«MULTI-OBJECTIVE DESIGN OPTIMIZATION OF A HYBRID PV-WIND-BATTERY SYSTEM »

Dhaker ABBES, André MARTINEZ,

Gérard CHAMPENOIS, Jean Paul GAUBERT

Presented by Dhaker ABBES

Plan

- INTRODUCTION
- DATA SOURCES AND LOAD PROFILE
- HYBRID SYSTEM MODELS
- MULTI-OBJECTIVE OPTIMIZATION PROCEDURE
- RESULTS AND DISCUSSION
- CONCLUSIONS & PERSPECTIVES

INTRODUCTION

Context and motivation

- This work is part of a project "GERENER" supported by the Poitou Charente Region and aiming to develop a hybrid PV-wind-Battery system. It includes energy management taking into account power production and instant consumption user demand.

- Our main research areas are :
  - Modeling & Simulation
  - Control
  - Optimization
    - Optimum production management
    - Minimizing the economic and ecological cost

INTRODUCTION

Problematic

- **Design of stand alone hybrid renewable energy systems is a crucial issue.**

- **In this context, simulation and optimization of these systems have been carried out by a number of researchers and studies.**

- **Our contribution differs from other studies on :**
  Optimization objectives considering a new approach based on Embodied Energy (energy required by all of the activities associated to a production process) in addition with Life Cycle Cost (LCC) and Loss of Power Supply Probability (LPSP).

- **A triple Multi-Objective design optimization is proposed.**

DATA SOURCES AND LOAD PROFILE

Sources

- **In this study, we use half-hourly data from 2002 to 2009 available on the National Wind Technology Center- Colorado (Latitude: 39° North, Longitude: 105° West, Elevation: 1855 meters) web site.**

RENEWABLE ENERGY POTENTIALS OF THE NATIONAL WIND TECHNOLOGY CENTER, COLORADO

Year	Photovoltaic Potential (Kwh/year/m²)	Exploitable* wind Potential (Kwh/year/m²)
2009	1608	1077
2008	1682	1336
2007	1644	1111
2006	1694	1306
2005	1650	948.1
2004	1629	906.5
2003	1636	1109
2002	1702	922.7

* Calculated using wind data speed between 3.5 m/s and 25 m/s

DATA SOURCES AND LOAD PROFILE

Sources

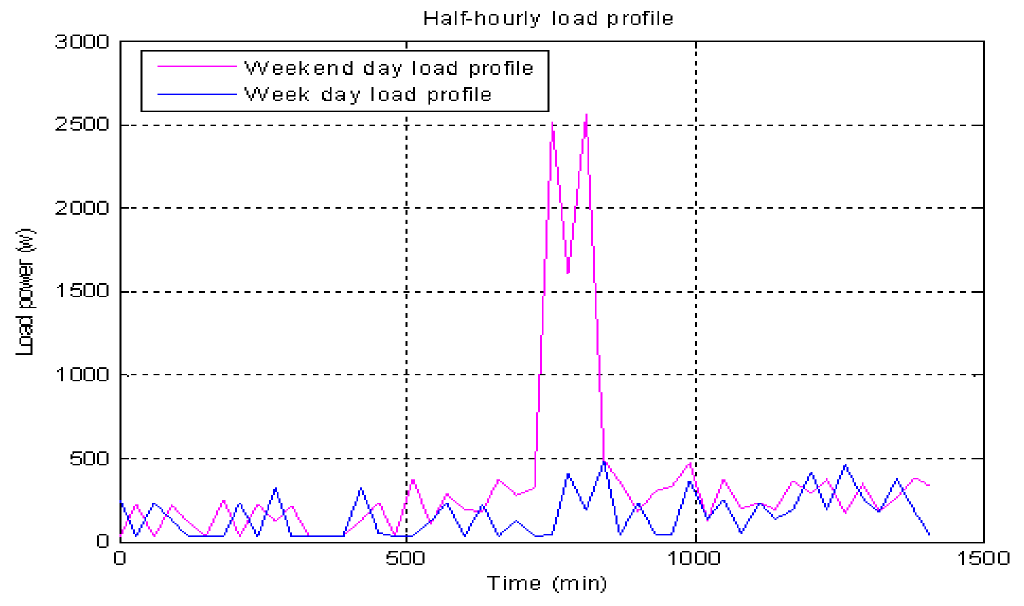
- **Photovoltaic potential is prevailing wind potential. Therefore, for the optimization procedure, data of the year 2009 with the lowest photovoltaic potential will be used.**

- **Experiments have shown that this choice will increase the probability that design meets optimization criteria for all years, especially in terms of unmet load.**

DATA SOURCES AND LOAD PROFILE

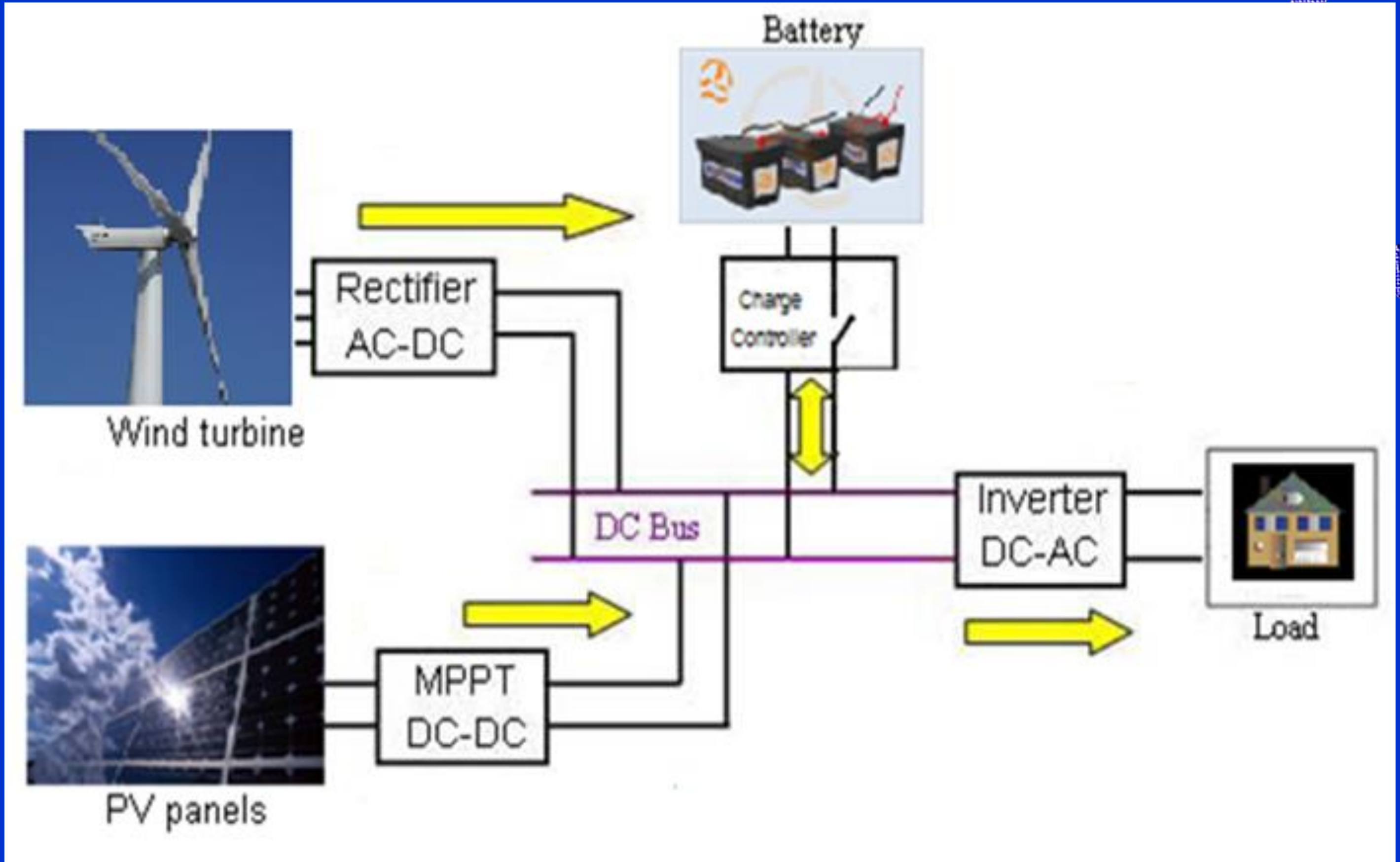
Load Profile

- Real consumption data which were acquired in a typical home of 4 occupants, outside cooking, heating and hot water have been used.
- Averaging acquisition period is half an hour to be in adequacy with energy resources.
- Data correspond to a weekday and a weekend day. These days are reproduced for the whole year.



Half-hourly load profile

HYBRID SYSTEM MODELING



Schematic diagram of Wind- PV hybrid system with battery storage

HYBRID SYSTEM MODELING

Wind Turbine Model

- **Swept area (*Awt*) has been considered as decision variable for wind turbine sizing. Consequently electrical power output of a wind generator is given as follows:**

$$Pwg = Cp \cdot \eta gb \cdot \eta g \cdot \frac{1}{2} \cdot \rho \cdot Awt \cdot V^3 = \eta t . \frac{1}{2} \cdot \rho \cdot Awt \cdot V^3$$

With: ρ [kg/m^3] = Air density $= \frac{353.049}{Ta} e^{\left(-0.034 \frac{Z}{T}\right)}$ and $\eta t = Cp \cdot \eta gb \cdot \eta g$

All parameters are described below:

Z [m] is the elevation and Ta [°C], temperature,

V [m/s]: wind speed,

Awt [m^2]: wind turbine swept area,

Cp: turbine efficiency,

ηgb: gearbox efficiency,

ηg: generator efficiency,

As most wind turbines available today are three-bladed horizontal axis, this technology is considered for our study with an overall efficiency factor ηt = 35 %.

HYBRID SYSTEM MODELING

Photovoltaic Generator Model

- **Output electric power from the photovoltaic generator is given by the following equation :**

$$Ppv = \eta pv \cdot Apv \cdot Ir$$

where

ηpv: power conversion efficiency of the module (power output from system divided by power input from sun),

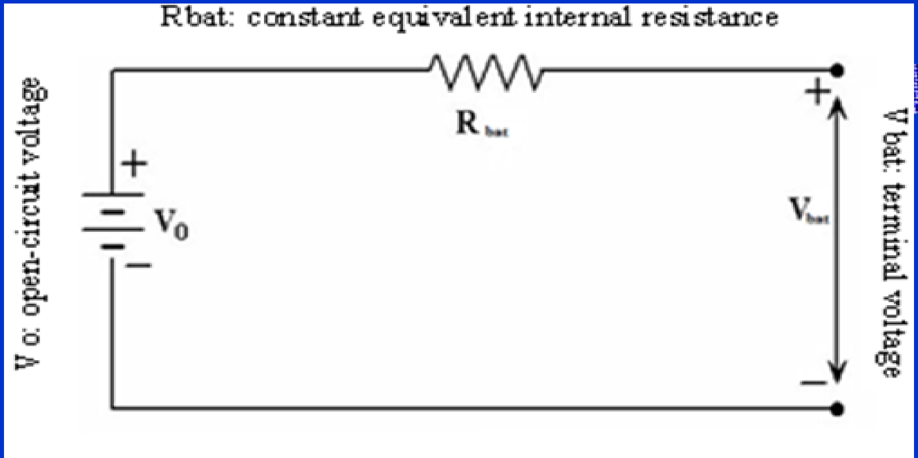
Apv [m^2]: surface area of PV panels,

Ir [W/m^2]: solar radiance.

For this study, a polycrystalline silicon technology has been used with 13% of efficiency ·

Battery

- Lead acid batteries have been considered. A simple but sufficient model has been implemented for optimization method .



Ideal Lead-acid battery model

- For longevity consideration, State Of Charge (SOC) is delimited by the following constraints:

$$SOCmin \leq SOC(t) \leq SOCmax$$

where SOCmax and SOCmin are maximum and minimum allowable storage capacities.

HYBRID SYSTEM MODELING

Battery

- An intelligent switcher manages the connection of batteries, during four phases :

- If batteries' state of charge is below SOCmax (100 % Cn) and Pload <Pres, the excess of energy is stored in batteries.

- If batteries' state of charge is above SOCmin (20% Cn) and Pload>Pres, energy previously stored is used to support lack of energy (battery discharge).

- If batteries' state of charge is equal to SOCmax (100 % Cn) and Pload <Pres, energy is lost.

- If batteries' state of charge is equal to SOCmin (20% Cn) and Pload>Pres, there is an unmet load. In this case, Pload must be equal to Pres by load shedding.

MULTI-OBJECTIVE OPTIMIZATION PROCEDURE

Optimization problem formulation

Object functions:

Minimum → Life Cycle Cost:

$$LCC\,(Apv,\ Awt,\ Cn) = Co + Cinst + PWmaintenance + PWreplacement$$

$$= 942 * Apv + 1877.5 * Awt + 8.4 * Cn + 4712$$

&

Minimum → Hybrid system primary Embodied Energy cost:

$$EE(Apv, Awt, Cn) = 5300 * Apv + 1644 * Awt + 50 * Cn$$

&

Minimum → Loss of Power Supply Probability

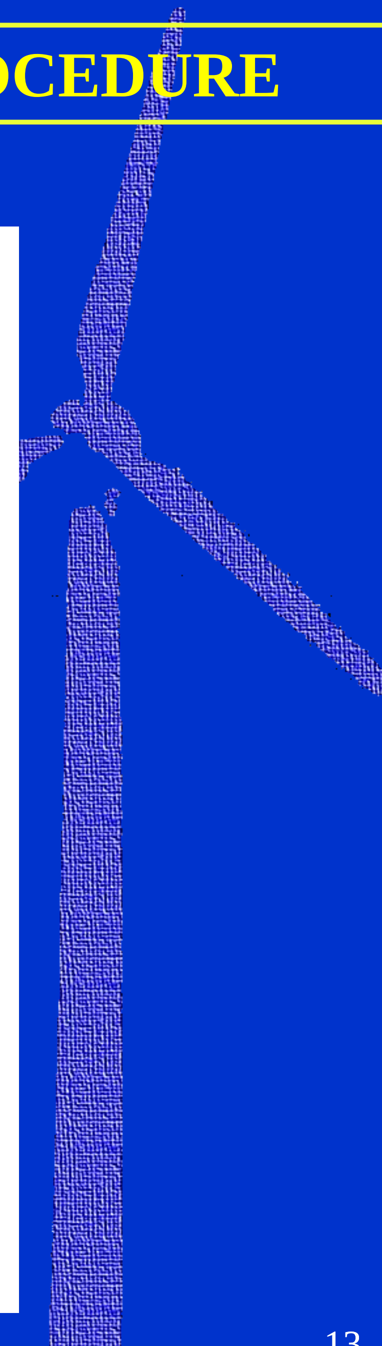
$$LPSP(\Delta t, Apv, Awt, Cn) = \frac{\sum_{t=1}^{T} DE(t, Apv, Awt, Cn)\Delta t}{\sum_{t=1}^{T} Pload(t)\Delta t}$$

Constraints: feasibility for an autonomous residence:

$$Apv\_\min \le Apv \le Apv\_\max$$

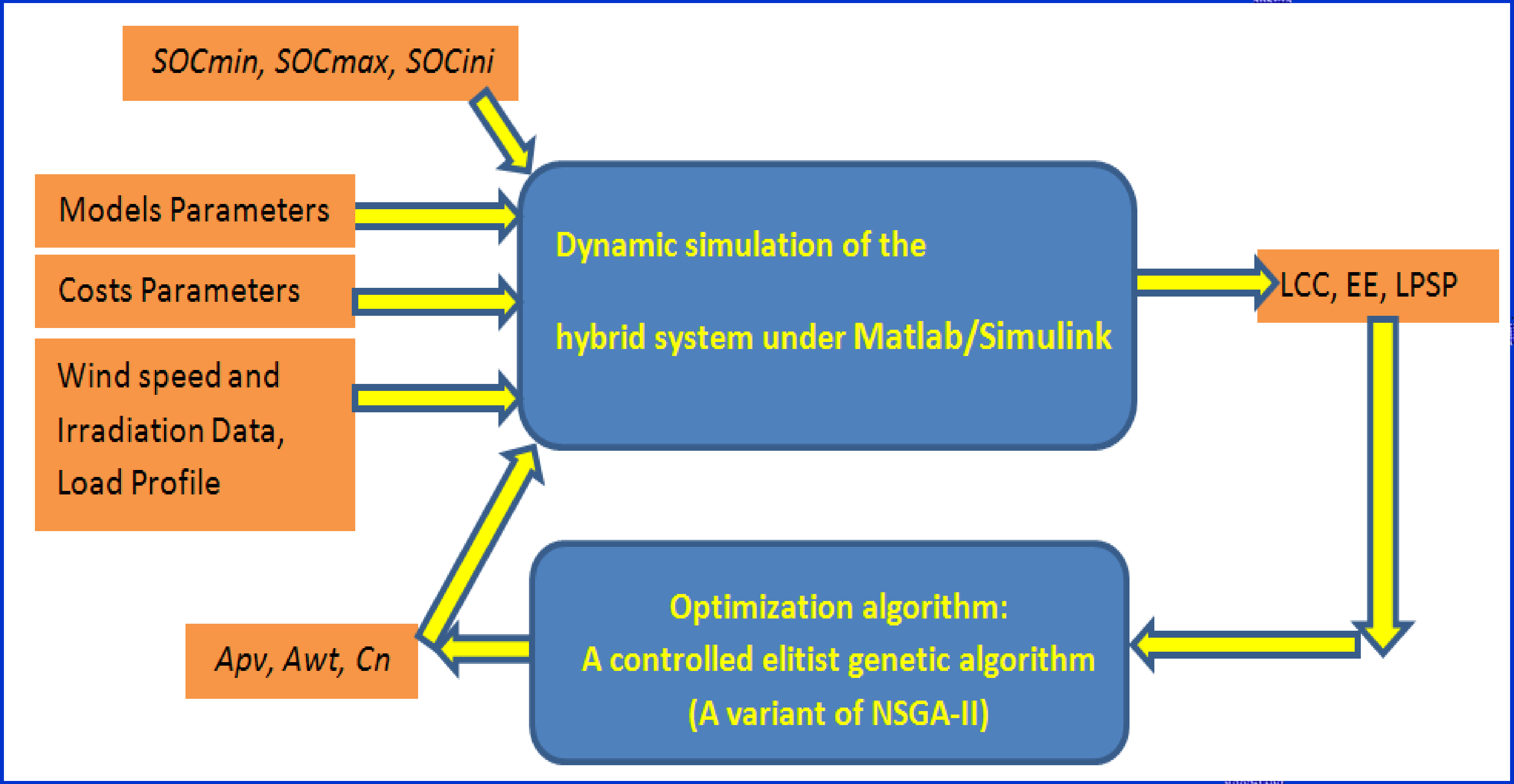
$$Awt\_\min \le Awt \le Awt\_\max$$

$$Cn\_\min \le Cn \le Cn\_\max$$



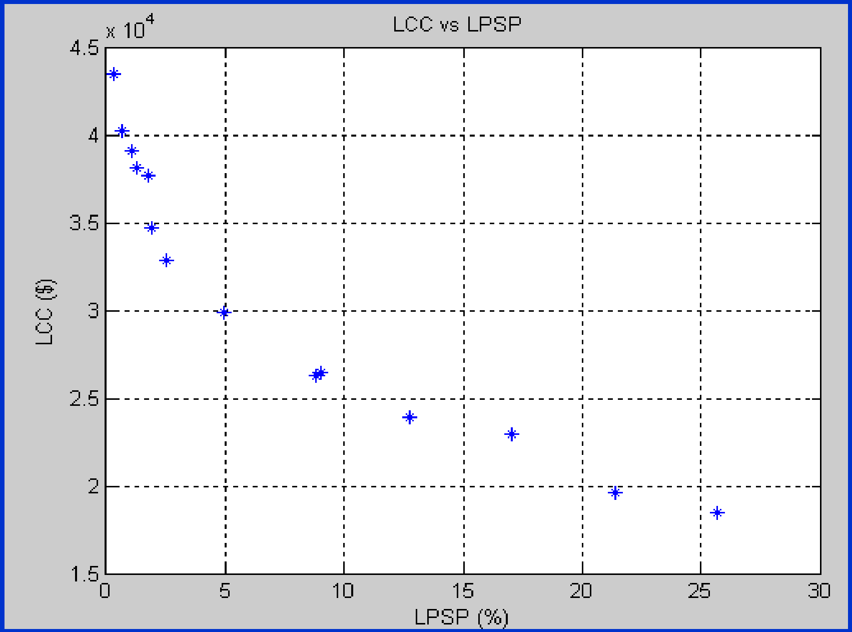
MULTI-OBJECTIVE OPTIMIZATION PROCEDURE

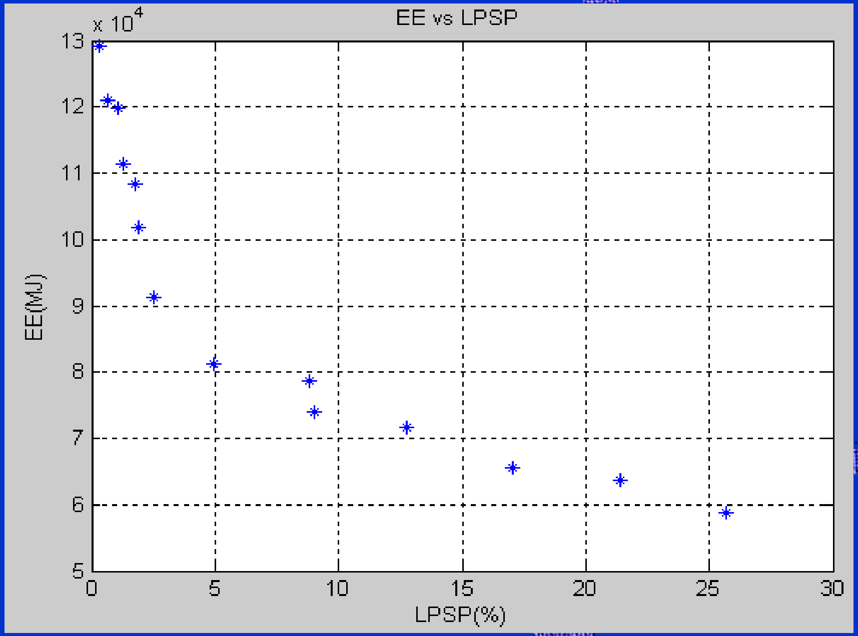
Computational Method and Algorithm



RESULTS AND DISCUSSION

Pareto Front





- The more the consumer tolerates load shedding, the greater the hybrid system is undersized and therefore cheaper in terms of both Life Cycle Cost and Embodied Energy Requirements.
- There is a considerable costs increase between sizing the system to provide 95% of system electrical needs vs. providing 100% of system needs.

RESULTS AND DISCUSSION

Retained Solution

- **We have chosen the solution that satisfies a 5 % LPSP criterion :**

- Photovoltaic modules' installed area *Apv* =12.282m^2, (8 sharp 170 W panels for instance),

- Wind turbine swept area *Awt* =3.015m^2, an Aeromax Engineering (Lakota S, SC) wind turbine has a close swept area of 3.43m^2 with a low LCC,

- Battery bank storage capacity gives *Cn* = 225.591Ah, 4 US 185 Deep Cycle Monobloc Battery 12V 200Ah in series can be installed.

RESULTS AND DISCUSSION

Solution Evaluation

- For all years, our hybrid system provides more than 95% of the electric needs (LPSP<5%),
- User does not have to incorporate another source of electricity into the system,
- There is a considerable excess that needs somewhere to go. It can be used in cooking or in water heating supply.
- A reasonable LCC near 30000$ is obtained and 81332 MJ or 22610 kWh embodied energy is required to reach the sum total of the energy necessary for an entire product life cycle.

CHOSEN SOLUTION EVALUATION

Year	Load Kwh	PV Kwh	Wind kwh	Excess kwh	Unmet load kwh	%Unmet Load (LPSP)
2002	1903	2864	1109	1619	55.32	2.907
2003	1903	2751	1332	1740	71.03	3.732
2004	1893	2752	1098	1517	70.86	3.743
2005	1894	2772	1139	1581	66.34	3.503
2006	1903	2846	1569	2040	45.63	2.398
2007	1898	2762	1334	1751	70.67	3.723
2008	1907	2832	1604	2057	54.69	2.868
2009	1898	2722	1294	1693	89.93	4.738

CONCLUSIONS AND PERSPECTIVES

Conclusions

- A controlled elitist genetic algorithm have been applied to the Multi-Objective design of a hybrid PV-wind-battery system, minimizing, simultaneously, three objectives: life cycle cost (LCC), system embodied energy (EE) and Loss of power supply probability (LPSP),

- Optimization has been insured by a dynamic model of the system under Matlab/Simulink,

- Contrary to single-objective optimization, we have found a set of solutions (14) known as a Pareto optimal set,

- Embodied Energy analysis has shown that batteries are greedy on primary energy requirements.

CONCLUSIONS AND PERSPECTIVES

Perspectives

- It is important to improve batteries manufacturing process and their lifespan, for example by better energy management techniques,

- It would be useful to develop a tool with a Graphical User Interface for hybrid power systems design optimization according to the proposed method. It will help designers to make their decisions more consciously about environmental impact.

ACKNOWLEDGMENT

We would like to thank Region Poitou-Charentes (Convention de recherche GERENER N° 08/RPC-R-003) and Conseil General Charente Maritime for their financial support

Thank You !

Questions ?