduino Ethernet cards. The use of the Raspberry PI and Arduino allows

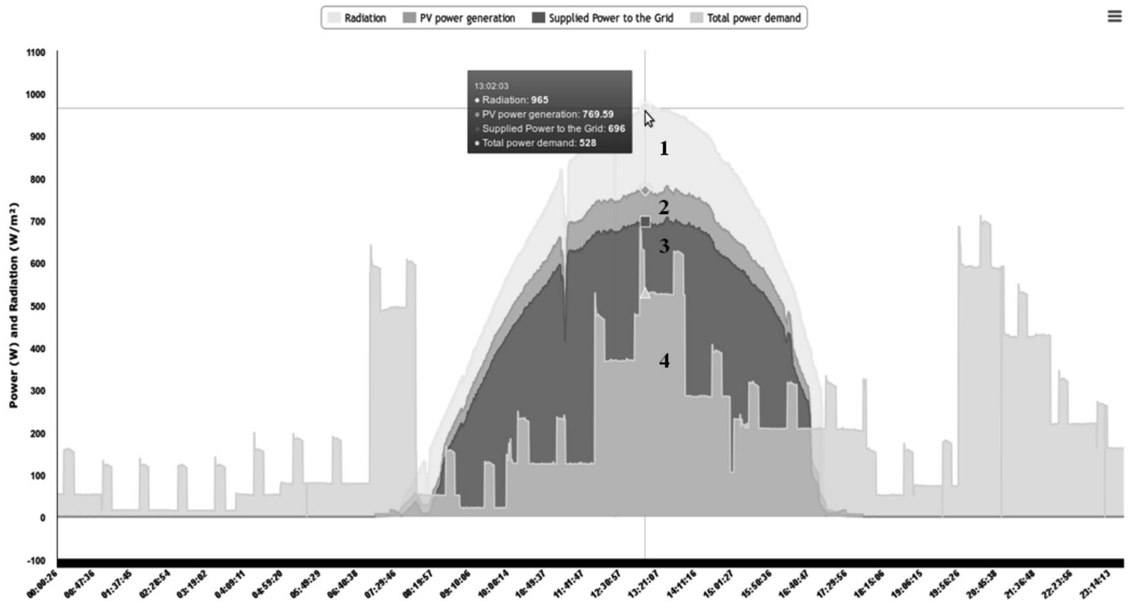


Figure 8. The system balance curves show the evolution of the radiation, PV energy DC and AC, the consumption and auto-consumption.

to control all the appliances via internet network technology, with a particular interest given to management strategy of the appliances. The latter has been conducted by using of the Arduino card. The functioning processes of the appliance was carried out according to the program developed for this purpose. Several effects were considered such as the customer behaviour towards electricity consumption.

The website server was developed under GNU-Linux kernel under open software. Its main application was to manage the whole data delivered by the system, in order to determine the performance of the grid connected PV system together with the electricity consumption by appliances, and the electrical network functioning during the whole period under investigation.

Future work will be focused on calculation of the live cycle cost for this installation and to develop software in open source platform (GNU-Linux kernel) for the economic sizing task. Also, in the next work we will introduce the energy cost in the monitoring system, this allows the customer to check and control his electricity bill in real time.

Author Contributions: Adel Ghouari and Chaâbane Hamouda contributed to the conception of the study and the discussion of the results. Adel Ghouari performed the experiments and developed the monitoring system. Abdelaziz Chaghi and Mohamed Chahdi wrote the paper. Mohamed Chahdi corrected and finalized the paper.

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ABOUT THE AUTHORS

Adel. GHOUARI obtained his Master in Industrial Engineering from Hadj Lakhdar University of Batna, Algeria. Currently, he is pursuing his Ph-D degree at the department of Industrial Engineering. His main research interests are in the Smart Grid system and the monitoring of a grid connected PV system. Department of Industrial Engineering, Laboratory of Automation and Manufacturing, University Batna 2, 05 avenue Chahid Boukhlouf 05000 Batna, Algeria; e-mail: adelghouari@hotmail.fr.

Dr-Ing. Chaâbane HAMOUDA received his doctorate from the Technical University of Berlin (TU Berlin), after a brief experience in the semi-conductors industry he joined the University of Batna, Algeria (UHLB). He was the director of the research unit and responsible for the training of advisers in energy saving and environmental protection for the benefit of the National Electricity and Gas Board (Sonelgas). He is currently a senior lecturer at the Industrial Engineering Department of the UHL Batna. Department of Industrial Engineering, University Batna 2, Algeria; e-mail: chaabanehamouda@yahoo.fr.

Prof. Abdelaziz CHAGHI. He received his engineering degree from the University of Oran, Algeria in 1980, and M.Sc. from Manchester University, United Kingdom in 1984. He received Doctor Degree in Power Systems from University of Batna, Algeria in 2004. Professor Chaghiis responsible for the research team in charge of "Power quality in distribution power systems" at LSP-IE research laboratory, University of Batna. His research interests include power systems optimization, power electronics, power quality, renewable energy, harmonic, and FACTS devices modeling and control. Department of Electrical Engineering, University Batna 2, 05000 Batna, Algeria; e-mail: az_chaghi@yahoo.fr.

Dr. Mohamed CHAHDI was graduated from the universities of Dundee and Glasgow in Scotland, UK. In 1982, obtained his Msc from the University of Dundee (Scotland) and in 1986 he earned a PhD in physics from the university of Glasgow in Scotland. His research work focused on the study and preparation of amorphous Silicon (a-Si:H) for electronic devices applications, in general and the solar cells, in particular. In 1998 he was promoted to Professor of physics at the university of Batna in Algeria. Currently, he is involved in teaching of both graduate and post graduate students and has a particular interest for nanoscience and nanotechnology. Department of physics, University Batna 1, 05000 Batna, Algeria; e-mail: Chahdi.mohamed@yahoo.fr.