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Wind Turbines and Biodigesters

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Abstract — *The hybrid systems of renewable energy can contribute in a significant way to the durable development in several isolated areas. This paper discusses an optimization solution of a hybrid system of renewable energy. We consider the example of the combination of two common renewable energy resources namely wind and biomass. We present the estimation of the energetic potential for each considered renewable energy resource that can be extracted from a given site; and then we propose their repartition in order to optimize the exploitation of these available resources while meeting the global specific energy demand.*

The general problem can be formulated as a problem of optimal allocation of limited resources constrained to meet specific demands. We consider a situation where the installed energetic capacity of each resource is continuous. The approach adopted to solve this type uses the simplex linear programming method. We also present some examples to illustrate the proposed technique.

Keywords: Hybrid renewable energetic systems, optimal, wind turbine, biodigester

1 Introduction

The topic of optimizing the integration of renewable energy sources in a complementary way is a very interesting but a challenging one both scientifically and technologically. The general issue of combining renewable energy sources we are considering can be stated as follows. In a specific site, given the capacities of some renewable energy sources and an energetic demand, how to determine the optimal repartition of these energies that meets the demand.

In this study we will consider the combination of two renewable resources such as wind turbine energy and biodigesters. We will address the problem in a case that the energy to be allocated is continuous. Few approaches were proposed to solve this problem with and without taking into account energy storage systems such as batteries, diesel engines, hydrogen, etc. Among these approaches, we can notice linear programming, dynamic programming, genetic algorithms techniques, etc.[1, 2, 3, and 4].Some software for analysis and optimization of hybrid energetic systems has been developed and are actually largely used such as HOMER, SOMES, RAPSIM, SOSIM, etc. [5, 6, and 7]revise some relevant

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papers concerning the simulation and optimization techniques, as well as the tools existing that are needed to simulate and design stand-alone hybrid systems for the generation of electricity.

As proposed in reference [1], we modelled the problem of resource allocation in terms of linear program and solve it with the simplex algorithm. To illustrate our analysis, we provide an example combining wind turbines and biodigesters.

2 Energy resources estimation

2. 1 Estimation of annual wind turbine energy

The following expression can be used to estimate the power generated by a wind turbine[8]:

$$P_{Turbine} = \frac{1}{2} C_P \rho \pi R^2 V^3, \tag{1}$$

where

V is the wind speed,

R the blade radius,

C_P the operating efficiency factor,

ρ the density of air at sea level, which is about 1.2 kg/m^3,

with

$$V = V_0 . (\frac{h}{h_0})^{\alpha} \tag{2}$$

h : The hub height

h_0 : Reference height which is usually 10m

V_0 : The known wind speed at the reference height ($h_0 = 10\ m$)

α : The power law exponent, which is usually taken as 1/7

If we consider a small wind turbine built up in our laboratory with a blade diameter of 3 m and an operating efficiency factor $C_P = 20\%$ at a reference average wind speed of 4.2 m/s, then elevated only at 30 m height, we obtain a wind speed of about 6.97 m/s. This gives an estimated power of about: $P_{Turbine} = 287\ Watts$.

If we assume that the wind turbine produces an expected power of 2190 hours per year, then it would produce about: 628 kWh/year. The swept area of the wind turbine is 7 m2.

2.2 Estimation of annual biogas energy

We use the Chen-Hashimoto model which is given in Ref.[9]to estimate the power generated by a methane digester:

$$P_{bio} = [\ \mathrm{B0}.[1 - (\mathrm{K}/\mu\mathrm{m} - \mathrm{HRT} + \mathrm{K} - 1)\ ].(M0/HRT)].V, \qquad (3)$$

where:

HRT : Hydraulic retention time.

MO : Matter oxidizable.

V :Biodigester volume (m^3).

B : Biological efficiency.

$\mathrm{Q_m}$: Production of methane (m^3/d).

$\mathrm{B0}$: Production potential of methane.

K : Constant of inhibition ($\mathrm{K} = 0.6 + 0.021.10^{0.05}.\mathrm{Mo}$).

$\mu\mathrm{m}$: Kinetic coefficient ($\mu\mathrm{m} = 0.013 * \mathrm{T} - 0.129$).

The expression in Eq.3 can be used to estimate the annual energy produced by a given reactor subjected to given conditions of exploitation. Besides, it can be used to design a reactor given an expected estimate of the energy.

For instances, if we consider a continuous bioreactor of Volume $\mathrm{V} = 4\ \mathrm{m}^3$, volumetric flow rate $\mathrm{Q} = 0.3\, m^3/d$, the hydraulic retention time can be estimated as $\mathrm{HRT} = \mathrm{V/Q} = 13.33\mathrm{days}$. In our regional context, we use the organic fraction of solid waste mixed with the activated sludge in mesophilic condition, with matter oxidizable $\mathrm{MO} = 5\mathrm{g/l}$. The kinetic coefficient can be estimated as, at a temperature25 °C, $\mu\mathrm{m} = 0.013 * \mathrm{T} - 0.129$ and $\mathrm{B0} = 0.1\mathrm{m}^3/\mathrm{kgMO}$; As a consequence, the daily produced energy can be estimated to be about $\mathrm{Q_m} = 0.07\, m^3$. Assuming a functioning of the reactor during 335 days a year, we can estimate the annual production of energy as $\mathrm{E_{bio}} = \mathrm{Q_m}.335 = 23.5 m^3 / year$

The obtained energy can be converted into other forms of energy such as heat, electricity and both. One m3 provides, when converted into electricity, about 10 kWh. If we convert the annual methane production into electricity, we can expect energy of about 235 kWh/year [10].

3 Modelling hybrid systems

We consider the renewable energy resources E_i with the available capacity limit L_i. We need to provide also the unit costs of each resource C_i as well as the global demand D to be met. The general form may be that of a linear programming problem of minimizing a cost function Z_T under given constraints. The problem can be expressed as follows:

$$\min Z_T = C_{wi}\ E_{wi} + C_{bio} E_{bio}$$

$$\left\{\begin{array}{l} \min Z_T = \sum C_i . E_i \\ \sum E_i = D \\ E_i \le L_i \\ E_i \ge 0 \end{array}\right\} \text{ (i = wi, bio)} \tag{4}$$

2. 1 Application

Let's consider two combination examples of renewable energies sources: the wind turbine energy E_{wi} with the limit L_{wi} and the biogas energy E_{bio} with the limit L_{bio}. Let's also provide the unit costs C_i of each energy as well as the global demand D.

These problems have been solved by Linear Programming technique. The optimal repartition of renewable energies and their percentage to participate to satisfy the global demand are presented in Tab.1 and Tab.2.

2. 2 Example for region (A)

According to the data provided in Table.1 corresponding to region (a), the problem can be expressed as follows:

$$\begin{array}{l} \min Z = C_{wi} E_{wi} + C_{bio} E_{bio} \\ \min Z = 0.08\, E_{wi} + 0.1\, E_{bio} \\ E_{wi} + E_{bio} = 90\ (KWh/an) \\ E_{wi} \le 70\ (kWh/an) \\ E_{bio} \le 60\ (kWh/an) \end{array} \tag{5}$$

Table 1: Optimal Energy Repartition

Data			Results	
Energy resource	Unit cost (DA/kWh)	Capacity limit (kWh/year)	Energy repartition(kWh/year)	Repartition in %
E_{wi}	0.08	60	$E_{wi} = 60$	67
E_{bio}	0.1	50	$E_{bio} = 30$	33
D=90(kWh/year)			Min Z= 7.8Da/year	

2.3 Example for region (B)

According to the data provided in Table.2 corresponding to region (b), the problem can be expressed as follows:

$$\min Z = C_{wi} E_{wi} + C_{bio} E_{bio}$$

$$\begin{aligned} &\min Z = 0.6\,E_{wi} + 0.5\,E_{bio} \\ &E_{wi} + E_{bio} = 130\,(KWh/an) \\ &E_{wi} \le 84\,(kWh/an) \\ &E_{bio} \le 100\,(kWh/an). \end{aligned} \tag{6}$$

Table 2: Optimal Energy Repartition

Data			Results	
Energy resource	Unit cost (DA/kWh)	Capacity limit (kWh/year)	Energy repartition (kWh/year)	Repartition in %
E_{wi}	0.6	84	$E_{wi} = 30$	23
E_{bio}	0.5	100	$E_{bio} = 100$	77
D=130(kWh/year)			Min Z= 68Da/year	

2.3 Comments

For the region (A), we obtain the following distribution; wind has the lowest cost, so it is completely consumed. Its capacity is completely used and it participates at 67%. Other resources were used according their lowest cost and capacity.

For the region (B), we obtain the following distribution; biomass has the greatest capacity at the lowest cost. It participates at 77%. Other resource were used at low percentage: 23% wind according to their lowest cost and capacity,

Finally; we notice that the management system works as follows: it initially selects the energy which has the lowest cost until it is completely consumed, then selects the next low cost and son on.

Knowing the characteristics of the energy and of the site enable to sizing the appropriate renewable energy system to be used. Various scenarios have been simulated. In most cases, we have noticed that the equality constraint is very hard to fulfil leading to infeasible solutions. To overcome these cases, we need to release the equality constraint by an inequality constraint.

4 Conclusion

The estimated power and annual energy production for each renewable energy source are directly related to the different parameters. The parameters depend on environmental conditions (wind velocity, temperature), on the design characteristics of each energetic system (rotor diameter and hub height of the wind turbine, peak power, waste, volume of digester, etc.) and on geographical characteristics of the site (latitude, longitude, altitude), in this case, given an estimation of the annual energy production and a cost of each unit of the renewable energy source as well as an annual demand, the simplex algorithm outputs (if possible) the optimal repartition of each renewable energy resource. Upon knowing the energy and the characteristics of the site, we will be able to determine the size of the renewable energy system to be used. Based on various simulations; we find that the management system works as follows: it initially selects the energy which has the lowest cost until it is completely consumed, then selects the next low cost and son on.

References

[1] A.K. Akella, , M.P. Sharma, and R.P. Saini, Optimum utilization of renewable energy sources in a remote area, Renew. Sust. Energ. Rev. 11 (5) 2007, 894–908

[2] D. Manolakos, G. Papadakis, D. Papantonis and S. Kyritsis, A simulation-optimization program for designing hybrid energy systems for supplying electricity and fresh water through desalination to remote areas, Energy, 26 2001, 679–704

[3] M.K. Deshmukha, and S.S. Deshmukhb, Modeling of hybrid renewable energy systems, Renew. Sust. Energ. Rev., 12 (1) 2008, 235–249,

[4] R. Ramakumar, P.S.Shetty, and K. Ashenai, A Linear Programming Approach to the Design of Integrated Renewable Energy Systems for Developing Countries, IEEE Transactions on Energy Conversion, EC-1 (4) 1986.

[5] G Bekele.,and B. Palm, Feasibility study for a standalone solar–wind-based hybrid energ.y system for application in Ethiopia, Appl. Energ., 87 (2) 2010, 487–495.

[6] A. Farret, and M.G.Simoes, Integration of Alternative Sources of Energy, John Wiley & Sons, Inc., 2006.

[7] J. L .Bernal-Agustın, and R. Dufo-Lopez, Simulation and optimization of stand-alone hybrid Renewable energy systems, Renew. Sust. Energ. Rev., 13 (8) 2009, 2111–2118

[8] H. Polinder, M.R. Dubois, and J.G. Slootweg, Generator systems for wind turbines. Proc. of the international conference and exhibition on power conversion, intelligent motion and power quality, Nuremberg. 2003,

[9] W. C. Hu, K. Thayanithy, C. F. Forster, A kinetic study of the anaerobic digestion of ice-cream wastewater. Process Biochem., 37 (9) 2002, 965–971.

[10] R. Coudure, J. Castaing, Bilan de fonctionnement d’une unité de méthanisation de lisier de porc, Journées Rech. Porcine en France, 29 1997, 335-342.

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