Microgrid Operational in a remote village of Abricots in Haiti

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Abstract: As we approach 2030, Haiti is among the countries where access to electricity is difficult, with less than 45.4% electrical coverage (2019); According to a report by "The Spectator Index" published in January 2018 regarding the least electrified countries in the world. A present, Haiti is the third among the worst in the world (in 2017), after Nigeria (2nd) and Yemen (1st). The problem of lack of access to electrical energy is a major obstacle to the economic and social growth of the country. Diagnostics on the Haitian electrical system prove that the production costs of electrical energy are very high and the commercial losses are enormous, even deficit. This article reviews the literature and proposes the use of an off-grid microgrid based on solar energy to supply 271 households in the village of Abricots, a community clearly isolated from the rest of the country, in order to facilitate sustainable access to electricity for this marginalized population of Haiti. This study allows us to understand the feasibility aspects of the project, to size the components of the microgrid, in order to coordinate the supply and demand of energy, while optimizing the operational cost.

Keywords: energy renewable; photovoltaic microgrid; solar energy; hybrid generation;

1. INTRODUCTION

According to the latest data published by International Energy Agency (IEA 2019), 840 million people are living without access at electricity (IEA and World Bank, 2019). Unless efforts are stepped up significantly, an estimated 660 million people would remain without access to electricity in 2030 (Jane Ebinger & al. 2017); a large part of these people lives in Haiti. It is obvious that energy is essential to the improvement of the quality of life of any contemporary society, since it has become indispensable to the human development. To achieve this, alternative energy resources must be tapped near remote areas. In this sense, renewable energy technologies offer the promise of clean and abundant energy gathered from self-renewing resources such as the sun, wind, earth, and plants (Stanley R. Bull, 2001). In fact, the ever-increasing global demand for electricity and dwindling fossil fuel reserves make renewable energy demand in high worldwide.

One of the valuable uses of non-conventional energy sources is to electrify those rural areas and remote villages, far from distribution network lines and power plants, where installing distribution system is not economically viable (Bahadur Singh Pali & al, 2016). One of the reasons why the microgrid is gaining so much interest now is its ability to allow for the integration of renewable energy into the power grid, thereby expanding the generation portfolio and having potentially beneficial carbon impacts (Juan Manuel Carrasco, 2011).

"To improve the lives of the 1.2 billion people across the globe with the lowest income, and to reach the vast potential of rural electrification, the decade 2014-2024 has been declared by the UN General Assembly as the decade of Sustainable Energy for All" (Jonas Tjäder & al. Annexe 6).

Latin America and the Caribbean is closing in on universal access, with an access rate of 98%, leaving close to 12 million people without access to electricity in 2017, the majority of these numbers are in Haiti (World Bank & Al., 2019).

The study of reveals that, due to its geographical location, Haiti has abundant solar and wind energy resources (RINA consulting, 2019). Decentralized renewable energy can have a primary role in increasing electricity coverage in off-grid areas and in generating electricity at a lower cost than electricity generated from fossil fuels (RINA consulting, 2019). The photovoltaics generation can reduce the dependence on fossil fuels (Philip Raphals & al. 2008), because the level of sunshine lends itself well to photovoltaic and solar thermal production (Philip Raphals & al. 2008). The installation of a microgrid based on solar photovoltaic energy fits perfectly into an energy transition approach, in order to reduce the ecological risks linked to the use of fossil fuels, as well as the economic advantages.

This paper undertakes the feasibility study for the installation of the electrical microgrid in the Abricots region. It will be done under several aspects: the identification of the availability of energy resources; the choice of the type of microgrid technologies, the advantages and disadvantages depending on the availability of resources; the dimensioning of the microgrid components. The transmission and distribution of energy, investment costs, remuneration, pricing and marketing were not considered in this work. The PVsyst software is used in the calculations daily consumption and the Sun path in Abricots Area.

2. OBJECTIVE

The objective is to implement in the village of Abricots, an isolated microgrid that can meet the primary needs of the village inhabitants. The microgrid will operate based on photovoltaic solar energy, with a storage system with batteries, which can supply multiple types of loads. The system are projected to the current population and are flexible enough to the growth of demand for the next decades. The technical study of the network allows it to meet a consumption of 230 kWh per day, single-phase system of constant frequency 60 Hz.

2.1 Pre-feasibility study

This pre-feasibility study identifies the weather aspects of the Abricots site, in order to know the energy potential of the area and the viability of the installation. This study also presents the different types of technologies used in microgrids; the most advantageous technology, including its disadvantages; the study of the energy balance, as well as the dimensioning of the essential components of the microgrid.

2.2 Geographic study

Abricots is a coastal commune, more than 350 years old, with an area of 108 km^2; it is located in the rural areas of the department of Grand'Anse, in the extreme south of the peninsula of Haiti. In 2011, its urban population was 1353 (IHSI, 2015); 271 households, with five (5) persons per household). The geographic coordinates for Abricots are 18.6176° latitude, -74.2809° longitude, and 202 meters above sea level. The topography in the 3 km surrounding Abricots has very significant variations in elevation, with a maximum elevation variation of 254 meters and an average elevation above sea level of 97 meters.

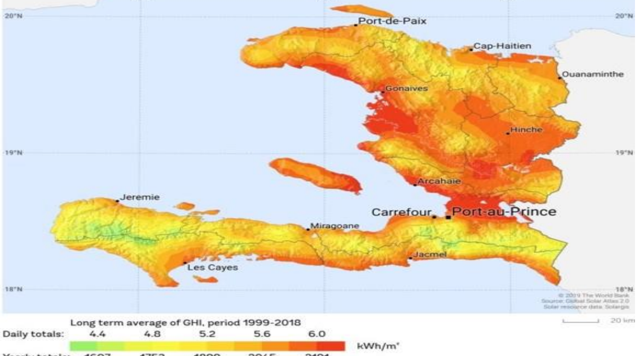

Figure 1. Haiti, Global Horizontal Irradiation

Over the course of the year, the temperature generally ranges from 23°C to 32°C and is rarely below 21°C or above 33°C. This map (fig.1) presents the Global Horizontal Irradiation (GHI) of Haiti (Solargis, 2020); it is a very important parameter for the calculation of the energy yield and the evaluation of the performance of photovoltaic modules. From this mapping, we can see that Haiti has a high solar potential. The GHI of Haiti is average 4.5 kWh/m^2/day. The meteorological data available in Abricots allows us to complete the table below (Table I), which proves to be very important in the production of electricity.

Table I. geographical data of Abricots

Abricots, Area of Grand'Anse, Haiti Latitude 18.6176904°; longitude -74.2809°		
Direct normal irradiation	4.530	kWh/m^2/d
Global horizontal irradiation	5.503	kWh/m^2/d
Diffuse horizontal irradiation	2.005	kWh/m^2/d
Irradiation at optimum angle	5.766	kWh/m^2/d
Air temperature	26.9	°C
Photovoltaic power out put	4.530	kWh / kWp
Altitude	202	m
Clouds	15%	
Wind Direction	East - South East	

This value can be measured or estimated from the solar fraction. The quantification of the incident irradiance for a day is given by a mathematical expression (Boukhlifa Hamza, 2017) which is written as follows:

$$E = E_m \sin\left[\frac{\pi(t - t_o)}{12}\right] \quad (1)$$

E: The maximum irradiance of the site (W/m2)
E_m: maximum irradiance of the site (W/m2)
t: solar time in hours.
t_0: time of sunrise (in Haiti, 06:00 am)

The sun path graph (Fig. 2) represents the position of the sun in the sky at any time of the day and from January to December. This position of the sun is entirely determined by two components which are the azimuth and the height of the sun. The PVsyst software generates the sun path diagram for the Abricots area and the energy production is simulated for each hour during the winter and summer seasons and, therefore, the system design has been optimized for annual, summer or winter performance. In order to function optimally, the photovoltaic installation will be subjected to as little shading as possible. However, some constraints related to the installation site (presence of mountain, trees, chimney, electric pole...) cannot be avoided at a reasonable cost. It is necessary in this case to relate precisely the losses induced by these shadows which can intervene on all or part of the modules in various seasons and at certain times of the day. The survey of the shadows enters the process of productivity of the solar panels, and to obtain the necessary information to calculate these losses. These are different obstacles whose shadow may reduce the illumination of all or part of the photovoltaic solar modules and consequently reduce the electrical energy they produce. Azimuth of 0º (i.e. oriented totally to the South). This angle (22º) is used for the off-grid. The following figure shows the typical sun path in the Abricots region with PVsyst software:

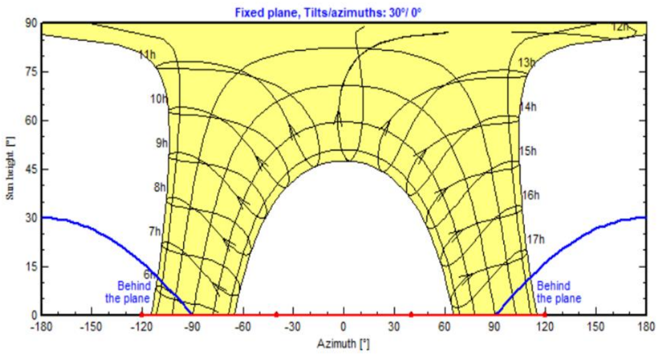

Figure 2. Sun path in Abricots Area

3. MICROGRIDS TECHNOLOGIES

Microgrid is defined as a group of interconnected loads and distribute energy resources (DERs) with clearly defined electrical boundaries, which acts as a single controllable entity with respect to the grid. It can connect and disconnect from the grid to enable grid-connected or islanded operation (Nicolas Plain, 2020). The costs associated with the different components of a solar microgrid are required to satisfy a certain quality of service depending on the intermittency of the solar resource in the study area (Daniel Cadilla & Al., 2017). Depending on these criteria, a microgrid can be chosen to optimize the production and investment costs. The following table shows some advantages and disadvantages of some power generation technology:

Table II. Types of generations for microgrids

Technology	Advantages	Disadvantages
Thermal (diesel)	- Low initial investment -High power -No need of electric energy storage	-High operating and maintenance costs -Normally, service is limited to certain hours of the day due to the cost of fuel.
Mini-Eolic	Low need for civilian infrastructure	-Need of electric energy storage - High variability depending on the wind resource - Need for reliable statistical data for dimensioning
Photovoltaic	- Very sharp decrease in costs in the last decade - Low need for civil infrastructure - Simple and low maintenance technology - In the Haiti the energy production is not significantly affected by the time of the year	-Daily cycle (no production at night) -Need for electric energy storage
Biomass	- Revalorization of organic waste and agricultural surpluses - Development of rural areas - Cleaning and monitoring of forests -Prevention of forest fires - Improvement of waste management - Ease of storage - Variable electricity production according to energy needs	- Material transportation costs - Biomass storage costs - Often it is necessary to do a drying process -Dependence of biomass production, often linked to the cycles of another main productive activity - Substitution of crops that have food purposes

One of the necessary criteria for the deployment of a microgrid is to provide a high power and quality requirement for users, i.e. to meet demand at an affordable price for all consumers, with a low level of failure. Schematically, the configuration of the autonomous photovoltaic microgrid equipped with a power electronic conversion system (bidirectional converter, step-up /step-down), inverters, etc. (see fig.3)

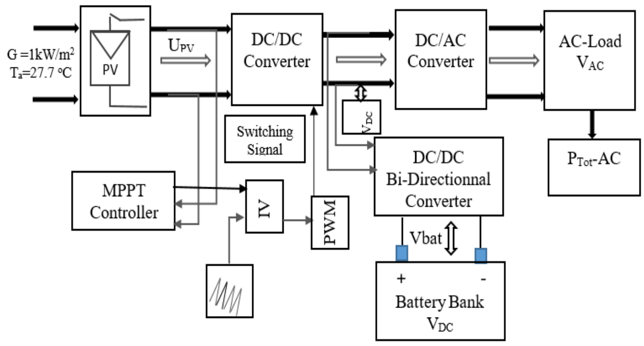

Figure 3. Block diagram for Off-Grid Photovoltaic

4. ENERGY PROFILE OF THE COMMUNITY

In this paper, energy calculations will be performed for an increasing demand of 271 households in the urban areas of the Abricots. In order to better size the microgrid, it is important to identify the category of consumers, i.e., types of customers, different economic activities, schools, buildings, industries, etc.) Therefore, it is best to analyze consumption on a daily, monthly, or annual basis. The characteristics of the loads are categorized according to the consumers; for a microgrid in a rural area, the basic energy needs are mainly: Telephones, radio, fans, TV, lighting, refrigerators, microbusinesses, carpentry, etc. The types of loads are defined according to Table II. The estimated energy consumption is 230 kWh/day.

Table III. Daily household consumers, Constant over the year, average = 230 kWh/day (Annual values)

	Quantity	Power	Use	Energy
		Watts	Hour/day	Wh/day
Lamps	300	10	10.0	33000
TV/Ventilador	170	75	6.0	76500
Radio FM /Mobile	250	10	11.0	27500
fridge/freezer	81	1000	24.0	81000
PC	70	24	7.0	11700
Total daily Energy				229700

These data allow us to obtain a first approach of the daily load curve of the village. This graph (Fig.4) provides an indication of the energy consumed per hour in the microgrid (PVsyst). According to the graph, the peak of consumption amounts to about 24.5 kW and will occur at about 20:00 to 24: 00 when all inhabitants are at home. The consumption is mostly under 3.5 kW between 1:00 AM to 6:00 AM when the residents are asleep.

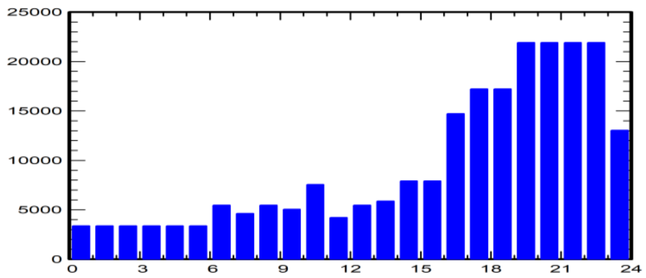

Figure 4. Daily global consumption graph

The overall electricity consumption will follow the cycle of daily, weekly and seasonal, and this depends on climatic factors, economic activity, seasonal festivals, or others. Table IV refers to the energy consumption per day, month and year in the commune of Abricots:

Table IV. Energy consumption by period

Period	Energy consumption (kWh)
Day	230
Month	6900
Year	82800

The production of electricity from solar energy is obviously produced during the hours of sunshine. The production level of solar generators is directly correlated with the energy consumption and depending on the irradiation. In terms of solar, Haiti has a large amount of solar power generation potential. It has an average of 3115 hours of sunlight per year (of a possible 4383), with an average of 8h31min of sunlight per day. In addition, 71.1% of daylight hours are sunny hours. The remaining 28.9% of daylight hours are likely cloudy or with shade, haze or low sun intensity (Rami C. Sleiman & Al., 2014).

The Fig. 5 shows the impact of the surrounding clouds on the solar penetration of the Abricots region. In Abricots, the average percentage of the sky covered by clouds experiences extreme seasonal variation over the course of the year. The clearer part of the year in Abricots begins around November 18 and lasts for 5.7 months, ending around May 7. The clearest month of the year in Abricots is January, during which on average the sky is clear, mostly clear, or partly cloudy 81% of the time. The cloudier part of the year begins around May 7 and lasts for 6.3 months, ending around November 18. The cloudiest month of the year in Abricots is June, during which on average the sky is overcast or mostly cloudy 77% of the time (weatherspark.com).

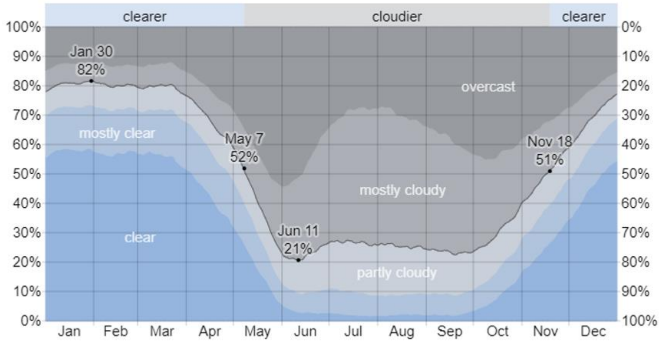

Figure 5. Cloud Cover Categories in Abricots

5. DIMENSIONING OF THE ENERGY NEEDED

The calculation of the energy to be produced depends on the daily consumption; however, it is advisable to increase this value by a safety percentage due to losses and other uncertainties such as weather variation, module efficiency, cable losses, etc. This percentage must be between 10% and 25%. Therefore, we apply an 18% increase as a margin or safety factor to compensate for the losses, defined by the report between Energy Produced (Wp), Energy Consumed (Wc) and Losses.

$$W_p = W_c + Losses \quad (2)$$

$$W_p = 230 + 230 * 0.18 \;\; ; \;\; W_p = 271.4kWh$$

6. SYSTEM DIMENSIONING

The components of the grid are the solar generators, inverters, regulators, batteries, and various other connecting elements such as lines, cables, transformers) and the associated devices (measuring and protection equipment, etc.) In this article, we only dimension the basic elements of the system.

6.1 Choosing the tilt of solar panels

In Haiti, the sun always faces south, so the modules must face south. The tilt, that is the angle between the horizontal plane and the modules should maximise the energy production. The inclination of the panel in this paper is considered to be fixed. In the Northern Hemisphere, place the solar module outside facing south, in a location that gets sunlight all day, and is well ventilated if possible. Haiti is located 7,894.85 km south of the Northern Hemisphere. In the table, they are the solar panel angle by season in Abricots:

Table VI. Optimal Tilt angles in Abricots

Optimal Tilt angles by season	
Spring	19.3°
Summer	4.3°
Fall	19.3°
Winter	34.3°
Optimal year-round tilt angle : 19.3° from horizontal	

The tilt of the modules is important because your modules will produce a maximum of energy when the sun is directly perpendicular to them. During the winter in the northern hemisphere, for example, the sun is low in relation to the horizon (footprinthero.com):

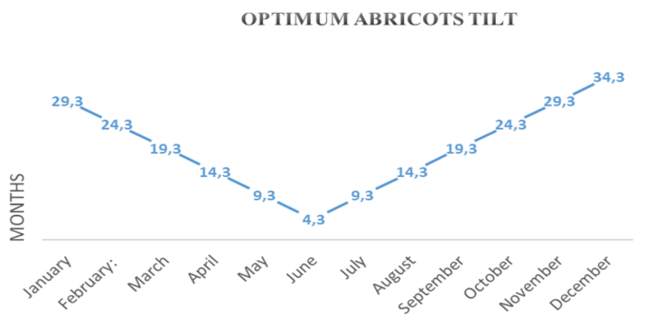

Figure 6. Optimal tilt angle by mouth

The figure 7 shows the solar irradiation in the horizontal plane in Abricots (Homer Energy software). Unlike grid-connected systems, where the highest average annual energy production is sought, in Off-Grid Systems, production is sought to be uniform throughout the year in order to avoid months with low production. Aiming to meet the load even with low irradiance, the chosen Tilt will be the one that maximizes energy production in the month of lowest energy production:

Figure 7. Solar irradiation in Abricots in horizontal plane

Based on the optimum angle for November, the energy production for a fictitious 1kwp system it was generated using the global solar atlas (globalsolaratlas.info). However, as show in the Table VII, when the optimum angle for December is chosen the June production is heavily affected. In this way, a has been looking for a Tilt that maximizes minimum month energy production. Table VII shows that the optimum tilt is 22°, with ensures that the all month of the year has an energy production greater than 129.1 kWh.

Table VII. Month least production for the respective tilt

Tilt	Month	Minimum Energy production
34°	June	112.6 kWh/month
32°	June	115.8 kWh/month
30°	June	118.9 kWh/month
28°	June	121.8 kWh/month
26°	June	124.6 kWh/month
24°	June	127.3 kWh/month
22°	November	129.1 kWh/month
20°	November	128.0 kWh/month

6.2 Dimensioning of solar generator

The nominal power (P) of the photovoltaic system that the must be determinate. The amount of solar energy that will be transformed into electrical energy depends of the average Irradiation (I_r) for the chosen tilt (22°), which for the region of Abricots is 4.5 kWh/m²/day for the lowest energy production month (November). The nominal power is determinate by equation:

$$P_{peak} = \frac{W_p * 1000}{I_r} \qquad (3)$$

$$P_{peak} = \frac{271.4 * 1000}{4.5} \Rightarrow P_{peak} = 60kW_p$$

The solar modules must provide a total peak power of 60 kWp. In order to know the number of modules needed for the installation, a correlation is made between the maximum total power (P) of all the modules and the maximum power of a single panel (P_U).

Table VIII. Data sheet of solar module

Maximum power	400 Wp
Panel type	Monocrystalline
Max-Power Voltage Vpm (V)	40,78
Max-Power Current Ipm (A)	9,82
Open-Circuit Voltage Voc (V)	49,55
Short-Circuit Current Isc (A)	10,59
PV Module Efficiency (%)	20.61%
Size panel	1956×992×35/40mm
Cell temperature	25°

The Monocrystalline panel type with a power of 400Wp is chosen for this microgrid. These modules were chosen for this project because of their efficiency and comes with a 25 years linear performance guarantee. The number of solar modules (N) is determinate by the equation:

$$N = \frac{P}{P_U} \quad (4) \qquad \frac{60 * 1000}{400} = 150 \text{ Modules}$$

To have a better performance, 150 solar modules are needed for the PV system. This equation allows the report between the number of modules in series (N_{Series}) (strings), and the System Voltage (U_{syst}) and the Open-Circuit Voltage (Voc):

$$N_{Series} = \frac{U_{syst}}{V_{oc}} \ (5) \qquad \frac{480}{49.55} = 10$$

With 10 modules are needed in series, this formula allows knowing the number of modules in parallel (Np) by strings; is the report between the quantity of modules (N) and quantity of module in Series (Ns_{eries})

$$N_P = \frac{N}{N_{Series}} \quad (6) \qquad \frac{150}{10} = 15 \text{ Modules in parallel}$$

6.3 Optimal inclination and distance strings collectors

The option of placing the collectors in full south mode allows for surface optimization; it is important that the strings be correctly arranged in order to reduce production losses (energiepluslesite.be)

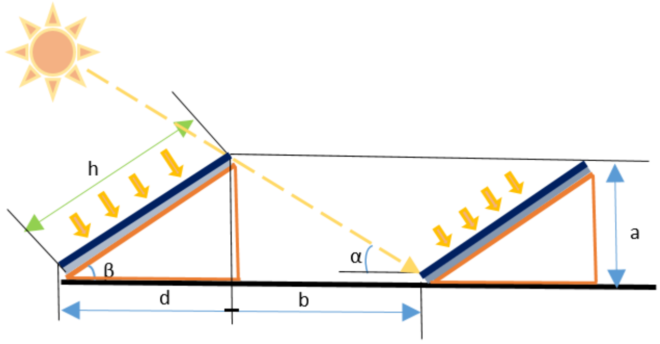

Figure 8. Location of photovoltaic strings collectors

In the figure VIII above, the configuration allows the strings collectors to be spaced to limit the effect of shading and is described by the following formula, which allows us to calculate the distance between axes d + b:

$$d + b = h\left(\frac{\cos\beta + \sin\beta}{tg\alpha}\right) \qquad (7)$$

h = size of the collector.
α = minimum solar height (usually taken on December 21, i.e. an angle of 16°)
β = inclination of the collectors.

6.4 Dimensioning of the storage system

Due to the intermittency of the generation, it is necessary to store energy using batteries; this stored energy will be redistributed when the solar energy supply is no longer available. The microgrid's storage system will be sized to allow an autonomous operation for 2 days. As for durability and longevity of the storage system, Lithium-ion batteries are preferred, with the advantages of 30 years lifetime, Lightweight, No maintenance, Low self-discharge, Good tolerance to low or high temperature, Very high cycle load (between 2500 and 5000 cycles).

The calculation of the capacity (C) in Ampere/hour (Ah) of the battery bank depends on the number of days of autonomy, the total energy consumed in watt/hours day, the admissible depth of discharge of the battery and the voltage. Table IX shows recommended voltages for a PV installation for different peak powers (M. Taïki Vaïtchemé, 2019).

Table IX. Range voltage Table

System Power (Wp)	Recommended voltage range (V_{bat})
0 - 500	12 V
500 - 2000	24 V
2000 -10000	48 V
>10000	> 48 V

In this microgrid, the system voltage is 480 V in order to reduce the current and to avoid large diameter cables. This formula is used to determine the storage capacity of the batteries pack:

$$Ct(Ah) = \frac{W_p * A}{U_{syst} * D_o D * \eta} \qquad (8)$$

$$Ct(Ah) = \frac{271400 * 2}{480 * 0.8 * 0.85} \Rightarrow 1663Ah$$

Wp: Energy produced / day
A: Autonomy during 2 days
U_{Syst} : Voltage System Battery (480 V)
$D_O D$: Depth of discharge (80%)
Cb: Capacity of a battery
Ct: Total capacity of the battery pack
η : Efficiency of the battery pack (85%)
Vbat: Voltage one battery (24 V)

The total number of batteries in the microgrid storage system is the product of the number of batteries in series by the number of batteries in parallel. The calculation having been made with batteries of 24 V and 150 Ah, and to determine the quantity of battery necessary by every string to allow a 2 days autonomy. In Table X, is inserted the number of cycles that can support each battery technology with a maximum discharge at 40% (P. Manimekalai, 2013):

Table X. Battery types and longevity

Battery Types	Cycles	Energy Density (Wh/Kg)
Lead Acid	700	30
Ni-Cd	1000 - 1500	45
Lithium-ion	500 - 1000	90

This calculation allows us to determine the number of battery in parallel (Q_{BP}); this equation is obtained by the report between Total capacity of the battery pack (Ct) and the capacity of one battery (Cb)

$$Q_{BP} = \frac{C_t(Ah)}{C_b(Ah)} \quad (9) \qquad Q_{BP} = \frac{1663}{150} \Rightarrow 11 batteries$$

This equation allows us to calculate the quantity of battery in series by string (B_S); is the report between the voltage system (U_{syst}) and the voltage of one battery (V_{bat}):

$$B_S = \frac{U_{syst}}{V_{bat}} \quad (10) \qquad B_S = \frac{480}{24} \Rightarrow B_S = 20 batteries$$

The battery has to store energy for many days and used without going over the D_0D max. The following equation can be used:

$$Q = \frac{Wc * A}{V * T * \eta Inv * \eta Cable} \qquad (11)$$

Wc = Energy consumed (W/h)

A = number of day of autonomy; V = system DC voltage,
T = maximum allowed $D_O D$ of the battery usually on battery data sheet (indicatively 0.3 - 0.9)
ɳinv = inverter efficiency (1.0 if there's no inverter)
ɳcable = efficiency of the cables delivering the power from battery to loads.

Table XI. Data sheet of solar battery

Battery type	Lithium ion
Battery capacity	24V/200Ah
Quantity of Battery	220
Battery pack voltage	480 V
Global capacity	1663 Ah
Percentage days with full battery	99.65 %
Percentage days with empty battery	0.1 %

6.5. Dimensioning of the solar controller

The charge controller is the central element of an autonomous photovoltaic system. It controls the flow of energy. Solar modules do not send a continuous flow of electricity at all times of the day. The charge controller therefore regulates the flow in order to supply the batteries evenly and to protect them. On the other hand, when it is very cloudy, and the modules are not delivering power, the user may need power. This would cause a significant discharge of the batteries. The controller will then have to intervene to avoid a too deep discharge that would damage the batteries. The charge controller must provide both monitoring and protection functions. At the input: it is necessary to ensure that the controller has a current intensity greater than or equal to that produced by the panels.

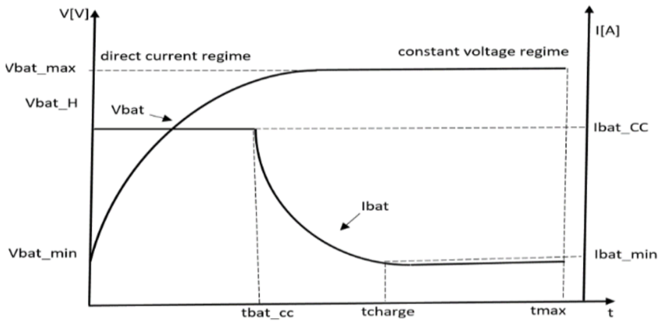

Figure 9. Curve typical charge and discharge battery

The specific parameters for battery recharging are the constant current charge current noted Ibat_CC defining (fig.9). This being said, when the battery is discharged, the voltage at the battery terminal is minimum; to recharge the battery, it needs a constant current. The MPPT regulator is chosen within the framework of this microgrid because of its capacity to respect the battery charge criteria in its three phases: *bulk*: sends a high charge current, 25% of its capacity; *absorption*: maintain the high voltage to complete the charge in a reasonable time; *float*: reduce the voltage (compensate for self-discharge). The maximum charging current (I_{max}) accepted by the controller must be compatible with the power of the panel (Jean-François Reynaud, 2011).

In order to store the maximum amount of energy produced, it is necessary to use lithium-ion phosphate batteries, with an efficiency higher than 95%, priority is given to longevity 1000-10000 charge/discharge cycles. The Table XII define Voltage behaviour in the battery system:

Table XII. Data sheet of solar controller

Nominal voltage of the battery pack	480V
PV Max. Input voltage (open circuit)	880V
Nominal PV Current	200A
Max PV Power	96kw
Quantity (1 regulator by string)	12

In its operation, the controller must meet the following conditions:

$$V_{out} = V_{Bat}\,; \qquad I_{sc} = \mathrm{I}_{max}\,; \qquad V_{oc} < V_{max}$$

The equation that determines the maximum voltage (U_{max}) allowed by the solar regulator is obtained by the correlation between the maximum voltage (V_{OC}) of a module by the strings of modules in series (N_{series})

$$U_{max} = Voc * N_{series} \qquad (12)$$

$$U_{max} = 49.55*10 \qquad U_{max} = 490.5(< 880Volts)$$

This value represents the maximum power that the solar modules can produce under optimal temperature conditions (25 ºC) and an irradiation of 1000 W/m^2. We also know that 1000 V is the voltage that should not be exceeded in the strings. As the temperature increases, the internal resistance of the module decreases proportionally. In this optics where the open circuit voltage can exceed the VOC of the panel; in this case, the voltage is increased by a coefficient of 1.1, allowing to have the maximum voltage in normal conditions of temperature and irradiation.

$$U_{max} = 490.5*1.1 \quad U_{max} = 539.55(< 880Volts)$$

The solar regulator must be able to withstand this maximum voltage of $539.55Volts$. We determine the maximum intensity (I_{max}) that the solar regulator can support by the report between The Current short-circuit (I_{sc}) by the quantity of module in parallel (Np)

$$\mathrm{I}_{max} = I_{sc}(A) * N_p \qquad (13)$$

$$\mathrm{I}_{max} = 10.59*10 \Rightarrow \mathrm{I}_{max} = 105.9A$$

I_{max} increased by a coefficient of 1.2 gives

$$I_{max} = 105.9*1.2 \Rightarrow I_{max} = 127.08A$$

The solar regulator must be able to withstand this maximum intensity of 127.08 A.

6.6 Dimensioning of the solar Inverter

The inverter is a power electronics device that generates alternating voltage and current from an electrical energy source of different voltage or frequency. In a photovoltaic system, it is used to convert the direct current (DC) produced by the solar modules into alternating current (AC). The inverter's control unit ensures that the photovoltaic array is operating at the optimal operating point (maximum power point or MPP) to guarantee maximum electrical energy

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production (Violaine Didier, 2007). Like all energy converters, the inverter has an efficiency expressed as a percentage, i.e. the ratio between the energy absorbed and the energy returned with a given power factor (Cos Phi). Depending on the load profile used in this microgrid, there are inductive and resistive loads (Table XIII). Inductive loads, such as refrigerators, whose power rating is multiplied by three at start up to determine the total capacity of the solar inverter.

Table XIII. Energy regularize for the inverter choice

Inductive loads (In Table III) 81000 × 3	Resistive loads 33000 + 76500 + 27500 + 11760	Power regularize (W)
= 243000	= 148760	391760

One solar inverter of 400 kW, superior to 391760 Watts is necessary power for the installation, while respecting the required clearance distance. The inverters have the following capacities: (Table XIV).

Table XIV. Solar inverter technical Specifications

Pure Sine Wave Off Grid Inverter, 400kW	
Rated input voltage	600V DC
Rated input current	667 A
Rated output current	606 A
Input voltage range	540 – 850 V
Rated power	400 kW
Rated output voltage	380 V or 480V
Number of phases & Frequency	3 phases, 60 Hz
Inverter efficiency	93%

7. CONCLUSION

Renewable energies represent not only an efficient way to reduce greenhouse gas emissions in order to better preserve our environment; but also above all, the only way to increase access to electricity in remote areas and isolated from national grids. According to the IEA, the global renewable electricity capacity is expected to increase by more than 60% between 2020 and 2026, reaching more than 4800 GW (RINA Consulting Ltd,2010). In the case of Haiti, renewable energy represents 15.05% of its energy matrix which is 413.52 MW (14.31% hydropower, 0.73% solar energy), so 61.002 MW. However, Haiti has great potential in solar energy which can contribute to 30% of its energy matrix, which can promote sustainable access to energy for the entire population. In this paper, we propose an off-grid system that can effectively meet the energy needs of 276 households living in the town of Abricots. Methodologically in this work, we have previously identified the energy needs of the population, followed by the calculation of the photovoltaic field, the storage system, the different converters and connectors. The results obtained in this work are calculate in an optimal way due to the accelerated growth of photovoltaic energy around the world.

Ultimately, this microgrid is sized not only with the objective of reducing the costs of energy operations, but especially with the objective of promoting sustainable energy inclusion of rural populations around the world, in Haiti in particular, while taking into account the evolution of the future population.

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