Study on Solar-powered IoT Node Autonomy

Alex Nguyen
ESIEE Paris
alex.nguyen@esiee.fr

Pedro M. Santos, Miguel Rosa
University of Porto
{pmsantos,up201406660}@fe.up.pt

Ana Aguiar
University of Porto
Instituto de Telecomunicações
anaa@fe.up.pt

***Abstract*—Renewable energy sources may ease the deployment of IoT nodes in smart city scenarios where access to a steady power supply is often limited. In this paper, we report experimental work to evaluate the feasibility of sustaining the operation of an IoT node from an autonomous power supply, composed of a photo-voltaic (PV) energy source, batteries and a controller. We measured a tentative deployment, observe that typical forecasting tools are inadequate to dimension such micro-supplies, and used greedy search to find the best system configuration.**

***Index Terms*—Smart cities, IoT, sensor node, power autonomy, renewable energy sources**

I. Introduction

Smart cities use data and models of urban processes (traffic, weather, human flows, etc.) to improve life in cities [1]. Actionable data must be collected by sensor nodes deployed in large scale and integrated in the Internet-of-Things (IoT). Oftentimes, infrastructural power supply may be limited or even unavailable at relevant locations. Renewable energy sources may be an alternative solution in these cases [2].

In this work, we study if the operation of an archetypal IoT node, a Data Collection Unit (DCU) [3], paired with a solar photovoltaic (PV) panel and adequate battery capacity, can be supported continuously and over long periods. We report an experimental characterization of the power consumption of a DCU, present a viability study using typical PV forecasting tools, and characterize experimentally the performance of a PV system to support the DCU. Then, we use greedy search to find the best values for combination of installed power and battery capacity.

II. Power Consumption of IoT node

We report the power consumption profiles of our archetypal IoT node (Fig. 1). The IoT node is composed by a processing unit (a Raspberry Pi v2), two boards that host sensors, a control board to bridge sensors and processing unit, and a power converter unit.

We measured the current between the power supply and the IoT node when active (tension is constant). The consumed power P can be obtained from $P = I.V$; the consumed energy E is obtained from integration of consumed instantaneous power: $E = \int P(t)\,\mathrm{d}t$. We evaluated the power consumption with four operational profiles: (1) no WiFi nor data collection (DC) from sensors active; (2) WiFi inactive but DC active; (3) WiFi active but no DC; (4) WiFi and DC active. The measurements were performed with an INA219 current sensor, that provides a range of 3.2A with a resolution of 0.8mA. The measurements were taken for 5 minutes, with resolution of 1s.

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Fig. 1. Data Collection Unit

Fig. 2. Set of PV system and DCU.

TABLE I
Measured Power Consumption by IoT Node

Operational Profile	1	2	3	4
Mean instant. cons. (W)	3.25	3.95	4.29	4.78
Cons./5 min (J)	975.74	1185.39	1287.21	1433.91
Cons./5 min (Wh)	0.27	0.33	0.36	0.40
Cons./day (extrapol.;Wh)	78.06	94.83	102.98	114.71

TABLE II
Production forecast per month (Wh)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
130	180	220	230	240	240	250	250	240	190	150	120

Tab. I shows the average power of each configuration, and the energy calculated by integration. We used the results to forecast the consumption of a full day (see last line of table).

III. Viability Study on Solar Power

We study the viability of a PV system to support the DCU operation using standard PV forecasting methods and the measured DCU power consumption. We used the simulation tool available on the website `http://re.jrc.ec.europa.eu/` to forecast the solar production in several configurations. This tool uses average meteorological data over the last 5 years. We choose the following parameters as a starting point: installed peak PV power: 50W; battery capacity: 180Wh; discharge cutoff limit (DCL): 40%; consumption per day: 120Wh (based on the maximum consumption reported in Table I, Profile 4's). Our case is an off-grid system.

For a solar installation with 50Wp (one solar panel) in the best conditions (clear sky and slope optimised), the simulation tool provides the results shown in Tab. II. Fig. 3 shows the distribution of off-days throughout the year according to the

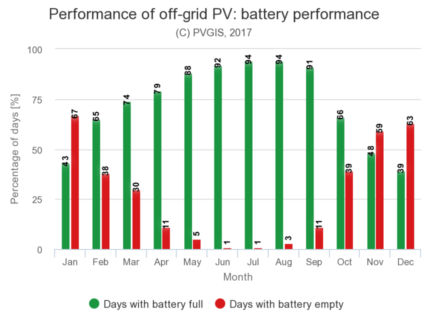

Fig. 3. Percentage of days with full/empty battery (initial configuration)

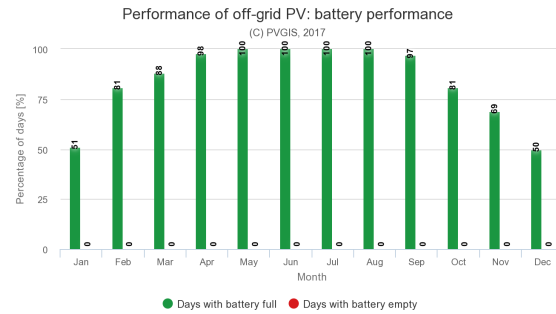

Fig. 4. Percentage of days with full/empty battery (best configuration)

TABLE III
MEASURED PRODUCTION AND PERFORMANCE OF PV SYSTEM

Yields (Wh)	Consumption (Wh)	Time in Bulk (min)	Perc. days with cutoff	Average cutoff time (hour:min)
116	81	357.4	50%	2h54min

simulation tool, indicating that the battery will be empty around 27% days in a year, mostly in the winter months.

IV. EXPERIMENTAL EVALUATION OF SYSTEM OPERATION

In this section, we evaluate the power production of a prospective PV system. The system is composed by: (i) two PV panels of 50Wp; (ii) an MPPT (*Maximum Power Point Tracking*) 100/15 BlueSolar Victron Energy controller; (iii) two GEL Lead-Acid 12V 7.5Ah batteries. The PV panels are placed at a slope of 35° to the ground, an azimuth of 0°, and oriented south. The batteries are connected in parallel between them and to the MPPT. The system only starts charging at 17V (the battery voltage + 5V); this was programmed in the MPPT. The discharge cutoff limit was set at 40% in the MPPT; the MPPT never allows the battery charge to go below that value. The deployed setup is shown in Fig. 2.

The experiment was made from the 30th of June to the 12th of July. The data was collected from the MPPT controller with a granularity of 1 second. The load was the above-mentioned DCU, collecting data from all sensors and forwarding to a cloud wirelessly (Profile 4). Tab. III presents the daily average values and ability of the PV system to support the DCU. We observed a load power cutoff, during which the DCU is not powered, controlled by the MPPT and due to low battery voltage. The cutoff happened in 50% of the experiment days and lasted 2 to 4 hours.

V. DESIGN-SPACE EXPLORATION

We set out to find a equipment configuration that guarantees that the battery is never empty at an acceptable price. The equipment parameters are: (i) installed power production capacity; (ii) battery capacity; (iii) discharge cutoff limit.

We used a greedy iterative search. At each iteration, we evaluate if it is best to increase the power production or the battery capacity to minimize the number of days with empty battery (DWEB). For equipment selection and cost computation, we used the website `https://www.solaris-store.com/`. The same forecasting tool of Sec. III is used to compute the number of DWEB. Fig. 5 presents the iterations of this algorithm. The black represents the start point; at each iteration, the two possible options are indicated by the arrows; the green

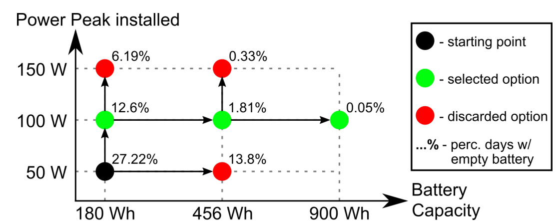

Fig. 5. Graphical depiction of iterations of design-space exploration.

dot indicates the chosen option, and the red dot the discarded one. An additional low-impact step to lower the DWEB (not shown in Fig. 5) is to change the DCL from 40% to 38%. The resulting configuration has an installed power of 100Wp, a battery capacity of 900Wh, a DCL of 38%, and a total cost of 338.3 Euros. Fig. 4 is the output of the simulation tool for this equipment configuration, showing 0% DWEB as intended.

The resulting setup would support DCU operation autonomously over 4.5 days, in case the battery is not recharged. This value is the ratio between: (i) the energy stored in a full battery, given by $E_a = \text{BattCp} \cdot (1 - \text{DCL}) = 900 \cdot 0.62 = 558\text{Wh}$; (ii) the DCU daily consumption, 120Wh.

Note also that it is better to place 2 solar panels of 50 Wp in series than just one solar panel of 100Wp. The voltage of each solar panel can be added to rise above 17V more easily, as this is the voltage at which batteries start charging.

VI. CONCLUSION

In this article we evaluate the ability of a photovoltaic and battery system to support an IoT sensor node. We observed experimentally that the power supply system dimensioned using typical PV forecasting tools lead to power outages in 50% of the days, for 2 to 4 hours. This is probably due to the meteorological conditions during the experiment differing from the average of the last 5 years used in the forecast. Our experiment indicates that classical PV dimensioning methods may be inadequate for such micro-systems.

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