

Technical and Economic Study of Different Hybrid System Structures Applied to Digital Terrestrial Television Broadcasting Sites in Benin Republic

¹Agbokpanzo Richard Gilles, ²Djossou Ayihaou Armand,
¹Kpomahou Fernando, ³Didavi Audace and ³Anatho Marius

¹ENSET Lokossa, UNSTIM, BENIN

²INSTI Lokossa, UNSTIM, BENIN

³EPAC, UAC, Abomey-Calavi, BENIN

Abstract: The digital terrestrial television (DTT) broadcasting centers of the ORTB suffer from the supply of electrical energy, which leads to the use of generators. The high cost of a photovoltaic installation, as a complete replacement of the generators, led us to opt for a power supply multi-sources. In this context, simulations of the behavior energy system were carried out with the HOMER software and several parameters were analyzed. The results compared to the existing system (conventional system) of the selected site show that the multi-source system with PV has a considerably reduced cost compared to the conventional system and pollutes the environment less. Therefore, our contribution is to propose an optimization multi-source systems to supply a transmission center ORTB taking into account information from the site to determine the powers of each source to be installed. Indeed, most DTT broadcasting centers are located in remote areas sometimes difficult to access.

Key words: Multi-source • Optimization • Cost reduction • HOMER

INTRODUCTION

In the contemporary era, the use of electricity is no longer a luxury, but a vital need. It is undoubtedly the most efficient energy vector, which explains its development. This development is at the center of the alteration of the environment by the increased release of greenhouse gases caused by the use of fossil and fissile sources, even their prices are unstable and uncertain. However, renewable resources are economically and environmentally advantageous, but their intermittent nature decreases their energy efficiency when exploited individually. The use of hybrid systems (multi-sources) is generally considered by all as a future solution, both efficient and reliable.

The present work concerns a stationary application of small size to feed a transmission center of the office of Radio and Television of Benin (ORTB). Indeed, the ORTB has a broadcasting network that includes 35 broadcasting centers, the broadcasting centers are equipped with

electronic telecommunications equipment, which through a radio antenna, radiates electromagnetic waves in the radio space. Therefore, they need a continuous and stable supply of electrical energy. Thus, to ensure the supply of electrical energy to the centers, thirty (30) centers closer to the public network are supplied by the electrical network of the Beninese Company of Electrical Energy (SBEE) with an emergency generator that consumes fuel (diesel). The five centers located on sites far from the electrical grid are powered by solar photovoltaic plants. After eight (8) years of the project's life, a technical and financial evaluation of the project's performance has shown that the fundamental problems that undermine the success of the project are mainly 'energetic', namely:

- The inefficiency of solar photovoltaic power plants: the system since its installation feeds a small part of the loads. This leads to believe for some executives that the solar panels have shown their limits and are inefficient for these applications of

radio and television communication relays and propose the installation of generators to replace the panels, which is contrary to the sense of energy transition for the 'sustainable development;

- The massive destruction of electrical and electronic broadcasting and transmission equipment (transmitters, encoders, decoders, etc.) by the considerable degradation of the quality and reliability of the SBEE's electrical network (regular outages, voltage dips, frequent and permanent voltage drops and rises, transient and harmonic distortions);
- A rapid and considerable increase in the electricity costs related to the supply of the transmitting centers;
- An increase in the operating costs of the generators due to repeated and long repeated and long power cuts in the SBEE sector (load shedding) due to the overall energy deficit at the national level;
- The production of energy by the generators induces the emission of CO₂.

Given the above, the various energy systems currently used to supply electrical energy are neither efficient nor profitable. It is essential to reflect on the most suitable energy systems that are efficient and economically profitable for the supply of electrical energy to ORTB broadcasting centers, especially since these analogue broadcasting centers will be transformed into digital broadcasting centers as part of the implementation of the Digital Terrestrial Television program (DTT).

Description of the System and its Operation

Presentation of the Existing System: The television or radio transmitters are electronic telecommunications equipment, which through a radio antenna, radiates electromagnetic waves in the Hertzian space [1]. They are usually placed in open country, on high points or in the center of a vast plain to benefit from the best engagement; they need a continuous and stable supply of good quality electrical energy for their operation. The site chosen for this study has conventional power and a 55 kVA emergency generator (EG) model C55D5 [5]; these two energy sources are mounted on an automatic inverter which allows the switching between the two sources. The center also has a voltage regulator that allows regulating the voltage coming from the sources and an inverter with 40 batteries of 12V 35Ah. This system, since its installation, presents some problems that undermine the success of the project, namely [2, 3, 4]:

- The massive destruction of electrical and electronic broadcasting and transmission equipment by the considerable degradation of the quality and reliability of the SBEE's electrical network;
- A rapid and considerable increase in electricity costs related to the supply of the transmitting centers;
- An increase in the operating costs of generators due to repeated and long power cuts in the SBEE sector (load shedding) due to the overall energy deficit at the national level;
- The production of energy by the 55 kVA generator induces the emission of CO₂.

Given all the above, it is essential to reflect on the most suitable energy systems effectively and economically profitable for the supply of electrical energy to the center, hence the system studied.

Presentation of the Studied System: The studied system consists of conventional energy, generator, photovoltaic generator and storage batteries. The electrical load is fed by the current delivered by each of the systems and the control of their load is ensured by a charge controller. All simulations must be preceded by a dimensioning. The main factors for the dimensioning are:

- Environmental conditions of the site (sunshine, temperature, humidity, wind speed);
- The load curve profile (consumption);
- Financial resources;
- Availability of materials on the local market.

Operating Strategy: The performance of a hybrid energy system is influenced by the choice of the operating strategy. In the case of the selected hybrid system, the priority is to satisfy the energy demand from the energy produced by the photovoltaic field. The battery is used as an energy and power buffer. In case of overproduction, it absorbs the surplus energy; conversely, when the production is insufficient to cover the needs, it gives back the accumulated energy. Using the information on the state of charge, the inverter generates an on/off signal to the grid or the generator.

Also, it ensures that the heating, minimum operating and cooling times of the diesel generator are respected. This function allows to limit the frequency of maintenance and improve the generator's longevity. In the event of greater needs, this is covered directly by the mains or the diesel generator connected to the system.

This considerably increases the system's efficiency and ensures a longer life for the batteries by limiting their energy flow. To limit the fuel consumption of the generator set, it must be operated optimally. The power required by the center can vary greatly, the inverter must regulate the current of the diesel and constantly adapt its power to the load. In short, the three main functions that our system must ensure are the following:

- Maintain safe system operation at all times to ensure reliable power supply to loads;
- Minimize fuel and maintenance costs;
- Optimize the life of the batteries and the diesel generator.

Site Specification and Mathematical Models Used: There are 29 transmission sites retained by the DTT program [4 5], our study focused on the site of Gbehoue, a district of the commune of Grand-Popo whose geographical coordinates are: latitude 6° 17' 00 North, longitude 1° 50' 00 East. Monthly solar radiation data for the site range from 4.21 to 5.54 kWh/m²/day with an annual average of 4.89 kWh/m²/day. NASA temperature data was also used in this work. The values obtained for this site are in the range of 25.3 to 29°C with an annual average of 27.4°C [8, 9]. In this study, the loads are AC type running continuously throughout the year with an average of 182 kWh/day and a peak of 8.031 kW.

Sizing of the Different Components of the System: The following formulas allowed us to make the dimensioning of the different components:

- Photovoltaic field [15]

$$Pc = \frac{1}{\eta_{ond}\eta_{reg}*H*PR} (E_d + \frac{st}{\eta_{bat}}) \quad (1)$$

η_{ond} : Inverter efficiency
 η_{reg} : Regulator efficiency
H: Irradiation
PR: Performance ratio

- Total number of modules [15]

$$N_{MT} = \frac{P_c}{P_{ci}} \quad (2)$$

N_{MT} : Total number of modules
 P_c : Total peak power
 P_{ci} : Unit peak power

- Inverter choice [19]

$$P_{onduleur} = 1,25 * P_a \quad (3)$$

- Battery capacity [18, 19]

$$C_{bat} = \frac{S_t}{V_{sys} * \eta_{bat} * dd_p * \eta_{ond}} \quad (4)$$

The number of serial accumulators is determined by the formula (5), the number of parallel branches is determined by the formula (6) and the total number of accumulators is determined by the formula (7).

$$N_{as} = \frac{V_{sys}}{V_{bi}} \quad (5)$$

$$N_{bp} = \frac{C_b}{C_{bi}} \quad (6)$$

$$N_{ibat} = N_{as} * N_{bp} \quad (7)$$

- Generator set.

The sizing of the generator set is done using the following formula [14, 19]:

$$P_{GE} = 1,2 * P_a \quad (8)$$

Technical and Economic Parameters of the Simulation: The exploitation of the previous formulas allowed us to choose the different energy components. Table 1 presents all these components and their cost on the local market.

In the software environment, we define the characteristics of the site of implementation and the data of the system to be studied such as the potential of available renewable energy, the coordinates of the site, the demand to be satisfied, the life span of the components and their characteristics. Also, we set operating constraints such as:

- Average sunshine: 4, 89kWh/m²/day ;
- Cost of energy paid to the SBEE: 0.260\$ or 150 FCFA;
- Cost of diesel: 0.899\$ (518 FCFA cost of diesel in February 2019);
- Cost of operation and maintenance of the system: \$2499.56 (i.e., the salary of two technicians for one year);
- Discount rate: 8% [14].

Table 1: Technical and economic parameters

System	Considered power	Unit price	Operating and maintenance cost	Lifetime	Pollution
PV	270Wc	154\$	2\$/yr [18]	20 yrs	0
Inverter	15kVa	6199\$	6\$/yr [18]	10 yrs	0
Sector	50kVa	34716\$			CO ₂ = 632 g/kWh SO ₂ = 2, 74 g/kWh NO _x = 1, 34 g/kWh
GE	12, 5kVa	12795, 36\$	0, 138\$/hr [18]	10 yrs	CO=140g/L CH ₄ =50g/L PM=209g/L
Batteries	1070Ah, 2V	509\$	2, 54\$/yr [18]	7yrs	0

RESULTS

HOMER simulates the system configurations with all the combinations of the components specified in the input. It eliminates from the results all infeasible system configurations, which are not in line with the electricity demand nor compatible with the specified resources and constraints. Once the calculation is completed and without any warning

message, the results are ranked according to lifetime cost. The set of solutions ranked by lifetime cost is as follows Figure 1.

We can also see the best solutions by type of system (Figure 2).

System Optimization: Figures 3 and 4 show the initial costs and the operation and maintenance costs of the systems respectively.

Double click on a system below for simulation results.

	PV (kW)	Label (kW)	H1070	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Batt. Lf. (yr)
					CC	40	\$ 0	19,791	\$ 194,312	0.298	0.00			
					LF	40	\$ 0	19,791	\$ 194,312	0.298	0.00			
					CC	40	\$ 75,615	12,143	\$ 194,835	0.299	0.66			7.4
					LF	40	\$ 75,615	12,143	\$ 194,835	0.299	0.66			7.4
					CC	40	\$ 87,831	10,954	\$ 195,382	0.300	0.72			8.3
					LF	40	\$ 87,831	10,954	\$ 195,382	0.300	0.72			8.3
					CC	40	\$ 63,399	13,516	\$ 196,098	0.301	0.60			
					LF	40	\$ 63,399	13,516	\$ 196,098	0.301	0.60			
					LF	40	\$ 87,344	12,365	\$ 208,742	0.320	0.66	1,903	730	7.4
					LF	40	\$ 99,560	11,233	\$ 209,847	0.322	0.72	1,502	730	8.3
					CC	40	\$ 75,128	13,737	\$ 210,001	0.322	0.60	1,905	730	
					LF	40	\$ 75,128	13,737	\$ 210,001	0.322	0.60	1,905	730	
					CC	40	\$ 99,560	11,323	\$ 210,733	0.323	0.72	1,546	730	8.2
					CC	40	\$ 46,445	20,013	\$ 242,932	0.372	0.00	1,905	730	
					LF	40	\$ 46,445	20,013	\$ 242,932	0.372	0.00	1,905	730	
					CC	40	\$ 53,131	20,142	\$ 250,884	0.385	0.00			20.0
					LF	40	\$ 53,131	20,142	\$ 250,884	0.385	0.00			20.0
					CC	40	\$ 65,347	20,194	\$ 263,612	0.404	0.00			20.0
					LF	40	\$ 65,347	20,194	\$ 263,612	0.404	0.00			20.0
					LF	40	\$ 64,860	20,363	\$ 264,791	0.406	0.00	1,903	730	20.0
					CC	40	\$ 64,860	20,374	\$ 264,897	0.406	0.00	1,915	730	20.0
					LF	40	\$ 77,076	20,415	\$ 277,518	0.426	0.00	1,903	730	20.0
					CC	40	\$ 77,076	20,437	\$ 277,730	0.426	0.00	1,927	730	20.0

Fig. 1: Set of solutions ranked by lifetime cost

Double click on a system below for simulation results.

	PV (kW)	Label (kW)	H1070	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Batt. Lf. (yr)
					CC	40	\$ 0	19,791	\$ 194,312	0.298	0.00			
					CC	40	\$ 75,615	12,143	\$ 194,835	0.299	0.66			7.4
					CC	40	\$ 63,399	13,516	\$ 196,098	0.301	0.60			
					LF	40	\$ 87,344	12,365	\$ 208,742	0.320	0.66	1,903	730	7.4
					CC	40	\$ 75,128	13,737	\$ 210,001	0.322	0.60	1,905	730	
					CC	40	\$ 46,445	20,013	\$ 242,932	0.372	0.00	1,905	730	
					CC	40	\$ 53,131	20,142	\$ 250,884	0.385	0.00			20.0
					LF	40	\$ 64,860	20,363	\$ 264,791	0.406	0.00	1,903	730	20.0

Fig. 2: Best solutions by system type

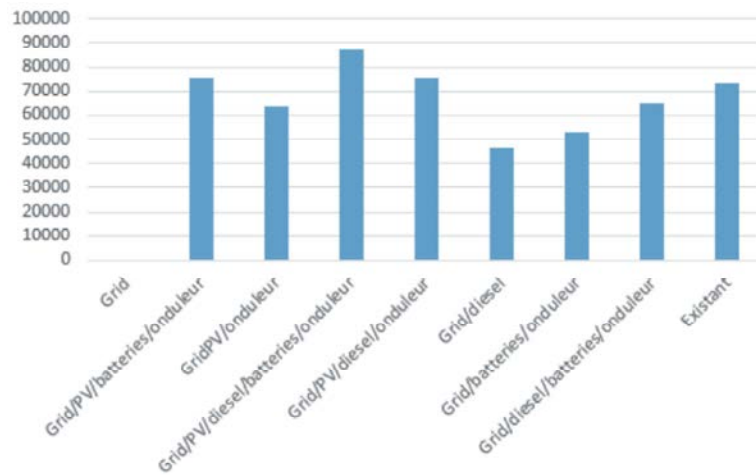


Fig. 3: Initial cost of systems in \$

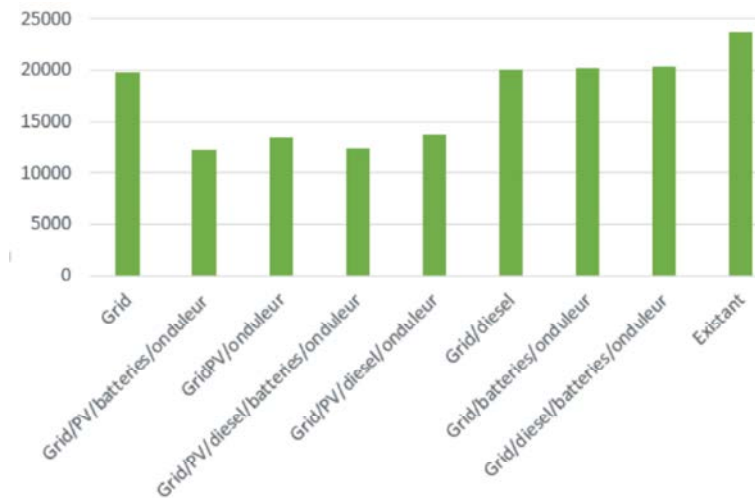


Fig. 4: Operation and maintenance cost of the systems in \$

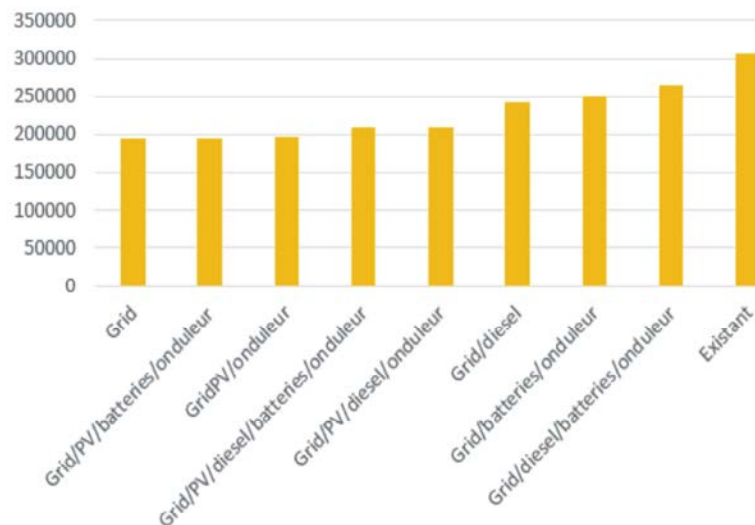


Fig. 5: Total life cycle cost of systems in \$

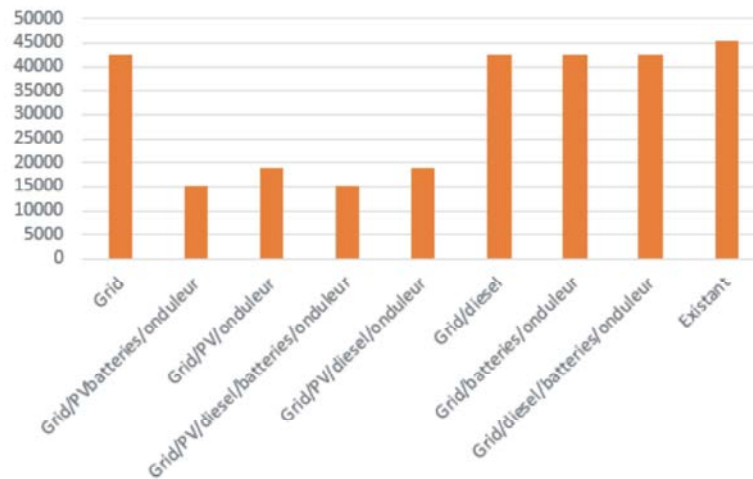


Fig. 6: Pollution emitted by the systems in kg

The results show that the system with the optimal Total Life Cycle Cost (TLCC) is the system with grid power alone with a TLCC of \$194312, after we have the hybrid systems (Grid/ PV/ batteries/ inverter), (Grid/ PV/ inverter), (Grid/ PV/ diesel/ batteries/ inverter), (Grid/ PV/ diesel/ inverter), (Grid/ disel), (Grid/ batteries/ inverter), (Grid/ diesel/ batteries/ inverter) and the existing system with respective TLCCs of \$ 194835, \$ 196098, \$ 204098, \$205361, \$ 238291, \$250884, \$250884 and \$ 280783 i.e., an increase of \$523, \$1786, \$9786, \$11049, \$43979, \$56572, \$86471 over the optimal system respectively.

Figures 5 and 6 show the total life cycle costs and total pollution emitted annually, respectively.

The histogram in Figure 6 shows that the inclusion of PV in a system reduces the amount of harmful emission emitted by conventional systems. The amount of pollution emitted by the hybrid systems (Grid/ diesel/ batteries/ inverter) and (Grid/ batteries/ inverter) is 42233 kg/year while the amount of pollution emitted by the hybrid systems (Grid/ PV/ batteries/ inverter) and (Grid/ PV/ diesel/ batteries/ inverter) is 15098.8 kg/year. The amount of pollution emitted by the Grid system alone and the hybrid system (Grid/ diesel) is 42254 kg/year while that of the hybrid systems (Grid/PV/ inverter) and (Grid/ PV/ diesel/ inverter) is 19000.9 kg/year. These results show that PV inclusion eliminates 64.24% of pollution emitted by hybrid (Grid/ diesel/ battery/ inverter) and (Grid/ battery/ inverter) systems and 55.03% of pollution emitted by (Grid/ diesel) and grid only systems. It is noted that for the optimization, the system does not operate the generator for this reason we have imposed hours of operation to the generator to see the impact of its doing so we observe an increase on the systems containing the generator.

DISCUSSION

Among all the studied configurations the synergy (Grid/ PV/ battery/ GE and inverter) is less expensive than the previous systems. During the daytime the PV field provides the energy to ensure the load when it will not be able to cover all the load due to the intermittent nature of the solar panels, it is relayed by the network in case of cut of the energy of the network the batteries ensure the interim, before their discharge, the GE takes over. But during the night the grid cut is relayed by the GE only after the discharge of the batteries; in the same way, we see a strong reduction of the pollution emitted by this system compared to the other systems.

Estimation of Consumption Reduction: The results show the evolution of the TLCC of the different systems for the site as a function of GE operating hours including the existing system. These histograms show that the conventional system has a higher TLCC than the other systems which evolves exponentially as a function of the operating hours of GE while that of the hypothetical systems evolves weakly as a function of the operating hours of GE this gives a clear idea of the fuel consumption and its associated costs with the conventional system; the choice of the optimal GE resulted in saving fuel consumption while the introduction of PV in the system reduces the operation of GE and therefore the fuel consumption by the system. Furthermore, the simulation showed that the reduction of the operating hours of the diesel generator could lead to minimizing the dependence on fuel which is essential for its operation, thus reducing the wear and tear and leading to an improvement of the system efficiency. Moreover, the increase of the storage capacity increases TLCC.

Reduction of Pollution Emissions: The addition of PV to power systems contributes significantly to reducing considerably to reduce the harmful carbon emissions by more than (62.53%) of the amount of harmful gas emitted by the existing system. This reduction justifies the overuse of diesel generator in the conventional system. Based on the presented results, the use of battery and PV shares in the conventional system to improve the reduction of harmful emissions; this shows that the upgrade of the conventional system +PV and batteries reduces harmful emissions as well as fuel consumption. However, the 100% PV/battery system has zero emissions and is considered the best system from an environmental point of view.

Technical and Economic Impact: The results show that the hybrid system (Grid/battery/diesel/PV/inverter) offers the best economic and technical properties over the life of the project in contrast to the system (Grid/batteries/GE/inverter) which gives the highest total cost. The results indicate that the increase in battery autonomy implies exorbitant initial costs due to the high capital of the batteries which impacts the CTCV of the system and consequently the ACE, but according to the technological evolution, a deflation of these systems (PV and battery) is in progress which would lead to the hybrid system of proven autonomy to reduce or even eliminate the harmful gases. Furthermore, a comparison with the existing hybrid system shows that the existing diesel generator is not optimally selected before the installation for the same load profile. The results show that the operation and maintenance cost of the PV system is very low compared to other systems but the initial and replacement cost is more expensive. Also, the hybrid system (inverter/grid/battery/GE) +PV is compared with the existing system to see the effects of using such a system on the fuel consumption of the diesel generator, harmful emissions and economic aspects. The results show that the conventional +PV system would reduce fuel consumption and generate less pollution. The operating hours of the diesel generator would also be reduced. It would work less with lower loads, which would reduce the frequency of maintenance, fuel consumption and wear and tear of the system in general, resulting in a reduction of the CTCV. Furthermore, regarding the technological evolution, we are expecting a decrease in the price of PV and battery systems in the future, which supports the idea of implementing highly renewable projects.

Environmental Impact: The results show that diesel and grid systems offer the highest rate of harmful emissions to

the environment. The results show that the diesel and the grid offer the highest rate of harmful emissions to the environment while the 100% PV battery system shows the best environmental property with no harmful emissions to the environment. However, the hybrid system (inverter/grid/battery/GE) +PV shows a less polluting environment. The increase of the energy produced by renewable energy would lead to a reduction of the harmful emissions generated by the system. It is also clear that the reduction of harmful emissions depends on the system configuration and the amount of energy generated by each system.

Choice of the System for the Power Supply of the Site:

The choice of a configuration among all those we have simulated for the power supply of the site will be done essentially based on the life cycle cost of the system on the amount of greenhouse gases emitted by the system and its sensitivity to the cost of a liter of diesel, but also its capacity to provide a continuous and reliable power supply. From the discussions, the synergy (Grid/PV/diesel/24 batteries/inverter) seems to be technically and economically the best system. To power our site with a hybrid (Grid/PV/diesel) +battery system, we need:

- A photovoltaic field of 39420 Wp;
- A 12.5 kVA diesel generator, to be replaced once;
- 24 batteries of 2 V 1070 Ah, to be replaced twice;
- A 15 kVA hybrid inverter, to be replaced once.

CONCLUSION

The inclusion of renewable energies in the conventional system has the performance of the system which minimizes the dependence on fossil fuels and eliminates dependence on fossil fuels and eliminates more than 68.9% of the harmful emissions emitted by the conventional system. Also, the analysis on the CTCV of the project shows that the inclusion of PV in the system and the choice of the optimal Genset allows a saving of \$108, 557 or (62539687.7 FCFA) on the CTCV and \$0.146/kWh or (84.11 FCFA/kWh) on the ACE.

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