World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:9, No:2, 2015

Optimal Design of a PV/Diesel Hybrid System for Decentralized Areas through Economic Criteria

D. Tsuanyo, D. Aussel, Y. Azoumah, P. Neveu

Open Science Index, Energy and Power Engineering Vol:9, No:2, 2015 publications.waset.org/10001101.pdf

***Abstract*—**An innovative concept called “Flexy-Energy” is developing at 2iE. This concept aims to produce electricity at lower cost by smartly mix different available energy sources in accordance to the load profile of the region. With a higher solar irradiation and due to the fact that Diesel generator are massively used in sub-Saharan rural areas, PV/Diesel hybrid systems could be a good application of this concept and a good solution to electrify this region, provided they are reliable, cost effective and economically attractive to investors. Presentation of the developed approach is the aims of this paper. The PV/Diesel hybrid system designed consists to produce electricity and/or heat from a coupling between Diesel Diesel generators and PV panels without batteries storage, while ensuring the substitution of gasoil by bio-fuels available in the area where the system will be installed. The optimal design of this system is based on his technical performances; the Life Cycle Cost (LCC) and Levelized Cost of Energy are developed and use as economic criteria. The Net Present Value (NPV), the internal rate of return (IRR) and the discounted payback (DPB) are also evaluated according to dual electricity pricing (in sunny and unsunny hours). The PV/Diesel hybrid system obtained is compared to the standalone Diesel Diesel generators. The approach carried out in this paper has been applied to Siby village in Mali (Latitude 12 ° 23'N 8 ° 20'W) with 295 kWh as daily demand. This approach provides optimal physical characteristics (size of the components, number of component) and dynamical characteristics in real time (number of Diesel generator on, their load rate, fuel specific consumptions, and PV penetration rate) of the system. The system obtained is slightly cost effective; but could be improved with optimized tariffing strategies.

***Keywords*—**Investments criteria, Optimization, PV hybrid, Sizing, Rural electrification.

I. INTRODUCTION

ELECTRIFICATION rate in Sub-Saharan rural areas is less than 14% [1], Over the two past decades, the awareness of the sustainable development notion and the necessity to supply reliable and cost effective electricity to rural areas have promoted the development of hybrid energy systems, Among them, a new concept on hybrid system called “Flexy-Energy” was developed [2]. In fact, despite the drastic drop of photovoltaic module cost during the last decades (around 1.5 €/Wp) [3], the necessary capital for the installation of an autonomous photovoltaic system is still high in Sub-Saharan Africa compared to the average living cost. The batteries included in this system have not only negative environmental impact, but can also absorb more than 40% of the total installation cost. However, with higher solar irradiation (more than 5.5 kWh/m²/day), solutions to integrate massively photovoltaic systems have been explored. PV/Diesel hybrid system could be a good solution to be provided. This solution has been studied particularly through ‘Flexy-Energy’ concept to make it more reliable, cost effective and attractive to investors**.**

II.“FLEXY-ENERGY” CONCEPT AND HYBRID PV/DIESEL MODELING

A. The “Flexy Energy’ Concept, Application to PV Hybrid System

The "Flexy Energy" concept can be defined as an original approach to produce sustainable electric, thermal and / or mechanical energy by optimizing not only the combination of several different origins energy sources available in a given site, but also the management of production and loads to feed through intelligent systems. As previously mentioned, an application of this concept in sub-Saharan zone, consists in a photovoltaic solar generator coupled with several diesel generator linked in parallel which will be eventually fueled with local biofuel and this without energy storage in batteries. The advantage of the uses of several diesel Diesel generators is that each one can be started or stopped according to the load profile. And loads are managed by dividing them into critical, secondary and controllable loads. The behavior of this system without batteries has been strongly studied to perform his reliability [4]. Fig. 1 presents the overall PV/Diesel hybrid system to be designed. A techno economical design of this system requires physical model and necessary investment criteria.

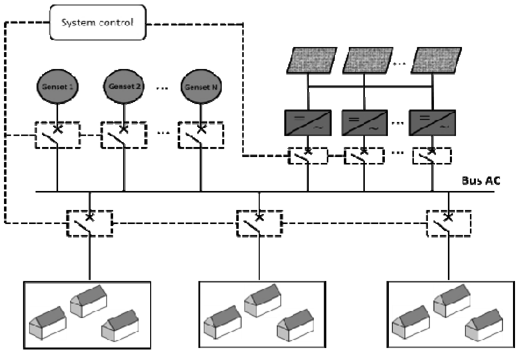

Fig. 1 Overview of a PV/Diesel hybrid system to be designed

B. Physical Model of PV Hybrid Systems

This section displays the physical model of a typical flexy-

D.Tsuanyo is with both Institut International d’Ingénierie de l’Eau et de l’Environnement /LESEE, 01 BP 594 Ouagadougou 01, Burkina Faso and Université de Perpignan Via Domitia /PROMES-CNRS, Tecnosud, 66100 Perpignan, France (e-mail: david.tsuanyo@2ie-edu.org or david.tsuanyo@promes.cnrs.fr).

energy hybrid solar PV/Diesel system. This assumes a thorough knowledge of not only the components of such a system but also their functioning.

When several Diesel generators operate in parallel, the whole PV/Diesel hybrid system is subject to two main requirements to ensure its reliability; they are:

- The stability of the frequency and voltage at any point of the electrical grid [5]. To ensure this, one approach is to use a single diesel generator (master) to set the frequency and leave the other diesel generators (slaves) operate at a constant load.
- During high PV generation and low load periods, there is a possibility of reverse power flow, and consequently voltage rise in the low voltage feeder [4], [6], [7]. The use of several generators partially solves this problem. And to avoid it completely, we notice the necessity to implement the dispatchable loads and/or controllable inverters.

According to these specifications, the following operational strategy is prescribed for the control of PV/Diesel hybrid system without battery storage as described by the flexy-energy concept:

- There is at least one diesel generator running at each moment.
- If the solar production is higher than demand, two solutions are possible:
- ✓ The dispatchable loads should be supplied by the system for the plant operation optimization
- ✓ Or the solar penetration rate must be reduced by shutting down some controllable inverters.
- No Diesel generator should operate at lower than 30% of its rated power.

Input Data

Hourly solar irradiance and electrical demand are supposed known and are considered as the optimization parameters of the hybrid system.

The case study chosen for this paper is the data from Siby village-Mali (Latitude 12 ° 23'N 8 ° 20'W). Tables I and II present respectively technical and economical parameters of the system.

Energy Flux Balance [8]

The hybrid system comprises PV panels characterized by the total power $\dot W_{peak}$, N_{inv} DC/AC inverters of a capacity $\dot w_{inv}$ for each (with a total power of $\dot W_{inv}$) and N_D Diesel generators of capacity $\dot w_1, \dot w_2, \cdots, \dot w_{N_D}$ (with a total power of $\dot W_D$). As the system is designed for supplying the whole electrical load ($\dot W_u$), energy balance writes:

$$\dot W_{inv}(t) + \dot W_D(t) - \dot W_u(t) = 0 \tag{1}$$

where $\dot W_{inv}$: electrical power supplied by the Ninv inverter (kW); $\dot W_D$: electrical power supplied by the ND Diesel generators (kW)

The solar electricity production can be expressed according to the peak power of the panels $\dot W_{peak}$, the efficiency of the Inverter (η_{inv}) and a lost factor F_{PV} takes into account the solar field losses. The power produced by the PV panels writes:

$$\dot W_{pv}(t) = F_{PV}\, \dot W_{peak}\, \frac{I_G(t)}{I_{\text{st}}} \tag{2}$$

This power can be converted by several inverters, each of them characterized by its capacity $\dot w_{inv}$, assumed equal for all of them in this study. As the set of inverters must be designed on the peak load point, we have:

$$N_{inv} = ENT\left(\frac{\dot W_{peak}\, max(I_G)}{\dot w_{inv}}\right) \tag{3}$$

From (1) and (2), Diesel production can be then deduced for each hour:

$$\dot W_D(t) = \dot W_u(t) - F_{PV}\, \eta_{INV}\, \dot W_{peak}\, I_G(t) \tag{4}$$

As for inverters, this power can be produced by one or several Diesel generators of capacity $\dot w_j$:

$$\dot W_D(t) = \sum_{N_D} \delta_j(t)\, \dot w_j \tag{5}$$

where we introduce the load factor $\delta_j(t)$, which will vary during time, and are bounded by 0 (Diesel generator off) or 1 (full load). This factor is important because hourly fuel consumption is deeply linked to it [9].

For the economic analysis performed in the next section, several quantities are required about the Diesel generators dynamic operation and are studied below: load ratio, service duration for each Diesel generator and total fuel consumption.

Optimal Management for Diesel Generators [8]

For a Diesel generator, the hourly fuel consumption approximately depends linearly on the load factor [10].

$$\dot f = (f_0 + f_1\,\delta)\,\dot w_D \tag{6}$$

with $\dot f$:fuel consumption, often expressed in (L/h); f_0, f_1: constants available from literature or experiments (L/kWh)

Notice that (6) leads to higher hourly consumptions (in L/h) when Diesel generator operate at weak loads [11]:

$$f = \frac{\dot f}{\delta\, \dot w_D} = \frac{f_0}{\delta} + f_1 \tag{7}$$

Hence, it is interesting to investigate the optimal management of the Diesel generators in view to minimize the fuel consumption. If the size of each is $\dot w_D$, the number of required Diesel generators can be expressed according to the maximum electrical demand, as the system must supply it, even if no sun is available (night or cloudy days):

$$N_D = ENT\left(\frac{max(\dot{W}_u)}{\dot{w}_D}\right) \tag{8}$$

The fuel consumption and the power load to be provided by the Diesel generators at time t write:

$$\dot{W}_D(t) = \dot{w}_D \sum_{N_{on}(t)} \delta_j(t) \tag{9}$$

$$\dot{f}(t) = \dot{w}_D \sum_{N_{on}(t)} \left[f_0 + f_1\, \delta_j(t)\right] \tag{10}$$

where $N_{on(t)}$ is the number of Diesel generators running at a time t, $N_{on} \leq N_D$. Therefore, the fuel consumption only depends on $\dot{W}_D(t)$and $N_{on(t)}$:

$$\dot{f}(t) = \dot{w}_D \left[N_{on}(t) f_0 + f_1 \sum_{N_{on}(t)} \delta_j(t)\right] = N_{on}(t) f_0 \dot{w}_D + f_1 \dot{W}_D(t) \tag{11}$$

Equation (11) shows that minimizing the number of running Diesel generators at each hour will minimize the fuel consumption. As a consequence, $N_{on\,(t)}$ could be chosen as:

$$N_{on}(t) = \left\lceil \frac{\dot{W}_D(t)}{\dot{w}_D} \right\rceil \tag{12}$$

Notice that this choice also minimizes the average operating time of the Diesel generators, and consequently the maintenance and replacement costs of these units (see next section). As we work on hourly basis, the daily average operating time $\overline{T}$ for each Diesel generator simply writes:

$$\overline{T} = \sum_{24} N_{on}(t) \times \Delta t \Big/ N_D = \sum_{24} N_{on}(t) \Big/ N_D \tag{13}$$

Although that $\delta_j(t)$ does not impact neither the fuel consumption (11), nor the operating time (12), it is preferable to work at maximum possible load for each Diesel generator. This implies that all operating Diesel generators could run under the same load $\delta(t)$, deduced from (10):

$$\delta(t) = \dot{W}_D(t) / \left(N_{on}(t)\, \dot{w}_D\right) \tag{14}$$

III. ECONOMIC CRITERIA

To establish a real balance between technical requirements and relevant economic viability, the integration of the two steps into a single process (techno-economical design) could allow directly a cost effective designing. Numerous economic criteria exist and among them, five have been selected to ensure the cost effectiveness and investors attractiveness of the system designed. They are the Life Cycle Cost, the Levelized Cost of Energy, the Net Present Value, the Internal Rate of Return and the Discounted Payback period methods.

A. The Life Cycle Cost and Levelized Cost of Energy Methods

Life cycle Cost consists to evaluate all expenses (investments, maintenance, operation and replacement) that occur during the life of the system in which are subtracted all revenues generated by the residues at the end of the project. It writes

$$LCC = C_I + USf(i,a,d)\left[C_M + C_O\right] + USf(i,a',d)\,C_R - PWf(i,a,d)S \tag{15}$$

The Levelized Cost of Energy is used to compare different technologies:

$$LCOE = \frac{LCC}{US_f(i,a,d)W} \tag{16}$$

The investment, maintenance, operation, replacement costs and salvage value vary with the size of the system.

B. The Net Present Value Method [12]

Assuming that cash inflows have the same value each year during the lifetime of the project,

The Net Present Value writes:

$$NPV = US_f(i,a,d).I - LCC \tag{17}$$

where cash inflows I (in €/year) is obtained by multiplying the kWh selling price during each day by the electric energy consumed during such day. It writes:

$$I = N.\rho.E \tag{18}$$

with ρ: Electricity selling price (€/kWh), E: Energy consumed (kWh/day). N: Number of the operating days per year. Equation (17) yields:

$$NPV = US_f.\rho.N.\sum_{t=1}^{24} W_u(t) - LCC \tag{19}$$

W_u is the electrical demand at each time step of the day in kW

C. The Internal Rate of Return Method

The IRR of an investment is the discount rate at which the net present value equals zero. It represents the minimum discount rate which can ensure the profitability of the project.

$$IRR = i_r^* \text{ such as } NPV\left(\left(CF_j\right), i_r^*, n\right) = 0 \tag{20}$$

An investment is considered acceptable if its IRR is greater than an established discount rate (or WACC, MARR, etc.). The higher a project's IRR, the more desirable it is to undertake the project.

IRR should not be used to range mutually exclusive projects, but only to decide whether a single project is profitable or not. While computing IRR, there is sometimes potential for multiple IRRs [12]-[14].

D. The Discounted Payback Period Method

These methods are widely used when liquidity is an important criteria to choose a project, especially for projects which investment costs are a limiting factor [12], [15]-[16]. The project with a shortest payback period has less risk than the project with longer payback period, so payback methods are measure tools of investment risk. They can be also quite useful when comparing similar investments. The Discounted payback period method examines the number of years required for a project's earnings to equal the initial investment. In other words, it is the amount of time required for the project to pay for itself. i.e.:

$$n^* \text{ such as } NPV\left(\left(CF_j\right), i_r, n^*\right) = 0 \tag{21}$$

E. Different Cost Models

Investment Costs

For the 3 sub-systems (i.e. PV field, Inverter and Diesel generators), specific investment cost in (€/kW) is expressed according to the system capacity (in kW) by a power law:

$$c_{I,j} = a_i \, \dot{w}_j^{-b_j} \text{ (€/kW)} \tag{22}$$

where aj and bj are 2 positive constants coming from statistical analysis of observed costs, and available from literature or data base [17]. Investment costs then writes:

$$C_I = a_{PV}\left(\dot{W}_{peak}\right)^{1-b_{PV}} + N_{inv} a_{inv}\left(\dot{w}_{inv}\right)^{1-b_{inv}} + N_D a_D\left(\dot{w}_D\right)^{1-b_D} \tag{23}$$

Maintenance Costs

Solar System (PV Panels + Inverters)

It corresponds to the panels cleaning, landscape maintenance (grass moving) and electronics supervising. It is generally taken as a percentage m_{solar} of the investment cost annualized on the project lifetime [18]:

$$C_{M,solar} = m_{solar}\left(C_{I,PV} + C_{I,inv}\right) UCRf(a,d) \tag{24}$$

where UCRf is the Uniform Capital Recovery factor given by:

$$UCRf\ (a,d) = a\,(1+a)^d / (1+a)^d - 1$$

Diesel Generators

Apart from the general maintenance (drain, change of cooling water and oil filter, sparkling plug …), the most critical points for the maintenance of diesel generators are Diesel starters, due to the multiple starts/stops.

Maintenance cost of the Diesel generators is related to their annual operating time. The hourly maintenance costs in €/h, is expressed by a linear law of the size [17]:

$$c_{m,D} = m_D + n_D \, w_D \tag{25}$$

Thence, annual maintenance cost writes:

$$C_{M,D} = N \sum_{j=1}^{N_D} c_{m,D} \, T_j \tag{26}$$

with N: number of annual operating days.

Operating Costs

Only Diesel generators have operating costs, related to the fuel consumption f. It writes:

$$C_{O,D} = N \sum_{t=1}^{24} c_f \, \dot{f}(t) \tag{27}$$

with cf: fuel price (€/L)

Replacement Costs

The replacement costs appear periodically, the period being the life time of the component. Assuming that same technology is used when replacement occurs, the replacement cost is equal to the investment cost:

$$C_{R,j} = C_{I,j} \tag{28}$$

Salvage Value

The salvage value is evaluated through the ratio of the remaining lifetime d'j at the end of the project and the lifetime dj of the components:

$$S_j = C_{I,j} \frac{d'_j}{d_j} \tag{29}$$

d'j can be expressed according to the number Nr,j of replacements during the project:

$$\text{Nr,j} = ENT\left(d/d_j\right) \tag{30}$$

Using (29) the remaining lifetime for component j writes:

$$d'_j = d_j - \left(d - d_j \, N_{r,j}\right) \tag{31}$$

Thence, the salvage value of component j becomes:

$$S_j = C_{I,j}\left[1 - \left(d/d_j - N_{r,j}\right)\right] \tag{32}$$

IV. OPTIMIZATION PROBLEM

A. Objective Function and Constraints

Through the physical model, there are 3 optimization variables $\dot{W}_{peak}, \dot{w}_{inv}, \dot{w}_D$. These 3 variables are sufficient to completely design the system: the number of the required inverters is determined by (3). The required power for the Diesel generators is given by (5). Thence, (8) and (9)-(14) allow evaluating the number of Diesel generators N_D, the daily fuel consumption, the average daily operating time and all the load ratios corresponding to an optimal management of the Diesel generators.

One obtains then the following optimization problem without any constraint (except the fact that all variables are positive): $Min\left(LCC\left(\dot{W}_{peak}, \dot{w}_{inv}, \dot{w}_{D}\right)\right)$

B. Resolution Method

Optimization is performed through Genetic Algorithm available in the open source Scilab software and refined by a quasi-newton method in order to be as near as possible to the optimal solution. The next section presents the results obtained

V. RESULTS AND DISCUSSION

The calculations show that Siby can be supplied in electricity by a PV/Diesel hybrid system characterized by a PV array of 19 kWp, an inverter of 18 kW and 3 Diesel generators of 7.2 kW each. Fig. 2 presents the state of electricity production during one day at which one can see that total electricity production equals the load during the day. The power produced by the solar PV and the Diesel generators vary hourly during the day. The performance of the system such as the number of Diesel generators in operation per hour, their specific consumption and their corresponding load ratio are respectively presented in Fig. 3, Fig. 6, and Fig. 4. The daily fuel consumption is around 82 liters and the average daily operating time is 10 hours. Therefore, the number of Diesel generators in operating, the hourly load rate of the hybrid system, and its specific consumption are obtained for each typical day.

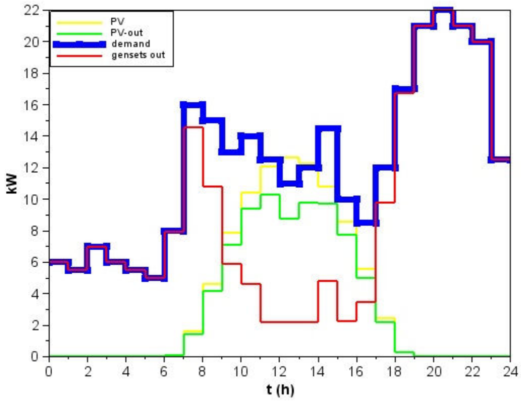

Fig. 2 State of daily electrical production and consumption

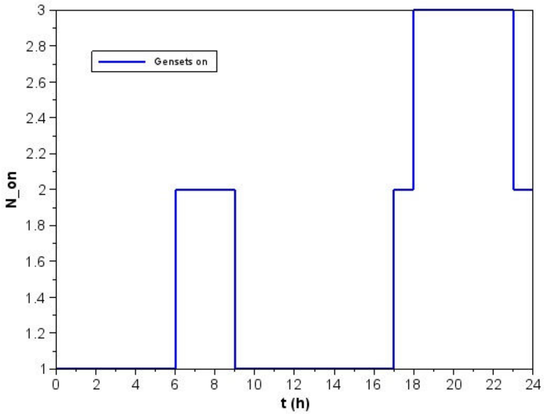

Fig. 3 Number of Diesel generators on

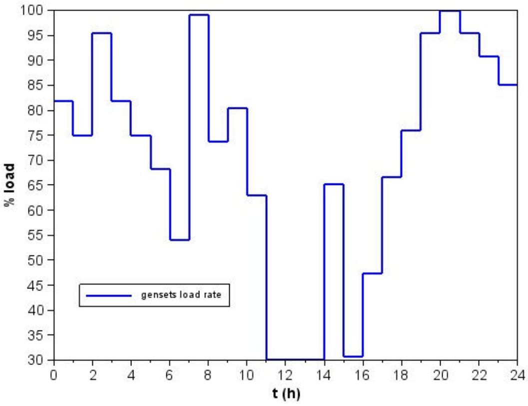

Fig. 4 Hourly load rate of each Diesel generator

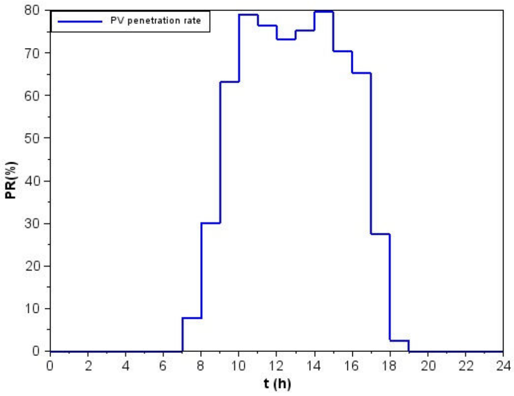

Fig. 5 PV penetration rate

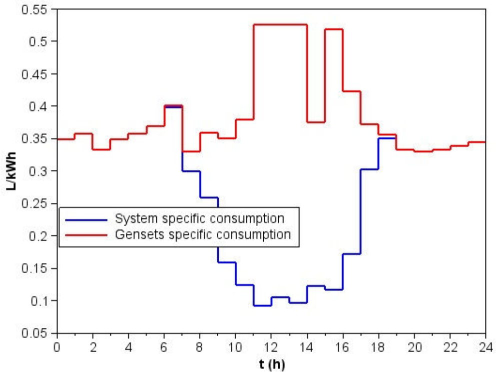

Fig. 6 Diesel and system specifics consumptions

The LCOE of the system is 32 c€/kWh and the LCC is 0.5 M€. With standalone Diesel generators system, the calculations show that it is possible to supply the same site by using 4 Diesel generators of 7 kW each and the LCOE is 37c€/kWh.

For 30c€/kWh as electricity price during the sunny hours and 37 c€/kWh during un-sunny hours, one obtain a positive NPV of 30 k€, an IRR of 18.7% significantly higher than discount rate (8%) and a DPP of 13 years, favorable for a system of 20 years lifetime. Fig. 7 presents the cash flow of the system.

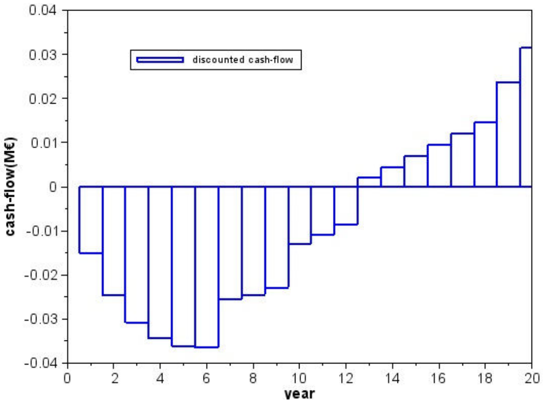

Fig. 7 Discounted cash flow of the system designed

TABLE I
ECONOMICAL PARAMETERS

Parameter	Name	value
a_1	PV acquisition	1.5 €/Wc
b_1	PV acquisition	0.03
a_2	Diesel generator acquisition	2.6 €/W
b_2	Diesel generator acquisition	0.72
a_3	Inverter acquisition	1.4 €/W
b_3	Inverter acquisition	0.27
m	1st Diesel maintenance factor	0.17 €/h
n	2nd Diesel maintenance factor	0.007 €
a	Discount rate	8%
i	Interest rate	4%
C_0	fuel oil cost	0.9 €/liter

TABLE II
SOME TECHNICAL PARAMETERS

PV	
maintenance rate: m_{PV}:	2%
PV life span	25 years
PV lost factor	90%
Inverter	
Inverter lifespan	8 years
Inverter efficiency	90%
Diesel generator	
generator lifespan	30,000 hours
Specific consumption factor f_0	0.246 l/kWh
Specific consumption factor f_1	0.084 l/kWh

VI. CONCLUSION

In this paper, the physical model and the economic criteria for designing a hybrid PV / Diesel type Flexy Energy were exposed. All this techno-economic study has been applied to design a reliable and cost effective PV / diesel hybrid system for Siby, village in Mali. Optimization of LCC and LCOE constrained reliability of the system was made from genetic algorithms. And the other economic criteria have been evaluated by fixing a dual electricity pricing; in sunny and unsunny hours. From the optimal solutions, optimal technical characteristics of the system (component size and mode of operation) and the values of the various economic criteria are obtained. With demand and global irradiation as optimization settings, this model is applicable to any other site.

ACKNOWLEDGMENT

The research reported in this paper is financially supported by 2iE foundation and The European Union Commission through the "Flexy-Energy" project.

REFERENCES

[1] Y. Sokona, Y. Mulugetta, and H. Gujba, "Widening energy access in Africa: Towards energy transition," Energy Policy, vol. 47, Supplement 1, pp. 3–10, june 2012.

[2] Y. Azoumah, D. Yamegueu, P. Ginies, Y. Coulibaly, and P. Girard, "Sustainable electricity generation for rural and peri-urban populations of sub-Saharan Africa: The 'flexy-energy' concept," Energy Policy, vol. 39, no. 1, pp. 131–141, Jan. 2011.

[3] M. Moner-Girona, R. Ghanadan, A. Jacobson, and D. M. Kammen, "Decreasing PV costs in Africa: Opportunities for Rural Electrification using Solar PV in Sub-Saharan Africa," Refocus, vol. 7, no. 1, pp. 40–45, Jan. 2006.

[4] D. Yamegueu, Y. Azoumah, X. Py, and H. Kottin, "Experimental analysis of a solar PV/diesel hybrid system without storage: Focus on its dynamic behavior," Int. J. Electr. Power Energy Syst., vol. 44, no. 1, pp. 267–274, Jan. 2013.

[5] I. Vechiu, H. Camblong, G. Tapia, B. Dakyo, and O. Curea, "Control of four leg inverter for hybrid power system applications with unbalanced load," Energy Convers. Manag., vol. 48, no. 7, pp. 2119–2128, july 2007.

[6] E. Demirok, D. Sera, R. Teodorescu, P. Rodriguez, and U. Borup, "Clustered PV inverters in LV networks: An overview of impacts and comparison of voltage control strategies," in 2009 IEEE Electrical Power Energy Conference (EPEC), 2009, pp. 1–6.

[7] R. Tonkoski and L. A. C. Lopes, "Impact of active power curtailment on overvoltage prevention and energy production of PV inverters connected to low voltage residential feeders," Renew. Energy, vol. 36, no. 12, pp. 3566–3574, december 2011.

[8] D. Tsuanyo, D. Aussel, P. Neveu, and Y. Azoumah, "Modeling and optimization of off-grid and battery less hybrid PV/Diesel systems," Submitt. Publ.

[9] D. Yamegueu, Y. Azoumah, X. Py, and N. Zongo, "Experimental study of electricity generation by Solar PV/diesel hybrid systems without battery storage for off-grid areas," Renew. Energy, vol. 36, no. 6, pp. 1780–1787, july 2011.

[10] O. Skarstein and K. Uhlen, "Design considerations with respect to long-term diesel saving in wind/diesel plants," Wind Eng., vol. 13, pp. 72–87, 1989.

[11] Y. Azoumah, "Systèmes énergétiques pour une production d'énergie durable: Du concept «Flexy-Energy» à l'optimisation constructale des réseaux de transferts," Habilitation à Diriger les Recherches, Université de Perpignan Via Domitia, Perpignan, 2013.

[12] D. Tsuanyo, P. Neveu, Y. Azoumah, and D. Aussel, "review of economic criteria for energy systems," Submitt. Publ.

[13] H. Kierulff, "MIRR: A better measure," Bus. Horiz., vol. 51, no. 4, pp. 321–329, july 2008.

[14] W. Short, D. J. Packey, and T. Holt, A manual for the economic evaluation of energy efficiency and renewable energy technologies. University Press of the Pacific, 2005.

[15] F. Lefley, "The payback method of investment appraisal: A review and synthesis," Int. J. Prod. Econ., vol. 44, no. 3, pp. 207–224, july 1996.

[16] A. Wambach, "Payback criterion, hurdle rates and the gain of waiting," Int. Rev. Financ. Anal., vol. 9, no. 3, pp. 247–258, 2000.

[17] M. Muselli, G. Notton, and A. Louche, "Design of Hybrid-Photovoltaic Power Generator, with Optimization of Energy Management," Sol. Energy, vol. 65, no. 3, pp. 143–157, february 1999.

[18] C. W. Ajan, S. S. Ahmed, H. B. Ahmad, F. Taha, and A. A. B. Mohd Zin, "On the policy of photovoltaic and diesel generation mix for an off-grid site: East Malaysian perspectives," Sol. Energy, vol. 74, no. 6, pp. 453–467, june 2003.