Quality Control Applied to the Photovoltaic Systems of the Galapagos Islands: The Case of Baltra and Santa Cruz

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Abstract—**The Galapagos Islands are considered an environmentally fragile place, so the government from Ecuador promotes the gradual implementation of renewable energy projects in its five inhabited islands (San Cristobal, Santa Cruz, Baltra, Isabela and Floreana); in fact, their objectives are to achieve 100% renewable electricity generation, but they will be difficult to achieve.**

In 2016, the power generation in Galapagos was 53.03 GWh. 85% of this energy was thermal (diesel) and 15% was renewable (wind, photovoltaic –PV- and biofuel).

The purpose of this research is to apply a quality control in the PV systems of Galapagos, such as, Baltra (0.067 MWp) and Santa Cruz (1.5 MWp). As an expert in high performance and optimal yield in PV systems the Instituto de Energía Solar (IES) – Universidad Politécnica de Madrid (UPM) has made quality control measurements in both PV generators. The measured parameters are: open-circuit voltage (V_{OC}), short circuit current (I_{SC}), maximum power (P_{mpp}), voltage at maximum power (V_{mpp}), current at maximum power (I_{mpp}) and *I-V* (current-voltage) curve. These parameters, extrapolated to standard test conditions (STC), are compared with the manufacturer data, in accordance with international standards. This analysis allows to determinate the technical quality of the installed modules.

Additionally, IES–UPM has interviewed to the local power company and it has surveyed to the population from Galapagos on matters related to renewable energy. With this research it is possible to verify the high degree of social acceptance of renewable energy.

Keywords-quality control; photovoltaic systems; Galapagos Islands; renewable energy; electrical parameters

I. INTRODUCTION

IES–UPM has 25 years of experience on evaluation of quality control in PV systems, particularly in developing countries. Quality control assessment in a PV system involve: documentation review related to the system, visual inspection, measurements and data analysis, interviews and surveys [1]. This procedure is carried out in PV systems of Baltra and Santa Cruz in order to verify the performance and safety of PV systems of Galapagos. This makes it possible to determine the specific quality requirements in solar energy projects [2].

This work is on the frame of the research "Identification and assessment of management models in isolated hybrid mini-grids applied to the case of Ecuador", under which the situation in Galapagos is being reviewed. To do so, IES–UPM has established a partnership with the Ecuadorian Ministry of Electricity and Renewable Energy (MEER) and the Provincial Electricity Company Galapagos ELECGALAPAGOS.

Quality control assessment is not included in the O&M plans for the PV systems of Galapagos because of the lack of knowledge and skills of the technical staff, but it is essential to ensure the sustainability of projects.

MEER and ELECGALAPAGOS have provided the necessary information and the access to the facilities to IES-UPM. IES-UPM has offered technical support and training in quality control of PV systems to the ELECGALAPAGOS staff to enable them to introduce this procedure in their O&M plans and into future contracts.

This technical consultancy work targets to assess the technical quality of PV generators of 0.067 MWp in Baltra and 1.5 MWp in Santa Cruz and in addition to identify the institutional and population perceptions of renewable energy projects. To that end, it was necessary to make onsite measurements for the electrical parameters in the PV generators and conducting interviews and surveys to institutions and population, respectively.

II. METHODOLOGY AND DATA ACQUISITION

A. Technical Information and Visual Inspection Review

The information review makes possible to know the current situation on the hybrid generation systems of Galapagos (technical characteristics, location and system operating conditions). This collected information will be useful on fieldwork.

A visual inspection is made prior to the measurements. Also, a thermal camera is used to reveal the presence of hot spots in the PV modules.

B. Characterization of PV Generator

The experimental characterization of the PV generator focuses on the measurement of the *I-V* curve per array to verify the nominal power and to detect possible faults. The measurements were performed, in wintertime, on September 13 and 15th in 2017 in Baltra and Santa Cruz, respectively.

Typically, PV modules are the most reliable components in a PV system [1]. The most common failures are related with hot spots and permanent short circuit in bypass diodes [1].

The measured electrical parameters are: V_{OC}, I_{SC}, P_{mpp}, V_{mpp} and I_{mpp}. These parameters are used to calculate the Fill Factor (FF) and the *I-V* curve of the modules.

To measure the operating conditions, irradiance (W/m2) and solar cell temperature (°C) a monocrystalline PV sensor is used. In addition, the tilt angles of the modules surface are measured. To ensure that the incident sunlight beam has a cone with an opening angle around 45° to the vertical tilt surface [3], the measurements were made between 11:00 a.m. and 14:00 p.m. The 33% in Baltra (22.26 kWp – six arrays) and the 10% in Santa Cruz (150 kWp – 27 arrays) from the installed capacity were measured.

An *I-V* curve analyser and a PV sensor from the same manufacturer have been used during the measurement process. The data sheet from both devices complies with the calibration parameters by IEC 61829 standard, as shown in Table I [4]:

TABLE I. TECHNICAL CHARACTERISTICS OF CURVE ANALYSER AND SOLAR SENSOR

Curve analyser	
Measuring	*I-V* curve
Measuring calculated values (STC)	V_{OC}, I_{SC}, V_{mpp}, I_{mpp}, P_{mpp}, FF, characteristic curve of module
Current measuring range	1 – 1,000 V (< ± 1%) (Voc > 5V)
Voltage measuring range	0.1 - 15 A (< ± 1%)
Measuring connection	Measuring cable
Ambient temperature	0 - 50 °C
Admissible relative humidity	< 80% RH
Sensor	
Measuring	Global irradiation, module temperature, tilt angle
Temperature measuring range	10 - 100 °C (± 3% in relation to a black body)
Irradiation measuring range	100 - 1,200 W/m2 ± 5%
Measuring connection	Non-contact measuring
Reference cells	1 monocrystalline, 1 polycristalline
Ambient temperature	0 - 60 °C
Admissible relative humidity	< 80% RH

The ideal conditions to measure the *I-V* curve outdoor are: clear skies (no clouds and no fog) and light wind conditions [3]. To achieve more accurate results during a measurement process, the user manual recommends 700 W/m2 minimum irradiance in the incident surface as defined in IEC 61829 [3], [4]. However, the climate conditions are variable in this period of year. Thus, we define a set of Acceptable Test Conditions (ACT) by: global in plane irradiance, $G \geq 500$ W/m2; diffuse fraction of *G*, $D/G < 0.2$ (clear day). This is based on experience acquired by IES on field work under varying operating conditions.

All the measurements are made on clean modules, in absence of shadow and, when possible, under stable temperature and irradiance conditions. The measurement process is done according to the user manual [4] and IEC 61829 standard [3].

C. Review Data and Extrapolation Method

The measurement data are extrapolated to STC (solar cell temperature T_c* = 25 °C; irradiance G* = 1,000 W/m2; solar spectrum AM 1.5G). To extrapolate data collection the next calculation are made [5], [6]:

$$I_{SC} = I_{SC}^* \, (G/G^*) \quad (1)$$

$$V_{OC} = V_{OC}^* \, [1 + \beta \, (T_c - T_c^*)] \quad (2)$$

β temperature coefficient of V_{OC} (%/°C)

$$P_{mpp}^* = V_{mpp}^* \, I_{mpp}^* \quad (3)$$

$$FF = (I_{mpp}^* \, V_{mpp}^*)/(I_{SC}^* \, V_{OC}^*) \quad (4)$$

The values marked with an asterisk (*) are in STC.

The uncertainty of this procedure is around 5%, which is enough to decide if the quality of modules is acceptable [1], [7].

Table II shows the data sheet of the PV modules installed in the power plant of Baltra and Santa Cruz:

TABLE II. TECHNICAL CHARACTERISTICS OF MODULES

Description	Baltra	Santa Cruz
Manufacturer	Mitsubishi Electric	BJ Power
Model	PV-MLE265HD	BJ-60Series-1
Cell	Monocrystalline silicon	Monocrystalline silicon
Power (Wp)	265	250
I_{SC} ***(A)***	9.08	8.768
V_{OC} ***(V)***	38.2	26.99
I_{mpp} ***(A)***	8.38	8.131
V_{mpp} ***(V)***	31.7	30.75
Tollerance of maximum power rating (%)	–0/+5	N/A[a]
β (%/ºC)	–0.35	–0.3307

a. N/A Information is not available.

The mean values from the extrapolation are compared with manufacturer data sheets in Baltra and the Flashing Report [8] in Santa Cruz, where 594 serial codes from the modules had to be verified due to the missing inventoried. In this paper 2% of PV system cable losses [9] are estimated and included in the total power losses.

D. Mistmach Losses in PV Power Plants

Prior estimates in the section C are based on the fact that all the modules operate in the same conditions. However, the modules are not identical because of the dispersion in the electrical parameters produced in the manufacturing process [5].

The theoretical mismatch losses of modules connected in series and parallel are proportional to the variance in I_{mpp} and V_{mpp}, respectively, as noted in (5) and (6) [10], [11]. The detailed calculation procedure is available in [10].

$$\text{Series losses (\%)} \;\; \alpha \;\; \sigma^2_{I_{mpp}} \tag{5}$$

$$\text{Parallel losses (\%)} \;\; \alpha \;\; \sigma^2_{V_{mpp}} \tag{6}$$

In order to reduce these losses, the selection of the modules in an array based on I_{mpp} [5], [10] is recommended. It is only possible to calculate the mismatch losses in Puerto Ayora (Santa Cruz) because the Flashing Report is available.

E. Interviews and Surveys

The collection of primary information about the renewable energy projects is a goal of this consultancy. To that end, interviews had been held with the management and technical staff of ELECGALAPAGOS. We used a focus group method to obtain opinions, perceptions and comments about the implemented renewables energy projects from an institutional and individual point of view.

Additionally, 30 customers from Puerto Ayora, in Santa Cruz, have been surveyed to know the social perception about the use of renewable sources of energy to electricity generation, electricity services and energy prices. The collected data are evaluated through a frequency analysis using the tool SPSS (statistical analysis software).

To complete this investigation, scientific literature and supporting documentation, such as reports, official websites and official statistics has been reviewed.

The results from the technical analysis, interviews and surveys are exposed in a descriptive study.

III. Quality Control Assessment of PV Power Plants in Galapagos Islands

A. Framework

The Galapagos archipelago consist of 19 islands and 200 small islets located in the Pacific Ocean some 1,000 km from the Ecuadorian coast [12], [13]. In 1978, the Galapagos National Park was declared a “World Heritage Site” by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) [13]. For that reason, the Ecuadorian government started to develop renewable energy projects. To achieve it, in 2008, the Ecuadorian government set into motion the ¨Galapagos Islands Zero Fossil Fuel Initiative”, which focuses mainly on electricity and transport sectors [14].

Accordingly, MEER, with allied governments support, has developed electricity generation projects using renewable energy sources to reduce CO_2 emissions and fuel consumption and to avoid fuel spill risk derived of maritime transportation [14].

Galapagos has four electricity generation systems: San Cristobal, Santa Cruz - Baltra (two interconnected islands through a 51,4 km cable), Isabela and Floreana. Table III [15]–[18] shows the power systems, penetration of renewable energy sources and electricity demand in Galapagos:

TABLE III. Generation Systems and Demand

Installed capacity	San Cristobal	Santa Cruz - Baltra	Isabela	Floreana
Wind (MW)	2.4	2.25		
Photovoltaic (MW)	0.0125	1.57		0.021
Diesel (MW)	8.3	13.9	2.74	0.15
Biodiesel (MW)				0.138
Total power (MW)	10.71	17.72	2.74	0.31
Batteries (MWh)		4 Pb [b], 0.268 Li [c]		0.096 Pb
RE (%)[d]	8.2	20	0	57
Demand (MWh/year)	14,400	27,850	4,540	197
Peak demand (MW)	3.37 (2016)	9.28 (2016)	1 (2016)	0.076 (2016)

b. Lead-acid batteries.

c. Lithium-ion batteries.

d. Percentage of used renewable energy in the matrix of electricity generation.

The first renewable energy project was initiated in 2007 and still today new projects are being developed. For instance, a system-hybridization is being carried out on Isabela, with the installation of 0.920 MWp of PV, a battery bank of 0.258 MWh and 1.62 MW of thermal energy (diesel and jatropha oil) [18].

In 2016, total electricity generation in Galapagos was 53.03 GWh: 4.96 GWh (85%) were thermal and 8.02 GWh (15%) were produced from renewable sources [15]. In the same year, to meet the energy needs from around 30,172 islanders [19], the consumption of electrical energy was 47 GWh [15], that means 1,577.93 kWh/capita consumption [15], [19]. It is worth mentioning from 1999 to 2016 the average annual growth of energy demand was 9% [15].

The current renewable energy projects avoid the consumption of approximately 993,700 gallons of diesel per year and the emission of 7,282.6 t CO_2/year [20].

1) PV Power Plant and Storage System of Baltra: Baltra has a PV system of 0.067 MWp, which produces 136 MWh/year on average [18], [20]. The storage system is hybrid and very innovative technologically speaking because it is composed by two battery banks with different techonology. The Pb batteries (4.03 MWh) store the energy surplus generated in the wind farm (2.25 MW) and the Li batteries (0.268 MWh) regulate the wind-generated energy fluctuations [18].

This project was implemented with the cooperation of the Japanese government in 2016, through the Japan International Cooperation Agency (JICA) [18]. Table IV [21] shows its technical characteristics:

“17th Funding Call for University Cooperation to Development” of Universidad Politécnica of Madrid.

TABLE IV. PV POWER AND STORAGE SYSTEM OF BALTRA

PV system		Batteries		
		Description	***Pb***	***Li***
Installed power (MWp)	0.067	***Capacity (MWh)***	4.03	0.268
Module	Monocrystalline silicon	***Operating voltage of a cell (V)***	2	22.2
Maximum power rating (Wp)	265	***Capacity of a cell (Ah)***	1,500	75
Number of modules	14 x 18 = 252	***Number of batteries***	224 x 6 = 1,344	23 x 7 = 161
Inverter (MW)	0.1	***Inverter (MW)***	0.5	0.5
Number of inverters	1	***Number of inverters***	1	1
Transformer (kVA - V)	100 - 480/400	***Transformer (kVA - V)***	600 - 480/210	500 – 480/210

The PV power plant and its storage system avoid the use of 12,000 diesel gallons per year and the emission of 15 t CO2 [20].

2) PV Power Plant of Puerto Ayora: This is a system of 1.5 MWp and it was implemented with the aid of South-Korea non-reimbursable cooperation in 2014, through the Korea International Cooperation Agency (KOICA) [18]. Table V [22] shows its technical characteristics:

TABLE V. PUERTO AYORA PV POWER

PV System	
Installed power (MWp)	1.5
Module	Monocrystalline silicon
Maximum power rating (Wp)	250
Number of modules	22 x 273 = 6,006
Inverter (kW)	17
Number of inverters	91
Transformer (kVA - V)	1,500 - 380 / 13,800

The power plant produces approximately 2,430 MWh/year, that means to save 194,000 diesel gallons and to reduce 1,475 t CO2 emissions to the environment per year [20]. The performance ratio (PR) of PV System in Puerto Ayora is 0.793 [23], [24].

B. Field Results

The sensitivity of solar cells to the spectral composition of the solar irradiance is the main problem that the measurement procedure has to evaluate the PV modules [25]. This feature varies considerably among different locations, climate conditions, seasonality and the time of day when the measurements are made [25]. During measurements in Baltra the irradiance was stable, but in Santa Cruz due to the climate conditions clear skies and cloudy periods alternated

1) Quality control on PV 0.067 MWp power plant in Baltra: To make the quality control asses in Baltra, six arrays (14 modules/array) were measured from 18 parallel connections, that means the 33% (22.26 kWp) of the installed capacity. Fig 1. shows *I-V* curve mean values in the measured arrays and the Table VI shows the difference between the manufacturer data sheets and the STC data:

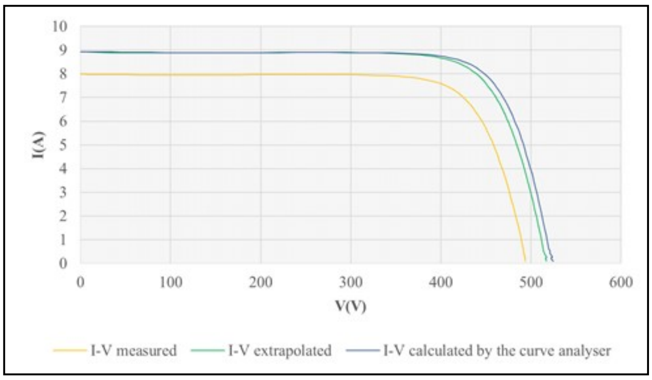

Figure 1. Baltra mean *I-V* curve

TABLE VI. DIFFERENCE BETWEEN MANUFACTURER DATA AND THE STC DATA - BALTRA

Parameter	Manufacturer	Extrapolation	Difference (%)
Isc [A]	9.08	8.93	–1.68
Voc [V]	534.80	516.81	–3.48
Impp [A]	8.38	8.43	0.53
Vmpp [V]	443.80	425.92	–4.20
Pmpp [W]	3,710	3,588.35	–3.39
FF	0.77	0.78	1.52

The mean power differences are 3.39% per array. These results include the cable losses, which means 260 W under the nominal power per array. This value is inside the 5% range of uncertainty defined in the assessment procedure. However, the power differences per array are between 1.60 and 5.48%.

2) Quality control on PV 1.5 MWp power plant in Puerto Ayora: 27 arrays (150 kWp) from 9 inverters were measured. Fig. 2 shows *I-V* curve and Table VII shows the differences between characteristic parameters of the modules in STC and the Flashing Report of BJ Power:

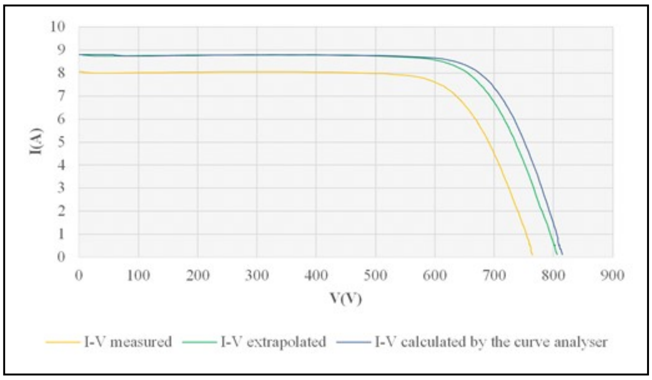

Figure 2. Puerto Ayora mean *I-V* curve

TABLE VII. DIFFERENCE BETWEEN MANUFACTURER DATA AND THE STC DATA – PUERTO AYORA

Parameter	Manufacturer	Extrapolation	Difference (%)
Isc [A]	8.94	9.10	–1.68
Voc [V]	832.07	804.94	–3.48
Impp [A]	8.46	8.35	0.53
Vmpp [V]	668.13	642.31	–4.20
Pmpp [W]	5,649.44	5,364.66	–5.31
FF	0.76	0.74	1.52

The mean power difference per array is 5.31%. The cable losses could be considered 2%. That means the power plant works under acceptable conditions. However, the power differences per array are in a range between 1.16% and 10.07%.

With these results it is difficult to assure if the modules are damaged. However, it could be verified with an additional visual inspection and with the measurement of module parameters with clear skies in the dry season (December to May).

In certain cases, the irradiance of the measurement exceeded the limit established by the analyser equipment (1,200 W/m2 ± 5%). These values reached 1,307 W/m2 (close to the solar constant equal to 1,367 W/m2), which may be caused by the presence of smalls clouds during the measurement. These clouds worked as a lens focusing the sunlight over the modules and increasing the real irradiance. This may justify that in several cases the differences of power were higher than 10.07%. These measures were discarded for the analysis.

Fig. 3 shows the probability density of the nominal power of the 6,053 modules (installed and replaced) in the Puerto Ayora power plant:

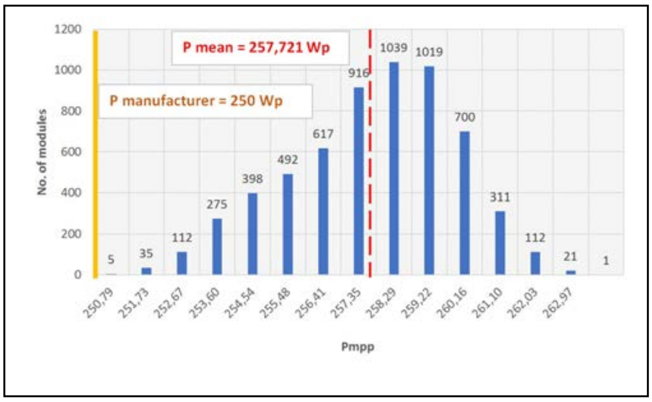

Figure 3. Power distribution of 6,053 PV modules in Puerto Ayora power plant

This analysis was made in 27 arrays to observe the P_{mpp}, I_{mpp}, V_{mpp} distribution of the modules. This proves that the modules were not classified for installation. The power plant has mean serial losses of 0.33% and mean parallel losses of 4.03%.

C. Field Experience and Conclusions of Assessment

Operating conditions (solar irradiance and temperature) were stable in Baltra during the measurement process ensuring the reliability of the results.

In Santa Cruz, there were both clear skies and cloudy periods, which made harder to obtain good measurements.

As per the established criteria, in those locations next to the Equator line, the optimal module tilt angle is equal to the latitude, but to avoid dust and dirt the recommended tilt angle of the modules is 10° above the latitude [5]. In Baltra (–0.46º latitude) and Santa Cruz (–0.74º latitude), the optimal tilt angle of the modules is 9.25º and 9.53º, respectively. Nevertheless, the tilt angle of the arrays is between 10° and 12° in Baltra and between 5° and 8° in Santa Cruz. The energy losses due to the deviations from the optimal tilt angle are negligible in both cases. The technical staff clean the modules once a year and according them, this is enough to keep the PV generator clean.

We verified the solar irradiation are better in Baltra than Santa Cruz, despite being very close to each other. The PR of the PV system in Baltra could be higher than the PR in Santa Cruz (0.793).

According to the quality control, the modules in the power plant in Baltra have mean power losses of 3.39% (2% of cable losses are included). With the initial conditions of the analysis, we could conclude that this PV generator has high levels of technical quality.

In Puerto Ayora, results show how the power plant is working under acceptable conditions. The mean power losses are 5.31% (2% of cable losses are included). However, the power losses -in some arrays near to 10%- seem to indicate a possible potential damage of the modules. This could be verified with a visual inspection and an additional measure with clear skies in the dry season or by checking I_{SC} per each module.

A thermal camera was used to try to detect hot spots in Puerto Ayora. During this inspection hot spots were not detected. Due to the size of the power plant, IES–UPM suggests to ELECGALAPAGOS to use a drone with a thermal camera to make these field inspections with a higher frequency.

PV system of Baltra and Santa Cruz are operational since 2016 and 2014, respectively. Both systems use different technologies and to compare them in terms of technical quality is not possible.

The strengths from both power plants are: good status from DC facilities, electrical protections, cabling, control system and cleaning of the modules. It should be noted the location and conditioning of the batteries hybrid system in Baltra.

The weaknesses to remark are:

- Wrong registered data of the irradiance in real time because there are higher than 1,367 W/m2,
- Available information which is not evaluated,
- Knowledge lack in PV system from the O&M staff,
- Equipment which is unused as a curve analyser,
- Missing coding and labelling of the arrays in Puerto Ayora,
- Missing information as the Flashing Report in Baltra.

Another issue detected in Puerto Ayora was that maintenance staff had replaced several inverters and modules without prior technical assessment. The modules were replaced because the presence of "snail tracks o snail trails". Up to now, this has cost about 10,880 USD [26], which has been covered through the manufacturer guarantee.

The snail tracks are a degradation phenomenon of c-Si solar cells, which receive this name due its appearance [27], [28]. Silver grid lines appear on crystalline silicon cell surface and are always associated with micro cracks [27], [29]. Fig. 4 shows one module, with snail tracks, installed on PV power system of Puerto Ayora:

Figure 4. Snail tracks on modules of Puerto Ayora

A research demonstrated the existence of four degradation products which cause this degradation, that is, snail tracks, and which affect the PV modules, such as: silver carbonate, silver phosphate, silver acetate and silver sulfide. PV module components and stress factors are involved [27].

To evaluate modules with snail tracks we could short-circuit an array with snail track and another one without it and compare both measurements. This measurement could be done with a multimeter. Only if the I_{SC} between both arrays has remarkable differences a new module would be needed. Another option is to use the *I-V* curve analyser available in the company to measure it. With this method we could verify snail tracks have not created a power reduction. This may be due to the initial stage of the snail tracks.

Visually and on surface of the modules the relevance of snail tracks is negligible. However these snail tracks could cause a higher damages in the modules [27]. In fact, some investigations [30], [31] have shown how snail tracks, which are correlated with the presence of micro cracks, can reduce the energy production between 9% and 29%. This situation suggests that ELECGALAPAGOS should assess periodically these modules.

Furthermore, although we have not evaluated the technical quality of the inverters, its replacement have reached the value of 498,000 USD [26] to the manufacturer. The failures causes are unknown, but according the technical staff, these seem to be related to the electrical grounding.

Sorting the modules by I_{mpp}, in Puerto Ayora, could reduce the mismatch losses up to 0.33%, but this is not negligible in terms of total power. Mismatch losses related to V_{mpp} will not have a high impact if a blocking diode is installed to avoid reverse currents. With these results we can conclude the modules there installed are similar among each other.

To enhance the sustainability of the projects, it is recommended to include the quality control procedures in the O&M plans.

IV. Institutional and Social Perception on Renewable Energies

A. *Institutional Perception*

Some features, strengths and weaknesses of the implementation of renewable energy projects in Galapagos have been identified during the interview process. The conclusions are highlighted below:

Ecuadorian Government promoted the ¨Galapagos Islands Zero Fossil Fuel Initiative" to preserve the fragile ecosystem of Galapagos Islands. This policy has some goals: to reduce the use of diesel fuel for power generation and the CO2 emissions and to avoid fuel spill risk using maritime transportation from the continent to the islands. This initiative has a positive impact on international organizations and that is why renewable energy projects has been implemented thanks to cooperation agreements. Some of them are: United Nations Development Programme – UNDP, Inter-American Development Bank – IDB, Inter-American Institute for Cooperation on Agriculture – IICA, United Nations Foundation – UNF, Global Environment Facility – GEF, Development German Bank – KfW, German Federal Ministry of the Environment, Nature Conservation, Building and Nuclear Safety – BMU, German Corporation for International Cooperation – GIZ.

MEER is the main sponsor of renewable energy projects in Galapagos and ELECGALAPAGOS is the main performer of these projects along with other external companies, which are recruited by cooperation agencies in coordination with MEER.

Further projects are planned, such as a second phase of already-finished projects in Santa Cruz - Baltra and Floreana and the integration of new systems in Isabela and San Cristobal.

The involvement of local institutions such as: Government Council of the Galapagos Special Regimen (CGREG), Galapagos National Park (PNG) and municipalities in project management and in activities related with the use of soil, environmental conservation and in management of economic the resources is remarkable.

It will be hard to reach the initiative goals due to the investment this kind of projects require. There are also others barriers such as the equipment transportation and logistics difficulties, the intensive use of soil, the lack of local trained staff, the low supply of construction materials, the stability problems of electric power systems and the growth of the electricity demand.

There are some awareness and training programs for the Galapagos population. They aim to control the growth in energy demand, to promote an efficient use of energy and to encourage the engagement of the population in renewable energy projects. Furthermore, the Government has promoted energy efficiency measures in the sectors with the largest energy consumption (residential, transport and touristic) and energy tariff incentives. For example, in the residential sector there is an incentive to promote the use of electrical vehicles and its tariff depends on the level of electricity consumption. The tariff is lower between 22:00 to 8:00 from Monday until Friday [32].

According to interviewees, renewable energy has become a reason to local professionals who are trained in mainland Ecuador to return to work in ELECGALAPAGOS.

They also call for regulations to promote distributed generation with PV energy systems.

There are weaknesses in the process of knowledge transfer from the implementing companies to ELECGALAPAGOS, which hinder the O&M works of the renewable energy systems. Training plans need to be included in forthcoming projects.

Regarding the PV systems, it is in the Santa Cruz power plant where more events occur during O&M, mostly related to modules and inverters replacement. The staff often replaces modules with snail tracks without an analysis of their electrical parameters. Also, it takes one to seven days to solve inverters failures.

Hybrids systems in Galapagos will continue functioning as non-interconnected systems due to the great investment the connection would require, to the logistical and transport challenges and to the high environmental cost that their interconnection would involve. An example of this is the interconnection between Baltra and Santa Cruz.

Despite a relatively high investment need it to implement renewable energy system, this has not an impact on the ELECGALAPAGOS economic and financial situation. Currently, administrative and O&M costs in generation, distribution, transmission, supply and trade of electricity are settled in the National Interconnected System (SNI).

The electricity tariff in Galapagos and in Ecuador mainland are the same. If we compare the electricity tariff for the residential sector in Galapagos Islands and that for the continental Ecuador, they are on average the same: 9.8 USc/kWh for an electricity consumption between 0 and 500 kWh [32]. This is due to the subsidies and incentives established by the Government. The introduction of renewable energy does not affect to the final customer price.

B. Social Perception

Table VIII shows the survey results which reveal the level of knowledge from population in renewable energies and satisfaction from customers in electric service and electricity tariffs:

TABLE VIII. SURVEY RESULTS

Question	Yes	No
Do you know what renewable energies are?	53.33%	46.67%
Do you know which renewable energy sources are used in Galapagos to generate electricity?	66.67%	33.33%
Do you know the renewable energy advantages and disadvantages?	50%	50%
Do you apply energy efficiency measures?	86.67%	13.33%
Do you agree with the electricity prices?	88.46%	11.53%

Question	Answer	Frequency
What do you think the main advantage of producing electricity from renewable energies in Galapagos is?	Less pollution	39.98%
	Caring for the environment	34.98%
	Use of the local resources	9.99%
	Reducing fossil fuel consumption	9.99%
	Reducing fossil fuel costs	4.99%
What is your opinion about the electricity service quality?	Very bad	3.30%
	Bad	6.70%
	More or less	20%
	Good	66.70%
	Very good	3.30%

Although the population seems to have an acceptable knowledge about renewable energy, educational and awareness campaigns should be carried out in the following topics: basic concepts of renewable energy (different types, advantages and disadvantages), electricity tariff depending on electricity consumption, electricity production mix, the importance of O&M in generation and distribution systems and the impact of demand on the energy system.

Despite the positive influence of efficiency energy campaigns, the customers need more information about electricity services (supply and demand).

The actions related to energy efficiency that they stand out are: to unplug devices which are not being used, the replacement of old appliances for efficient ones, the use of energy saving light bulbs and turn lights on only when it is necessary.

V. CONCLUSIONS

It is not possible to comply with the established technical measurement by standard IEC 61289 to measure the *I-V* curve under irradiance and temperature operating varying conditions. In these situations, the measurement criterion should be selected by the person who performs the work.

To apply quality control, assess in a PV system ensures sustainability to projects improving O&M plans, training staff and awareness campaigns and contractual requirements of the projects. The quality control procedures should be extended to other devices as inverters or batteries. After this consultancy work, ELECGALAPAGOS has started to introduce this procedure in their O&M plans.

The lack of knowledge in the operation and technical evaluation of PV systems may cause a mismanagement of economic resources. This is the main disadvantage that we have identified with our consultancy work.

The population is interested in the electricity services quality more than the technologies used to generate the electric energy. This also indicates that it is difficult to establish a direct link between control quality of PV systems in Galapagos and the social perception about the technology which is used to produce electricity.

On the other hand, in Galapagos, the donor countries use international cooperation as a strategy to promote their companies and local technology. This makes complex to demand that the technology and the procedures of installation compliance of international standards. Additionally, the technology guarantees are managed by the international cooperation.

In Ecuador, the local standardization institution (Ecuadorian Standardization Service –INEN) has adopted the IEC standards related to the technical quality of PV systems to the national context. However, in Galapagos, with this work, it is the first time PV systems are evaluated to verify its technical quality.

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