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Comparative study of solar and conventional energies for the continuity of public administrative service at the town hall of Zagnanado in central Benin

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Abstract— **The continuous functioning of the municipal administration is an indicator of the sustainability of the local public service. But since the reform instituting the prepayment mode of consumption, the disconnection of offices from the public electricity network creates conditions favorable to absenteeism of municipal officials and thus modifies the procedures in force.**

Aware of these dysfunctions which, in every respect disadvantage the users of the administration, the present reflection carried out from the case of the town hall of Zagnanado (in the center of Benin) made it possible to determine the demand for energy and therefore, to size a solar generator capable of supplementing the conventional network.

Thus, after having explored the advantages and disadvantages of each of the two off-grid and on-grid technologies, the evaluation of consumption over a 20-year horizon on the one hand and of the investment cost including the renewal of the other hand revealed that this parameter constitutes the main weak point of photovoltaic energy.

Index Terms— **essential services, photovoltaic solar energy, continuity of public service, off-grid energy**

I. INTRODUCTION

The availability of quantity and quality of energy is a determining factor in the provision of public services. Jacquet P. et al. [1, p. 298] add that access to electrical energy promotes “improved productivity of agricultural and economic activities” for communities. The Performances Management Consulting Firm [2, p. 33] for its part considers that “electricity is a major lever for the development of economic activities and an essential service for the significant improvement of living conditions”. Aware of this advantage, Gbaguidi [3, p. 20] concludes that “the use of electrical energy provides additional hours for work and therefore improves labor productivity”.

In Benin, SBEE is a public company which has the exclusive right to distribute this production factor. But the accumulation of operating losses has for a long time had a negative impact on the services of this public service delegate. For example, in 2015 the country experienced “load shedding of up to 16 hours per day” [4]. An in-depth examination of this poor performance shows that the shortfalls are justified, among other things, by excessive consumption. public administrations which have difficulty paying the bills. To overcome these cash flow difficulties, a new recovery plan was implemented from 2017 and now requires any subscriber (regardless of their public or private status) to equip themselves with a meter in prepayment mode in order to continue access to the network.

Therefore, many public administrations find themselves having difficulty paying credit in prepayment mode and are therefore periodically disconnected from the electricity network. Likewise, public procurement procedures increase the time taken to disburse the resources essential to this acquisition. Added to this are the difficulties of anticipating electricity consumption forecasts. The consequences resulting from this failure are numerous: absenteeism of administrative staff, increased delays in providing administrative acts, modification of procedures, user dissatisfaction, etc.

In order to contribute to overcoming this series of difficulties, the present study set itself the objective of analyzing the possibility of energy autonomy of the premises of the Town Hall of Zagnanado through the expression of the demand for electrical energy and the study methods of supplying this input by a photovoltaic solar system.

II. METHODOLOGICAL APPROACH

In order to achieve the objective thus defined, the present reflection is based on the postulate according to which continuous access to electrical energy is a serious avenue to take for the sustainability of the services provided by the municipal administration for the benefit of citizens.

Starting from this point of view, the reflection focused on three specific hypotheses. Initially, structural reasons favor the unloading of city hall offices and create absenteeism among civil servants. Then, the lack of anticipation in the prepayment of electrical energy is due to the failure to assess energy needs. Finally, the democratization of off-grid solutions thanks to photovoltaic solar technology is a possible solution for the permanent access of workstations

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to the electricity network.

To test these hypotheses, the article begins by tackling the problem of dysfunction of municipal administration during periods of power cut by identifying its manifestations. The consequences of discontinuous access to the electricity network were then identified through a campaign of direct observation of the functioning of the administration. A user survey then made it possible to identify the levels of dissatisfaction linked to this deficit. Subsequently, energy demand was expressed through a census of equipment (lighting and appliances). Using the manufacturers' nameplates and data sheets, the energy ratings were determined or calculated. On this basis, the different components of a solar generator were sized. By referring to local economic conditions, the evaluation of the cost of the investment was made and a comparison with the cost of access to the conventional network made it possible to reveal the advantages and disadvantages of using this technology over a horizon of 20 years.

III. RESULTS AND DISCUSSIONS

The implementation of the approach thus described made it possible to identify the malfunctions linked to the disconnection from the electricity network at the town hall as well as to determine the energy needs and to size a solar generator capable of ensuring the continuity of the public service.

2.1- Cause of the absence of civil servants

The absence of civil servants at the post during periods of power outage results from three (03) causes identified as below.

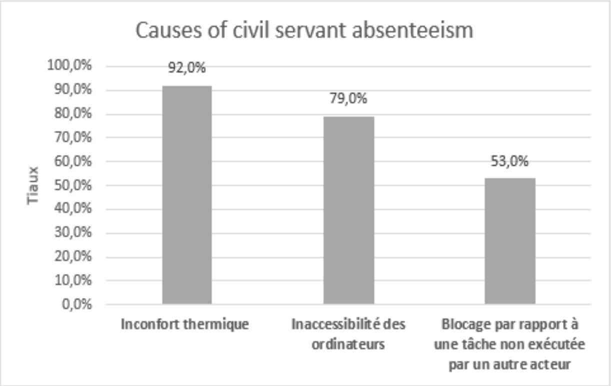

Figure 1: Causes of civil servant absenteeism

Reading Figure 1 reveals that thermal discomfort is the primary cause of abandonment of premises in the event of a power cut. The source of such a situation lies in the fact that the artificial ventilation and/or air conditioning which regulate the temperature of the rooms is interrupted in the absence of electrical energy.

Likewise, the absence of backup power prevents civil servants from using computers and other equipment such as printers to work or access data needed to provide services to citizens.

Furthermore, with certain tasks taking place on an assembly line basis, civil servants downstream of the activity find themselves stuck for an even longer period after connection to the electricity network.

2.2- Expression of energy needs

In order to determine the demand for electrical energy, a complete inventory of all equipment and lighting fixtures was made through their number and the determination of their unit power as summarized in Table 1 below.

Table 1: Electrical equipment and unit power

Designation	Quantity	Power (W)
Lamps	142	10
Brewers	52	70
Video projector	2	75
Air conditioner 2 hp	15	1472
Air conditioner 1.5 hp	23	1104
Computers	30	85
Printers	20	60
Sanitary wall lamp	7	10
Surveillance camera	4	60
Routers	4	30
Television	3	65
All connection equipment	1	200
Laptops, small equipment, …	1	200
Photocopier	2	900

Source: Field data

Following the previous table, the study also determined the average time of use of each equipment as summarized in the table below.

Table2: Daily use time of electrical equipment

Equipment	Time of use (hour)
Lamps	12
Brewers	12
Video projector	4
Air conditioner 2 hp	6
Air conditioner 1.5 hp	6
Computers	10
Printers	8
Sanitary wall lamp	4
Surveillance camera	24
Routers	12
Television	6
All connection equipment	12
Laptops, small equipment, …	12
Photocopier	4

Source: Field data

The reading of table 2 reveals a daily time of use varying between 4 and 24 hours for the various devices identified.

As a result of this inventory, the training manual for the Installation and Maintenance of Small Photovoltaic Systems [5] identified the sizing parameters.

Thus, insolation records for the reference area during the 12 months of the previous year are recorded in the table below:

Table 3: Insolation of the Bohicon weather station

Month	**I**	**II**	**III**	**IV**	**V**	**VI**
Solar irradiation, kWh/m²/day (Em)	5.84	6.13	5.91	5.49	5.19	4.68
Clouds, 0 – 1	0.64	0.63	0.57	0.53	0.51	0.47
Temperature, °C	26.13	26.51	26.15	25.87	25.75	24.90
Wind speed, m/s	3.37	3.35	3.48	3.17	2.90	2.82
Precipitation, mm	12	29	86	128	179	236
Rainy, d	1.1	2.5	6.2	9.7	12.8	16.6
Month	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Solar irradiation, kWh/m²/day (Em)	4.06	3.86	4.21	4.74	5.20	5.57
Clouds, 0 – 1	0.40	0.38	0.41	0.48	0.56	0.62
Temperature, °C	23.97	23.89	24.34	24.65	24.84	25.34
Wind speed, m/s	3.36	3.49	3.32	2.62	3.16	2.99
Precipitation, mm	127	71	139	156	50	15
Rainy, d	12.4	10.5	12.3	11.4	4.3	1.6

Source: [6]

Based on insolation data, average sunshine is defined as the average of the 12-month sunshine [5]. Either $\mathbf{E_m} = \frac{\sum_{i=1}^{12} \mathbf{E_i}}{12}$.

In digital application, the average sunshine is equal to$5{,}074\ \mathrm{kWh/m^2/j}$ about 5.1kWh/m2$^{/d.}$

It was then defined the coefficient of the metrological uncertainty which is a parameter that takes into account the charge and discharge efficiency of the batteries and the non-optimality of the modules due to hazards such as dust and aging. It is between 0.55 and 0.65. We set this value at 0.6 for this study $\mathbf{K_c}$ [5].

In order to optimize the sizing, the coefficient of simultaneity was also defined. This is because, in reality, not all electrical loads installed in buildings are operating at the same time. There's a discrepancy in their power-up. The value of simultaneity is less than or equal to the unit. In this study, we chose 70% for some appliances, 90% for others and 40% for air conditioners.

Based on assumptions, the energy requirements of the site per day are summarized as follows:

$$\mathbf{Ej} = \sum \mathbf{Puissance} \times \mathbf{heures\ de\ fonctionnement}$$

and $\mathbf{Ej'} = \frac{\mathbf{Ej}}{\mathbf{K_c}}$ where **E** $_j$' represents the corrected energy requirement due to the transformation of the continuous energy thus obtained into alternative energy.

Table 4: City Hall Daily Energy Requirement

Source: Field data, our calculations

Receivers	**Natu of th curre**	**Quantity**	**Unit Power (W)**	**Total Power (W)**	**Simultaneity factor**	**Time of use (hour)**	**Energy total (Wh)**
Lamps	AC	142	10	1420	0,9	12	15336
Brewers	AC	52	70	3640	0,9	12	39312
Video projector	AC	2	75	150	0,7	4	420
Air conditioner 2ch	AC	15	1472	22080	0,4	12	105984
Air conditioner 1.5ch	AC	23	1104	25392	0,4	12	121881,6
Computers	AC	30	85	2550	0,7	10	17850
Printers	AC	20	60	1200	0,7	8	6720
Sanitary wall lamp	AC	7	10	70	0,7	4	196
Surveillance camera	AC	4	60	240	0,9	24	5184
Routers	AC	4	30	120	0,9	12	1296
Television	AC	3	65	195	0,7	6	819
All connection equipment	AC	1	200	200	0,9	12	2160
Portable, small equipment	AC	1	200	200	0,9	12	2160
Photocopier	AC	2	900	1800	0,7	4	5040
Total energy (Wh/D)							**269 291**
Unforeseen	10%						**26929,1**
Total daily energy: Ej AC (Wh/D)							296 220,1
Corrected total daily energy: Ej' AC (Wh/J)							**493 700**

Therefore, reading this table reveals a daily electrical energy requirement of 493 700 Wh.

2.3 Sizing of a solar generator

In a study commissioned by the Republic of Benin as part of funding from the Government of the United States, it is recommended that "off-grid electricity consumers must have a reliable power supply based on a low-voltage three-phase 400 V grid similar to their counterparts served by the SBEE grid" [7, p. 280].

Based on this requirement, the analysis of the regulatory framework reveals a lack of local off-grid energy supply standards. However, according to the report, the application of international standards is essential. As such, the design approach for the generator is derived from the following six (06) standards:

- IEC 61215-1-1: 2016 - Terrestrial photovoltaic (PV) modules - Design specification and approval - Part 1-1: Special requirements for testing crystalline silicon (PV) photovoltaic modules;
- IEC TS 62941:2016 - Terrestrial photovoltaic (PV) modules - Guideline for increased confidence in

design specifications and type approval of photovoltaic modules;

- IEC 60287-2-1: 2015 - Electrical cables - Calculation of nominal current - Part 2-1: Thermal resistance - Calculation of thermal resistance;
- IEC 60364-7-712: 2017 – Electrical installations, low voltage - Part 7-712: Requirements for special installations or locations - Photovoltaic (PV) solar power systems;
- IEC TS 62257-1: 2015 - Recommendations for renewable and hybrid energy systems for rural electrification - Part 1: General introduction to the IEC 62257 series and rural electrification; and
- A4.6 IEC TS 62257-8-1: 2007 - Recommendations for small power and hybrid renewable energy systems for rural electrification - Part 8-1: Battery selection and battery management systems for autonomous electrification systems – Specific case of wet lead-acid car battery available in developing countries.

By combining these standards, the calibration of the solar generator amounts to the sizing of the photovoltaic field, the determination of the number and power of the batteries, the determination of the charge controllers, regulators, depending on the section of cables and protective equipment.

2.3.1- Sizing of the photovoltaic field

The sizing of the photovoltaic solar field comes down to the determination of the peak power as well as the number of modules based on the hypothesis of use of solar panels of the monocrystalline type of power 300 WC.

The power of the photovoltaic field is defined by the expression: $P_C = \frac{Ej'}{E_m}$ with: Sunshine in terms of the modules in kWh/m2 E_m /d and Ej' : Corrected daily total energy. [8]

The results from the numerical application of these formulas are recorded in the following table:

Table 5: *Number of panels and peak power to install*

Designation	**Quantity**
Peak power Pc of the PV field (WC)	96,803,954
Unit power (WC)	300
Number of panels to power	322.67
Number of panels retained	325
Peak power to install Pc (WC)	97,500

Source: Our calculations

2.3.2- Battery sizing

There formula for calculating the total battery capacity in Ah (Ampere hour) is:

$$C_B = \frac{E_J * k}{d_M * U_{syst} * K_{bat}}$$ [8]

k: number of days of autonomy;
Usyt: battery bank voltage (48 V);
dM: depth of the discharge (50%);
Kbat: battery efficiency (80%);
Ubat: voltage of a battery is 2 V.

The batteries are arranged so as to provide a suitable voltage and current to power the load in the event of absence of the generator photovoltaic. They are therefore arranged either in series or in parallel.

The number of batteries in parallel is determined by the formula: $N_P = \frac{C_B}{C_{bat}}$;

The number of batteries in series is determined using the formula: $N_s = \frac{U_{syt}}{U_{bat}}$;

The calculation of the total number of batteries is obtained by: = xNp

Table 6*: Configuration of the accumulator bank*

Designation	**Quantity**
System Voltage (Volts)	48
Battery voltage (V)	2
Battery Capacity (Ah)	1,700
Number of days of autonomy (Day)	2
Battery capacity (Ah)	30,856.260
Number of batteries in series	24
Number of batteries in parallel	18
Total number of batteries	432

Source: Our calculations

2.3.3- Charge controller sizing

For the regulator, it must support 150% of the total field power photovoltaic. Or the formula:

$$I_C = 1{,}5 \frac{P_C}{U_{Syst}}$$

The results of this calculation are summarized as follows:

Table 7*: Choice of charge regulators*

Designation	**Quantity**
IC charging current	3,047
Choice of regulator	MPPT 150/100
Number of charge regulators	**30**

Source: Our calculations

2.3.4- Converter sizing

The input power (DC side) of the inverter represents at least 90% of the power of the PV generator. To optimize safety, the power value is set at 95% of the peak power due to future load extensions. The power and choice of inverters are presented in the table below:

***Table 8**: **Power** and choice of inverters*

Designation	Quantity	
Converter power (VA)	109,000	
Choice of 48VDC/410VAC three-phase converter	**15000VA**	**5000VA**
Number of converters	**7**	**1**

Source: Our calculations

2.3.5- Sizing of cables and protections

The choice of cable section is made based on the operating current, the type of insulation and the nature of the voltage.

The operating current Iz is defined by: $\mathbf{I_Z} = \mathbf{q} \times \mathbf{I_N}$[8]

q: corrected coefficient depending on the type of protection (by circuit breaker, by fuse)
IN: Rated current

Table 9: Section and length of cables

Connections	Type of protection and operating current	Section mm2	Maximum length
PV field - Arrival box	23 DC circuit breakers 70A 07 DC circuit breakers 65A	35 mm2	20
Controller – Converter Box	23 Fuses 125 A 07 Fuses 100 A	50 mm2	20
Converter		50 mm2	20

Source: Our calculations

2.3.6- Equipment lifespan

Based on the information sheets from the equipment manufacturers and the guarantees offered, the table below summarizes the lifespan of each component of the generator as well as the number of replacements over a period of 20 years.

Table 10: Lifespan of solar generator equipment

Equipment	Lifespan (year)	Number of replacements in 20 years
Photovoltaic solar panel	25	0
Batteries	8	2
Charge regulator	15	1
Converter	15	1
Cables	25	0

Source: Our calculations

2.3.7- Estimated cost of producing the solar generator

Based on the results thus obtained, the study determined the amount necessary for the installation of the generator on the basis of a recent study carried out by the UNIDEV Cabinet [8], the table below summarizes the investment required for this project.

***Table 11**: Evaluation of the cost of the investment*

Designation	Amount including tax (in CFA Francs)
Site installation	1.5 million
Solar fields	73,950,000
Technical area	2,000,000
Technical local equipment	319 367 650
Cablework	8,253,750
Layout of the technical room, maintenance and monitoring and training	4,649,500
Grand Total Investment	**409 720 900**
Cost of renewal	**267 625 750**
Grand total of investment including renewal	**677 346 650**

Sources:[8], our calculations.

In total, the installation of a solar generator capable of ensuring all the energy costs of the Zagnanado town hall could cost around 410 million CFA francs. Including the cost of renewing the equipment, the investment will be 677,346,650 CFA Francs or annual depreciation of 33,867,332.5 CFA Francs.

2.3.8- Comparison of conventional grid connection solutions and solar generator

Following the previous investigations, discussions focused on the advantages and disadvantages of each of the two technologies as summarized below.

Table 12: **Advantages and disadvantages of energy solutions**

Solution	Benefits	Disadvantages
Conventional network	Relatively low production cost Possibility of extending distribution over a large area	Heavy investments for installation Requires the installation and/or extension of a Medium Voltage and Low Voltage network
Solar generators	Decentralized production Low operating load Limited	High installation cost The reliability of equipment

	maintenance Does not require a monthly fee Can support a mini distribution network	components is limited Secures a large space for solar field installation Production fluctuates according to climatic hazards

Source:[3]

Deciphering Table No. 12 reveals that the supply of electrical energy from the conventional network costs relatively less than the energy generated by the solar field which requires a heavy investment from the start. However, the latter solution offers autonomy due to its decentralization, low operating costs and the absence of monthly invoices. However, depending on the climate, production fluctuates. Likewise, the lifespan of equipment remains very short.

In order to verify the argument of the high cost of solar energy, a comparative analysis was carried out. For this, the evaluation of the cost of consumption on the conventional network was based on the daily needs expressed and the selling price practiced by the SBEE to which an increase of 1% was applied to take into account the revision. periodic transfer price of Kwh. On this basis, the table below summarizes the forecast budget for the operation.

Table 13: Comparison between the cost of connection to the public network and the energy of the solar generator

Connection to the conventional network				**Solar generator**
Consumption horizon	**Consumption**	**Unit prices**	**Amount**	
Day	493.7	147.5	72,821	92,724
Year	180 324	147.5	26,597,790	33,867,333
Consumption over 20 years	3,606,479	147.5	531 955 653	677 346 650

Source :[9], our calculations

Reading the previous table confirms that over a 20-year horizon, the consumption of electrical energy from the public network remains more competitive compared to the solar generator solution.

Conclusion

The permanent availability of electrical energy is a crucial variable for the continuous provision of public service. But the accumulation of unpaid consumption bills from many administrations very early led to a structural reform based on the adoption of the prepayment method. This new situation has lead in the wing since the ignorance of the demand for energy coupled with the cumbersome procedures for awarding public contracts lead to the unloading of administration offices for more or less long periods, thus jeopardizing the supply optimal performance of the administration.

In order to normalize this situation, the daily demand for electrical energy was assessed and therefore, a photovoltaic solar generator was sized and the parameters to be taken into consideration for its long-term sustainability were reviewed. These results made it possible to compare this technology to the traditional system and to find the relative limits.

IV. CONCLUSION

The permanent availability of electrical energy is a crucial variable for the continuous provision of public service. But the accumulation of unpaid consumption bills from many administrations very early led to a structural reform based on the adoption of the prepayment method. This new situation has lead in the wing since the ignorance of the demand for energy coupled with the cumbersome procedures for awarding public contracts lead to the unloading of administration offices for more or less long periods, thus jeopardizing the supply optimal performance of the administration.

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