Optimization of an electrochemical water disinfection cell PV power supply depending on the installation climatic zone.

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Abstract—The optimization of a power system for anElectrochemical Water Disinfection cell is presented. The aim of this work is to perform a flexible self- sustainable energy supply, based on solar photovoltaic energy source. As main characteristic, the EWD cell is designed to work mostly independently from the emplacementand over a wide range of electrical conductivity natural waters. Experimental measurement of free chlorine generation level is considered the leading variable for disinfection performance characterization. Solar power elements have been selected and tested in real sun conditions. To evaluate merit parameter variation along the effective lifetime, a simple battery ageing procedure has been performed under controlled conditions.Two PV power supply configurations, with and without accumulation support are analysed. A sample of three representative climatic zones has been identified and separately studied. The best compromise between water flow production and system cost constitute an unbiased estimator to optimize the power support selection. The results can be generalized in terms of local solar irradiations characteristics through a decision-making power design structure based on economic context, climatological characteristics and water production rates.

Index Terms—Electrochemical disinfection, Free chlorine, Natural water, Solar irradiation, Solar Photovoltaic

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1 INTRODUCTION

Electrochemical Water Disinfection (EWD) is a treatment method by which different disinfection species are generated from natural waters contents during an electrolytic process[1],[2],[3]. Particularly, free chlorine, constituted by two disinfection agents (hypochlorous acid an hypochlorite ions) is mainly dependent on the natural content of dissolved chlorides and water pH[4]. Values of residual free chlorine higher than 0,2 mg/l in disinfected waters accomplish international water quality standards advice by the World Health Organization [5].

The potential of renewals in EWD systems is considered one of the most promising solutions for isolated, rural and off-grid emplacements [6]. Depending on the availability of local energy resources, different solutions for energy supply can be managed. Photovoltaic energy supply has shown to be one of the most reliable and cost effective alternatives attending to its adaptation to very different climatological conditions.

The production of free chlorine during the EWD process is fully dependent on reliable and constant energy supply during operation [7],[8], requiring as wellenoughflexibilityto ensure a good performance on a wide range of natural waters. The design optimization of the power supply is therefore crucial. Isolated PV direct energy supply systems are technologically simple, demanding low operation and maintenance requirements [9] and therefore considered as first option for utilization. In those cases, the performance of PV modules is characterized by the dependence of current intensity produced with direct solar irradiation, reason why irradiation levels variation and its seasonality in time directly influences performance stability. The minimization of this effect can be achieved with the utilization of energy accumulation systems (batteries), stabilizing disinfection productivity rates and homogenizing system response. Even though, associated higher system costs has to be considered.

The aim of the actual paper is to evaluate the feasibility of non-conventional energy supply systems used in electrochemical water disinfection process, toadapt to any emplacement worldwide. In that sense, a comparative study based on the compromise between productivity gain stabilization and cost increase between direct and accumulated energy supply systems is carried out. Three different reference climatic zones were selected for study case, a very dry zone and two humid zones with high and medium low irradiations respectively.

Regardingthe diversity of natural water characteristics, even though there is no univocal relation between water chloride contents and electrical conductivities, this variable is considered an appropriate measurement reference [10]. In the actual work, results for water minerilizations range between 0,028 a 0,567 mS are presented.

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2 EXPERIEMENTAL

2.1 Setup

The experimental setup performed uses a non-commercial electrochemical cell as shown in Figure 1.Free chlorine generation analysis, solar module characterization and battery ageing definition were performed during the experiments.

Figure 1Experimental setup used in laboratory experiments.

The EWD cell consists of two parallel holed plate electrodes screwed in two fixed connection bolts within a standard polypropylene water filter casing. The electrodes are separated with standard Teflon rings of 1 and 2 mm thickness. Anode and cathode material are stainless steel 304. The active surface of both electrodes is 280 cm^2, the distance between electrodes varies from 1 to 18 mm during the experiments and the capacity of the casing vessel is 1l. Connection bolts are made of screwed steel M6 bars. Connection cables of 0,5 m length and $S=2{,}5mm^2$ are used.

Even if, the EWD cell will be powered by PV energy, during laboratory tests the power was supplied using a VELPS 5005 power adjustable 0-48V ± 2mV; 0-5A ± 5mA. Voltage and current intensity are measured directly on the power supply witchis connected directly to the electrodes. A simple DAQ allows the control on the temperature and electric conductivity using PCE-PHD1, 0-50ºC ±0,01ºC and 0 - 2mS ±0,001mS respectively. The pH meter used is TESTO 206-pH1, 0-14pH ±0,02. The free chlorine analyzer used is HI-701, 0-2,5mg/l ± 0,05. The chloride analyzer used is HI-3815, 0-100mg/l ± 1.

Two 53W monocrystalline (ISOFOTON I-53/12V) photovoltaic modules serially connectedare used.Module characterization is obtained using a SolmetricPVA-600 I-V curve tracer in real sun conditions.

Battery-ageing characterization was performed in a Clean Moura (Pb acid 85 Ah leader C_{20}) battery,using DM3058E Fluke multimeter/analyzer at constant battery discharge rate and forced charge/discharge cycles.

Three different natural water samples were selected for experimental tests (Table 1).

Table 1. EXPERIMENTAL WATER SAMPLES CHARACTERIZATION. ELECTRICAL CONDUCTIVITY (mS), TOTAL CHLORIDE CONTENT (MG/L),

Water Sample	**Electrical conductivity** (mS)	**Total chloride content** (mg/l)
1	0,028	7
2	0,107	10
3	0,567	35

2.2 Measurements

The definition and characterization of the EWD cell control parameters were exhaustively studied in[10]. The focus of the actual paper is the design of appropriate renewable based energy supply systems, considering relevant technical and economic associated constraints.

First, the characterization of cell performance on free chlorine generation is evaluatedfor different water samples and optimum cell operation ranges defined. Later, the capacity of specific PV module to fulfil the disinfection cell energy requirements on optimal operation ranges is evaluated.

Two different energy supply installation layouts are defined, direct energy supply and energy supply with accumulation system (batteries). A priori, direct energy supply installations are less efficient and instable (fully dependent on available sunlight), on the other hand, they rely on few installation components and easy operation and maintenance requirements (a major advantage on rural and isolated emplacements). Energy supply installations with accumulation systems, at first, allow longer productive periods and stability on operation, increasing the theoretical overall process efficiency. The higher technification level and dependence on operation and control spare parts are important factors to consider on decision-making. In that sense, the characterization of accumulation systemis presented.

A final comparison between the two proposed layouts based on the compromise between disinfection production rates and system costs associated to EWD process is presented in section 3.3.

2.2.1 Free Chlorine generation

The objective of this section is to evaluate the influence of main cell performance parameters on free chlorine generation. The relationship between effective electrical field current intensity (I), cell exposure time (equivalent to disinfectionflow rate) and free chlorine generated (efficiency indicator of the disinfection process) is analyzed under controlled laboratory conditions. All samples were filtered by 0,2 microns membrane, preventing any turbidity and preserving maximum disinfection capability [11].

The effective electric field current intensity has been described as a product of three independent functions of the electrolysis leading variables: cell voltage;inter electrodes gap and water electrical conductivity[10]. Cell voltage of 24 V is constant through all experiments. Inter electrodes gap between 1 and 18 mm are used to ensure current intensity variations between 0,5 and 4A.

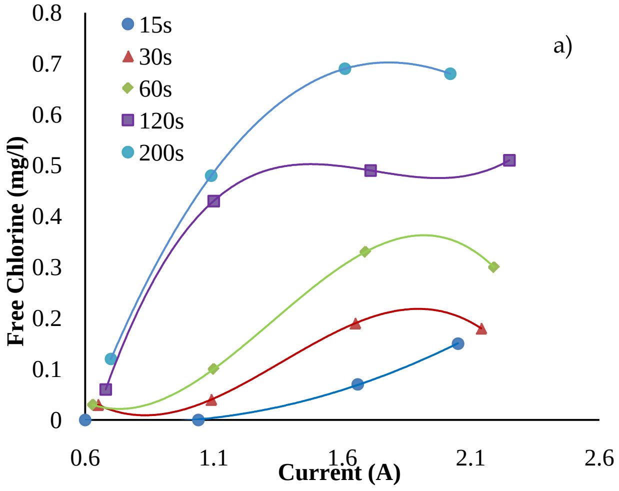
In real conditions, chemical characteristics of natural waters considerably vary along the year in both quantity and type of dissolved salts. Water electrical conductivity is used to express the number of total dissolved salts (TDS) without salts type differentiation. Considering the influence of dissolved chloride on free chlorine generation, initial values of total chloride content and electrical conductivity (table 1)were evaluated in the three extreme natural water minerilizations tested.

Exposure time, correspond to the total period that same water sample is exposed todisinfection cell. Table 2 shows the equivalence on water flow rates (cell productivity) and the five exposures periods considered to evaluate its influence on free chlorine generation during experimental tests.

Table 2. CORRESPONDENCE OF EXPOSURE TIME (SECONDS) AND EXPECTED WATER FLOW RATE (LITERS/HOUR).

Expected Water flow rate (l/hour)	**Exposure time** (s)
240	15
120	30
60	60
30	120
15	240

Figure 2 shows the main results obtained in all experiments,worst-case scenario reference values obtained is used for further calculations in sections below.



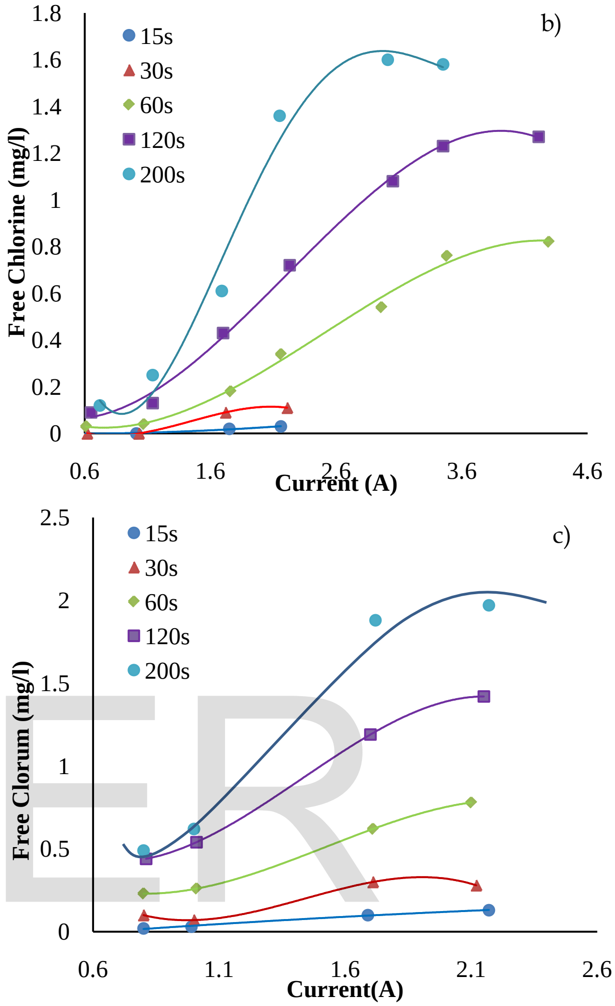


Figure 2Influence of current intensity (I) and exposure time (15s; 30s; 60s; 120s; 200s) on free chlorine generation (mg/l) in three water samples: a) 0,028mS; b) 0,107mS; c) 0,567mS.

Independent on the water sample evaluated, current intensities over 1,6A and exposure time of 60s or higher assurefree chlorine production over 0,2 mg/l.

There is a current intensity interval (specific for each water mineralization) in which no significant increase on free chlorine production is observed (saturation effect). Current intensities over those interval values increase the overall system energy consumption and can induce the release of DBP (Disinfection by products) from stainless steel electrodes (e.g. Cr_6).

The measures taken do not show a direct relation between electrical conductivity, total chloride values and free chlorine generation, probably associated to the different chemical composition of the dissolved salts. (The characterization of salts composition exceeds the objectives of the present research).

2.2.2 Energy supply characterization

Considering an off grid EWD cell operation, two basic premises are established: cell low energy consumption (defined in 2.2.1) and energy supply autonomy and reliability. Considering its versatility to adapt to a wide range of climatological conditions, photovoltaic solar energy (PV) was selected.In any case, other non-conventional renewable energy source could be used.

To evaluate the potentiality of PV based energy supply, two possibilities are considered (see figure 3): an easiest direct operation layout design, where solar module is directly connected to the disinfection cell and a more complex installation where the disinfection cell is connected to an energy accumulation system.

Figure 3 Schematic layout of PV energy supply installations: a) Direct installation, b) Installation with energy accumulation

In the case of direct installation, the solar module will be responsible for system performance control, in the case of installation with accumulation, system performance will be determined by the energy demanding system (in this case the EWD cell).

Concerning direct installation layout, PV modules performance is characterized by equation 1 and equation 2.

$$V = V_0 + m\, v_t \ln\frac{G}{G'} - \beta(T - T') \quad (1)$$

$$I = I_0 \frac{G}{G'} \ln\frac{G}{G'} + \alpha(T - T') \quad (2)$$

Where: I is the current intensity (A);$I_0$the current intensity in standard conditions (A);V is the cell potential (V);V_0 the cell potential in standard conditions (V); G is the global solar irradiation (W/m²); T the ambient temperature (ºC); (T´,G´) the values correspondent to AMS measurements; (m, v_t)are characteristics of module material; α and β are constants.

Figure 4 shows the dependence of the main panel characteristics obtained from (1) and (2), considering that α and β constants are small and the dependence on T can be neglected. Current intensity depends linearly with solar irradiation whereas cell potential is quite independent on it. Figure 4a shows the IV and PV curves of utilized solar module. To assure the operation at low irradiations, module potential should not be lower than 16V.

The dependence of current intensity with solar irradiation is presented in Figure 4b. The linearity is maintained even in high range of irradiations. In the case of direct energy supply installations, operation at stable current intensity values will require the utilization of sophisticated electronic control, increasing the total system cost.

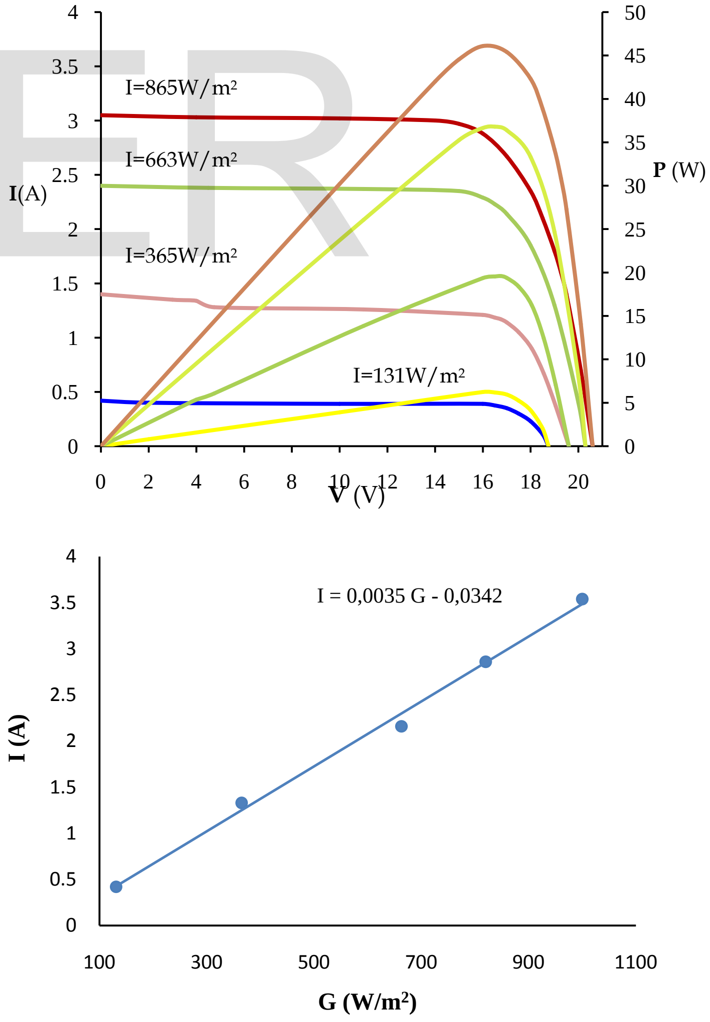


Figure 4a) Curve I-V and P-V of module ISOFOTON I-53 obtained in real sun conditions b) Influence of Solar radiation (W/m²) on current intensity

(I) throughout a typical day in climate conditions between temperate and semi arid at constant operating potential of 12V per module.

In installations with energy accumulation, 100% of total solar irradiation collected by PV module is stored and uninterrupted operation of disinfection cell (24h) at constant energy supply achieved. Size and battery capacity is set by worst-case cell operation parameters (maximum operation time, maximum energy required, etc.). PV module should meet charge/discharge battery requirements.

The biggest technical constraint on batteries utilization is their efficiency losses by wear out. To predict the possible repercussion on EWD cell performance, a battery ageing characterization was performed. Figure 5 shows the result obtained in six periods of its useful life. Tests were performed at constant discharge rates and continuous charge/discharge cycles.

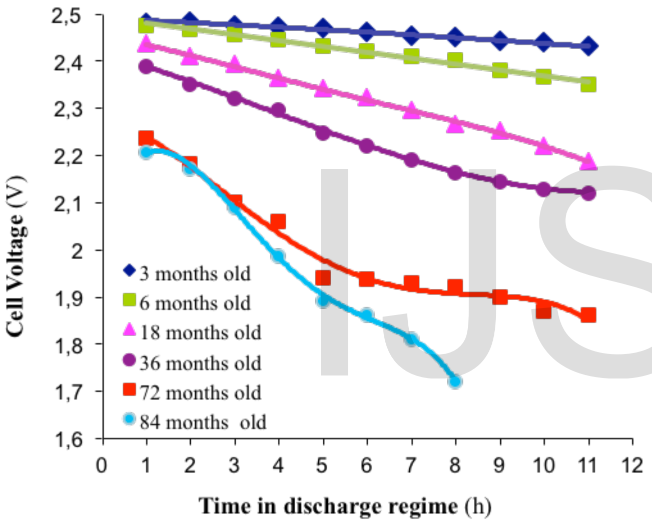


Figure 5Performance of a Clean Moura (Pb acid, 85 Ah) battery with the ageing effect. Cell voltage (V) and time in discharge regime (h) of the battery in different periods of its useful life (3, 6, 18, 36, 72 and 84 months).

Ageing process considerably influences battery performance in all periods of its useful life, further description of battery ageing on EWD cell operation is presented in section 3.2.

3 RESULTS AND DISCUSION

Independent on geographical zones, PV based energy supply installations should assure the correct operation of the EWD cell. In order to obtain significant results, three different regions with very distinct year round solar irradiation distribution and climatological conditions, are selected for study case. Table 3 resumes the main characteristics of the three emplacements selected.

Table 3. CLIMATOLOGICAL CHARACTERISTICS OF THE THREE EMPLACEMENTS SELECTED FOR STUDY CASE

Emplacement reference	**Climatological Characteristics**
REGION 1. Atacama Desert, Chile	Very dry climate High direct irradiation Low diffuse irradiation Seasonality on year round irradiation distribution
REGION 2. Pacific coast, Nicaragua	Humid Climate High global irradiation High diffuse irradiation Low Seasonality on year round irradiation distribution
REGION 3. Humid coast, Galicia	Humid Climate Medium/Low global irradiation Medium diffuse irradiation Seasonality on year round irradiation distribution

To obtain a global overview on the available solar energy, Figure 6 shows the average monthly global irradiation levels in both emplacements. The values presented (SPH)represent the mean time in hours of a hypothetic constant solar irradiation over 1000W/m², calculated by the integration of the full range of solar irradiation along the day. Data presented is obtained from [12].

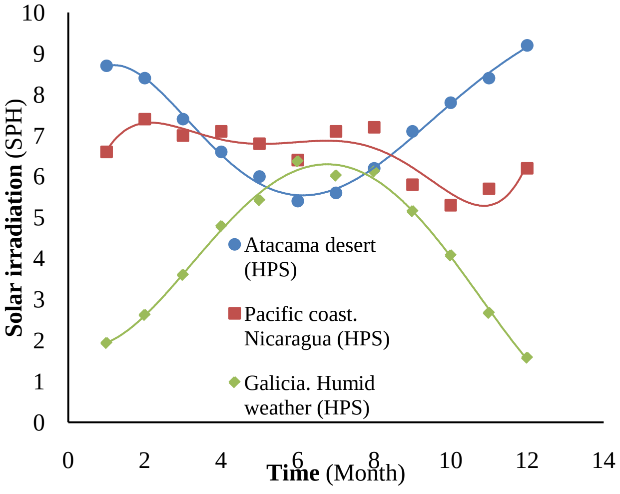


Figure 6Typical yearround distribution of Solar radiation (SPH)on a sunny day for three study case emplacements.

In case of direct energy supply installations and taking into account the linearity between I and G (figure 4b and eq2), at low irradiations values, the system will not be able to achieve the minimum electric field current needed to assure reference free chlorine generation. Furthermore, the recalculation of the energy over this threshold will depend on the climatological conditions and the number of sunlight hours.In order to obtain the minimum irradiation values for appropriate cell operation, it is necessary to extract from total monthly irradiation the ones that correspond to electric field current required for free chlorine generation. In those conditions its compulsory the utilization of daily irradiation distribution information.

Figure 7 shows the curves of instantaneous daily irradiation distribution for typical sunny days in two extreme irradiation periods (winter and summer) for each emplacement. The total area of each curverepresents the full integration on daily global irradiation rang corresponding to 100% of irradiation collected.The horizontal desplacement observed is associated to artifitial country timing definitions.

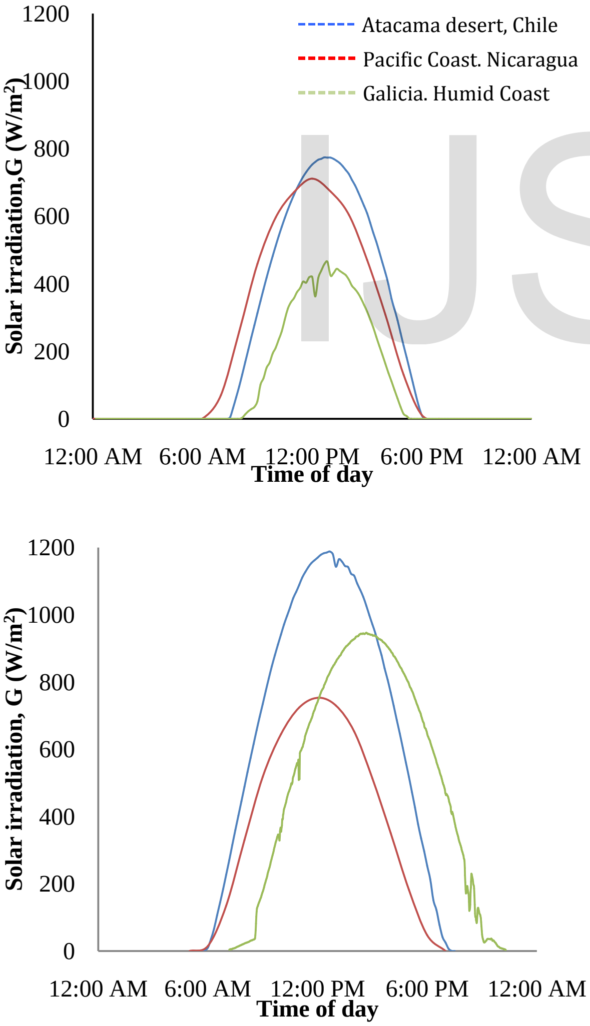


Figure 7Typical instantaneous daily irradiation distribution of a sunny day for three different climatic regions, a) wintertime, b) summertime.

3.1 Direct installation, without energy accumulation

EWD process efficiency is dependent on three main variables, cell exposure time, water electrical conductivity and electric field current intensity. Important variations on current intensity imply drastic differences in free chlorineproduction (section 2.1.2). Cell exposure time is inversely proportional to disinfection flow rates and particularly important on free chlorine generation.Even so, exposure timessmaller than 60s do not achievedisinfection reference valuesin low mineralization-waters (figure 1).

In the case of direct energy supply installation, current intensity is set by solar irradiation, the optimum operation parameters will be defined by the minimum values of solar irradiation and exposure time required to assure free chlorine reference levels (0,2mg/l) in all water samples. To obtain them a simple approach based on previous evaluations analysis is proposed.

Using data from figure 1, minimum current intensity values required for appropriate disinfection are extracted. The correspondence on solar irradiation (lineal dependent with current intensity) is obtained from equation 3 and Figure 4b).

$$G = \frac{I - I_0}{\alpha} \tag{3}$$

Where: G is the global solar irradiation (W/m²), I the current intensity (A), I_0 the Panel Current in standard conditions (A),αthecalibration constant.

The minimum EWD effective irradiation values will correspond to the irradiation need for reference free chlorine generation on the most unfavourable water sample.

Figure 8 shows the main results obtained for exposure periods of 60, 120 y 200 seconds respectively. Note that horizontal lines (red) establish the reference disinfection values of free chlorine and vertical linesdefine the minimum values of irradiation obtained for appropriate operation of the system. Correct working regime (green line) corresponds to the optimal operation of the cell for worst-case scenario (most unfavourable water sample).

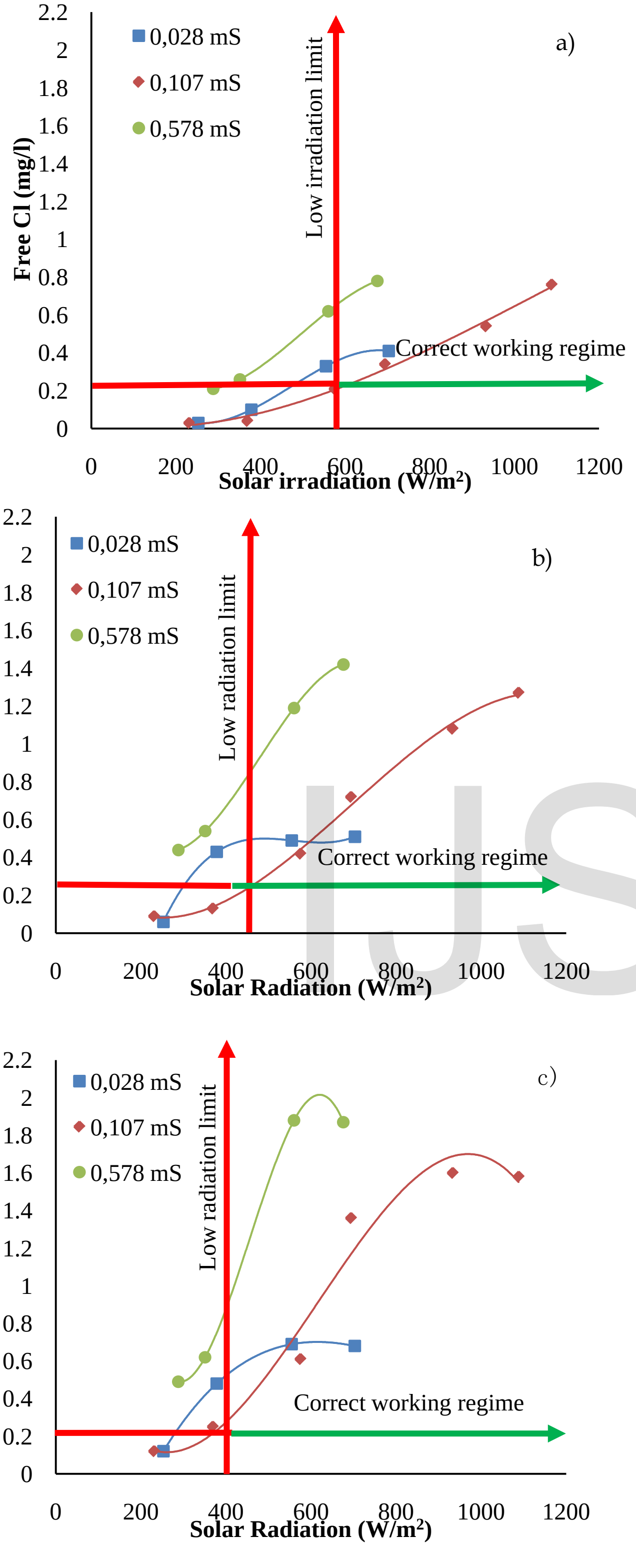


Figure 8Free chlorine generation (mg/l) and instant Solar irradiation (W/m^2) for three different natural water mineralization's (0,028mS; 0,107mS; 0,578mS) and exposure period of a) 60s, b)120s, c) 200s

Higher exposure times require lower irradiation values for same disinfection efficiency. For exposure times of 60s, solar irradiation should exceed 600W/m² in order to ensure 0,2mg/l of free chlorine in all water samples. For exposure periods of 120sthe minimum solar irradiation required is established around 400W/m². For exposure periods over 120s (figure 7c) there is no significant increase on the generation of free chlorine, and small reduction on solar irradiation required is presented comparing to exposure periods of 120s. However, production rates decrease and possible undesired effects on water quality due to over exposure are expected.

Considering reference solar irradiation ranges required for direct operation obtained from figure 8 (between 400 W and 600 W), the maximum percentage of effective irradiation collected by PV module is evaluated. It corresponds to the estimated period of direct cell operation and is obtained from the integration of each curve area (figure 6) over the defined reference irradiation values.

Table 4 and table 5 resumes the values obtained for summer and wintertime sunny daysfor reference irradiations over 600 and 400 W/m²respectively in all emplacements.

	Day light (h) (Winter-Summer)	**Percentage Irradiation collected** (%) G>600W/m²	
		Winter	Summer
Atacama Desert	10,9 - 13,5	40	60,5
Pacific Coast Nicaragua	12 - 12	25	33,4
Humid Coast Galicia	8 - 15,3	0	42,4

Table 4. EXPECTED MAXIMUM IRRADIATION COLLECTION (%) IN SUMMER AND WINTERTIME SUNNY DAYS IN THE THREE STUDY CASES, FOR IRRADIATIONS OVER 600W/M2.

Table 5. EXPECTED MAXIMUM IRRADIATION COLLECTION (%) IN SUMMER AND WINTER TIME SUNNY DAYS IN THE THREE STUDY CASES, FOR IRRADIATIONS OVER 400 W/M^2.

	Day light (h) (Winter-Summer)	**Percentage Irradiation collected** (%) G>400W/m²	
		Winter	Summer
Atacama Desert	10,9 - 13,5	60	71,6
Pacific Coast Nicaragua	12 - 12	50	50
Humid Coast Galicia	8 - 15,3	12,5	51

Performance verification

The definition of optimized cell performance parameters is determined by the operation conditions. Depending on desired flow rate, correspondent exposition time is established and minimum values of solar irradiation (effective irradiation) will be required to assure specific current intensity cell demand.The percentage of irradiation collected over effective irradiations, will so determine the cell operation period and correspondent production rates (l/day) in direct operation.

In order to visualize the expected performance of the disinfection cell in real conditions, the effective solar irradiation collected by PV module (%) in two extreme solar irradiation periods (summer and winter) are presented for different disinfection flow rates (Figure 9). All values, consider effective irradiations correspondent to current intensity over 1,6 A.

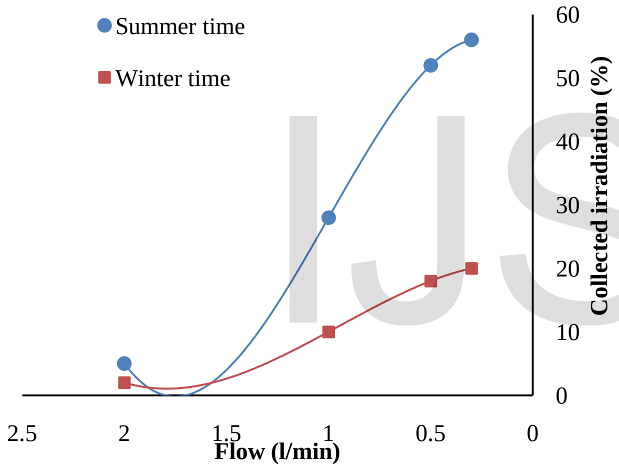


Figure 9. Percentages of irrradiation used and the average disinfection flow calculated (l/min) for sunny summer day and cloudy winter day in warm climate. Water mineralization 0,578mS.

Assuming that flow rates of 0,5l/min require effective irradiations over 400 W/m^2 and flow rates of 1l/min effective irradiations over 600 W/m^2 for appropriate disinfection, it can be observed that as smaller is the flow rate, higher effective irradiation can be collected (%). In all cases, the variations due to seasonality are relevant. Expected disinfection rates (liters/day) and available solar irradiation (including seasonality) are so, the most important factors to consider on decision making in order to supply year round water requirements in direct operation. Comparative performance with energy accumulation systems is presented in section 3.3.

3.2 Installation with associated accumulation system (batteries).

In the case of energy accumulation system installations, the most important element on the overall system is the battery. It is responsible to store the energy collected by PV module and supply cellenergy demand. Incorrect battery operation resulting from damages and ageing process can influence the correct operation of the overall system. Figure 4, show the influence of ageing process in battery performance, it can be concluded that at same complete charge/discharge cycles at constant discharge rates, ageing process reduce initial battery voltage V_0 and increase the total voltage variation (ΔV).

From same figure, calculated ΔV, vary from 0,1 V in six months old battery to 0,4 V in seventy-two months old. In the case of 24 V batteries, it will represent variations from 1,2 to 4,4 V (6 and 72 months old respectively).

To evaluate the influence of maximum expected battery ΔV on cell performance, and considering that cell potential (V) is lineal dependent with the electric field current (I), the influence on current intensity variations is analysed in laboratory conditions.Figure 10 shows this effect on three water samples and 24 V battery simulating.

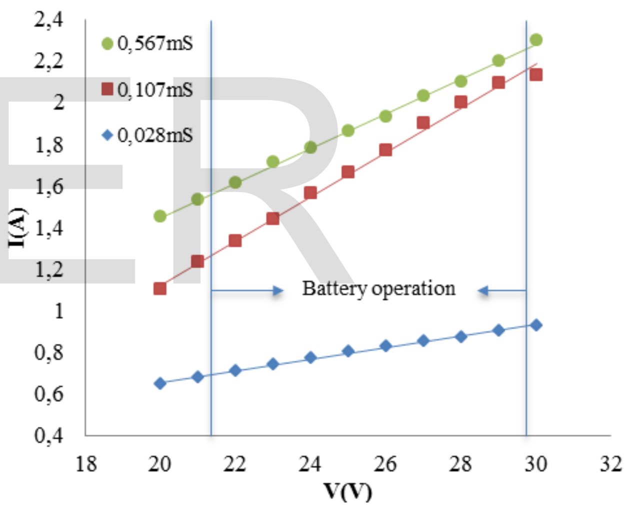


Figure 10. Influence of potential (V) variation in current intensity (I) for three different water samples (0,028mS; 0,107mS; 0,567mS)

In the worst-case scenario (most unfavorable water sample on free chlorine generation), and considering the limits of battery operation, maximum 0,9A variation is observed. Note that slope variations are due to different inter electrodes gap used during the experiments. From figure 1, it can be concluded that such variation can significantly influence free chlorine generation.In order to stabilize the current intensity supply, aregulation unit has to be developed in order to manage and adjust operational parameters (water flow, etc…) to achieve the desired free chlorine concentration in acceptable battery discharging rates[13].

Considering that the productivity of EWD cell on installations with energy accumulation is fully dependent on the battery performance, appropriate dimensioning attending to size and acceptable discharging rates should be considered during selection process. As general reference, energy accumulation systems should be oversized in order to assure that the maximum daily discharge would be less than 30% guarantying an assumable variation.

3.3 Comparison between direct installation and installation with energy accumulation.

Direct energy supply installations are highly dependent on PV module performance and climatological conditions, while energy supply installations with accumulation, strongly rely on initial battery characteristics and ageing process. In both cases, exposure time and specific current intensity values define the disinfection efficiency of the electrolytic cell.

For decision-making on the most appropriate energy supply layout, a comparative parameter proposal was established and defined as the total amount of available drinking water per day with monthly frequency. Equation 4 expresses it.

$$\text{Daily production}\left(\frac{\text{l}}{\text{day}}\right) = \text{PV}_{\text{working time}}\left(\frac{\text{h}}{\text{day}}\right)\cdot \text{Flow}\left(\frac{\text{l}}{\text{h}}\right) \qquad (4)$$

Where: Flow is calculated attending to cell exposition time (see example table2),and $\text{PV}_{\text{working time}}$ is calculated differently depending on the layout used. In *direct installation* is defined by the solar panel working time over EWD effective irradiation level (this variable is dependent on exposition time). In *installation with accumulation* it correspond to battery working period, defined as the numberof hours per day of battery operation with a state of charge (SoC) higher than 70% in the middle point of its useful life.

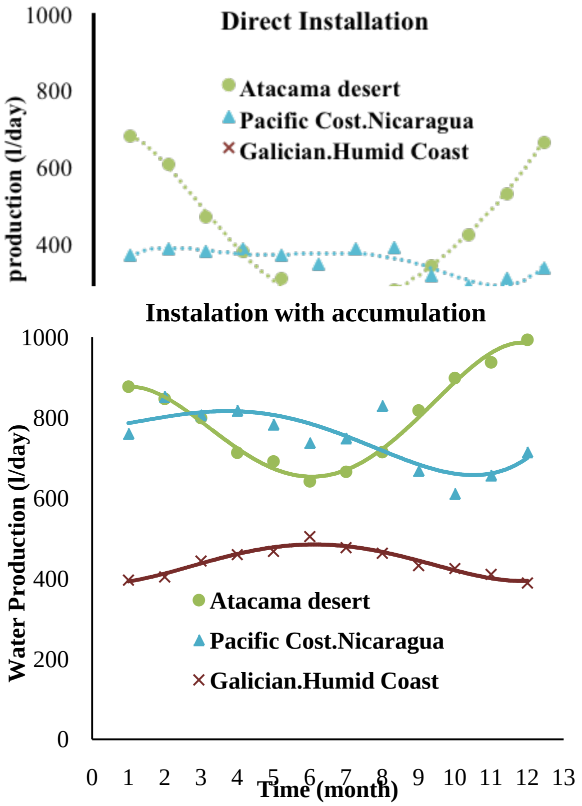


Figure 11. Evolutions of water production (l/day) during a year round in three different climatic regions (Atacama Desert; Nicaragua's Pacific coast; Galician Humid coast) in a) direct energy supply installations and b) installation with energy accumulation.

For comparative calculation, water flow correspondent to exposure time of 60s and most unfavourable water sample on free chlorine generation are used as reference. Figure 11 shows theresults obtained in both cases in monthly frequency evaluation.

The effect observed in both layouts is similar for all studied cases. The use of batteries increases monthly drink water production (litters) and stabilizes year round productivity at more constant production rates.

The increase of water production with energy accumulation is more significant for lower irradiated emplacements, where the use of batteries is advised to assure minimum considerable production levels year round. In higher irradiated emplacements it can be considered that the system could operate even during 24h per day (it should be considered that batteries must be selected specifically for each emplacement).

Once evaluated the variations on productivity and stability in both layouts, a final decision-making variable is considered, the system cost. Considering the increase on drinking water availability with energy accumulation system, correspondent system cost variation is analyzed. Equations 5 are used for calculation of both variables.

$$\text{R}_\text{p} = \frac{\left({}^{\text{l}}/_{\text{day}}\right)_{\text{accumulation}}}{\left({}^{\text{l}}/_{\text{day}}\right)_{\text{direct}}} \qquad (5)$$

$$\text{R}_\text{c} = \frac{(\text{Cost})_{\text{accumulation}}}{(\text{Cost})_{\text{direct}}}$$

Where: *Rp*is the ratio of water production increasing and *Rc* is the ratio of cost increasing between energy accumulation and direct systems utilization.

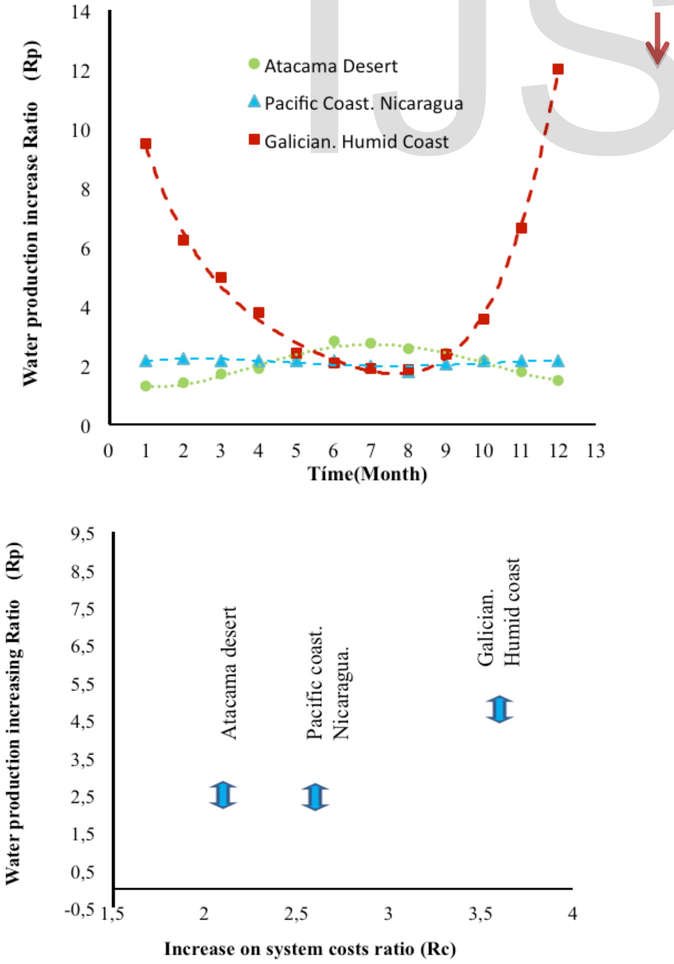
Note that cost evaluation depends on a wide number of variables (components costs, assembly costs, etc…). In order to simplify the evaluation process a standard Pb battery with average price around 40% of total PV system cost was exclusively considered. Furthermore, the calculation on the number of batteries needed for cost evaluation, considers the minimum irradiation levels on wintertime in the three study case zones as well as the expected number of days in total darkness (one of the reason why Galicia shoot up full costs). Figure 12 shows the results obtained from previous equations in the three emplacements.

Considering that higher *Rp* values correspond to higher increases on water production with energy accumulation systems, and higher *Rc* values imply higher costs of energy accumulations systems utilization some observations can be extracted.

Figure 12 a) shows how seasonality increases *Rp* values (red arrows), it means that battery utilization for year round productivity stabilization will be more required in higher seasonality emplacements. From other part most irradiated emplacements present the smaller *Rc*values (Figure 12b)), it can be concluded that they will require less number of batteries to increase and maintain productivity due to the higher available irradiation.

Figure 12. a) Water production increasing ratio (*Rp)* variation during a year for three different climatic regions (Atacama Desert; Nicaragua's Pacific coast; Galician coast). b) Water production increasing ratio (*Rp)* and correspondent cost increasing ratio (*Rc*) with energy accumulation systems utilization for three study cases.

For global comparison, the rate between costs and annual productivity (*Rc/Rp*) is calculated and shown in figure 12b). The obtained results can be used as input for a rude decision-making table based on irradiation conditions, amount and seasonality. The flux diagram is shown in figure 13. As example, for a high-irradiated zone suffering from high seasonality, the production gain associated to accumulation is higher than the costs increase. For this reason, as first approximation a powering supply with batteries will be the best option. By the contrary, in a high-irradiated emplacement associated to low seasonality, a direct power supply will be the best option. In this case, the accumulation is only associated to an exigent water needs level. Finally, low irradiated places will always require accumulation PV system toensurewaterproduction



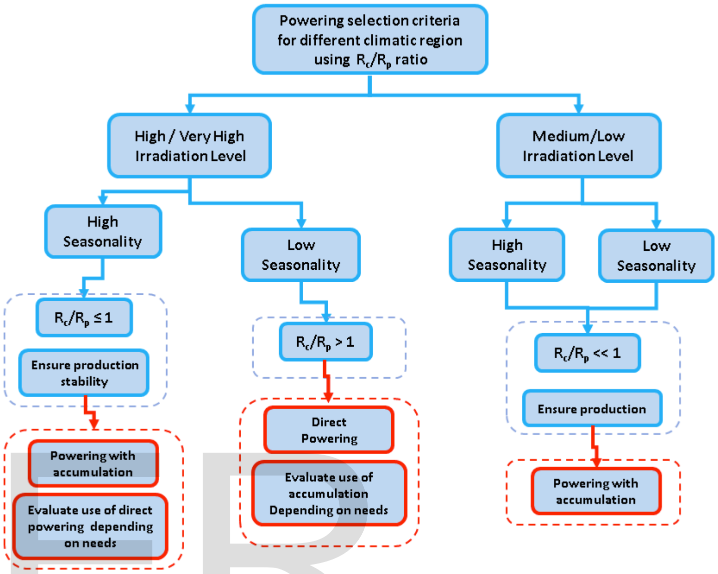


Figure 13.Selecting criterion guidelines for energy supply decision-making considering local irradiation, year round seasonality and (*Rc/ Rp) ratio.*

4 CONCLUSIONS

A PV based power system for EWD cell has been evaluated. The system has been designed to work in an extended range of water mineralization and climatic zones in optimal conditions. As main characteristics, renewable energy supply, low power consuming and accessible worldwide materials were considered.

Natural water samples with electrical conductivity from 0,028 mS to 0,567mS have been evaluated. Free chlorine generation level has been considered the leading variable for disinfection performance characterization. Exposure time and electric current intensity are measured. Exposure periods below 60s do not assure disinfection requirements in direct energy supply operation. Exposure periods over 120 s do not significantly increase free chlorine generation. Electric current intensities over 1.6A are essential for a correct operation.

In order to optimise the power supply system, two different PV configurations have been evaluated: With and without accumulation support. A sample of three representative climatic zones has been identified and separately studied.

Direct PV system constitutes the simplest and cheaper power supply option. In this case, the local solar irradiation, and then the panel current moderate the working regime. The collection efficiency as well as the water rate production depends on exposition time, being in the best of the cases lower than 50%. Moreover, hardly suffer from the seasonality.

The inclusion of batteries in the PV power system increases the daily water availability and stabilizes the production rates along the year, as well as increases the overall system cost. This effect is independent of the climatic zone of the installation. The main associated disadvantage is the increase of costs.

Two high-irradiated zones (dry and humid) and a medium-low irradiated humid emplacements has been used as representative of the existing climatic zones. A simple decision-making organogram has been designed to provide the best power supply option. Economic context and climatological characteristics and have been taken into account to obtain the best compromise between production rates, stability and costs.

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