Sensitivity Analysis by Using Optimization Technique for Sizing a PV grid Connected Home

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Sensitivity analysis for optimal sizing of a PV grid connected home

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I. Introduction

The purpose of this work is to study the impact of user defined data on the optimal sizing of PV-connected to grid. As the variety of inputs in such type of optimization problem is high, it is interesting to clustering them under hypotheses, and then manages the sensitivity analyses. In the first part three hypotheses was generated due to types of inputs, in the second part a combination of the hypotheses was studied for a defined study case. At the end a brief sensitivity analysis of the sizing PV grid connected system has been presented.

Key words: Sizing multi sources systems, sensitivity analysis, Net present Value, Profitability index.

II. Problem statement

Sizing PV grid connected system (*PVGs*) is based basically upon knowledge of a vast data like (load curves, meteorological information, economic facilities, inverters technologies ...etc) [4]. As found in the state of art there is a lot of commercial software that calculates the size of *PVGs* [5] (like number of PV modules to install in the system, the size of the battery…etc), or it formulate optimization problem depending on user defined data which is applied in this work, the optimization problem was formulated in Mixed Integer Linear programming *MILP* and solved with Ilog CPLEX solver [8]. PV and battery models are described in [1] and [2].

III. Study case

A cogeneration system (multi sources) has (figure1), this system represents a domestic house of 80 m², situated in Lyon (France), and electric energy is supplied by three sources: electrical grid, a group of PV modules, and lead acid battery.

The objective is to find the optimal value of sizing variables: PV module number, battery capacity and grid subscription. In addition to sizing results an intelligent load management that allows the best utilization of all supplying sources was done. Finally an economic study depending on the sources functionality was held, this aims to find out if this installation is profitable or not, by calculating the Net Present Value NPV of cash flows [3] over the study period then find out the profitability index PI. This two variables are defined in equations1 and 2 respectively:

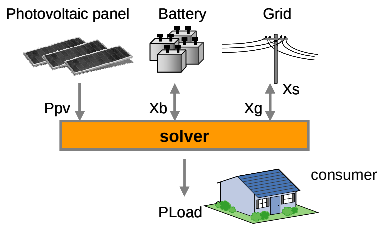

Figure 1 Cogeneration system (Multi sources)

$$NPV_{CF} = \sum_{i=1}^{i=T} \frac{CF_i}{(1+a)^i} - I_{invest} \qquad (1)$$

$$PI = \frac{NPV_{CF} + I_{invest}}{I_{invest}} = \frac{NPV_{CF}}{I_{invest}} + 1 \qquad (2)$$

Where a : the annual interest.

I_{invest} : system Initial cost.

IV. Optimal sizing Hypothesis

Inputs of sizing problem are classified into three major types:

- Technical specification of electrical sources. In other word data sheet information (for example PV module type, DoD% of the battery…etc).
- User data. This one describe the user in particular case, like load curve, solar insulation, outdoor

temperature, possible integration of PV in the building…etc.

- Energy market data. This information includes energy prices (sell and purchase), and the subsidies ratio, annual interest rate.

In order to do the sensitivity analysis, inputs had been handled via group of hypothesis. Inspired from the last mentioned inputs, hypotheses are classified to:

1. Hypothesis of specified user (*HSU*): this hypothesis describes all inputs of specified user (geographical situation, load curve, comfort…etc).
2. Hypothesis of specified sources (*HSS*): This hypothesis describes all technical data retrieved from producers of electrical installed sources.
3. Hypothesis of specified energy market (*HSEM*): In this hypothesis energy market data are defined.

The sensitivity analyses (*SA*) which will be presented later depend on one *HSS* and different *HSU* and *HSEM*.

Starting by the *HSS* a model of photovoltaic of type (Solar-Fabrik SF 150/2A) is used, for reliability issue the system also contains a lead acid battery with depth of discharge rate DoD = 0.30%, while the subscription with electrical grid is levelled to 12 kWh.

The *HSU* describes a domestic load. To establish load management user should define the percentage of controllable load in his/her installation. As can be seen from figure 2 a 288h was created , based on 24h measured consumption, reason to have consumption curve close to reality in lack of real data (actually it represent 12 typical days, each day represent a month). Meteorological data is acquired from [7] for tilt angle of 30°. In present work the only parameter which had been varied in *HSU* is the maximum surface that user could have to install PV modules, so four hypotheses were studied: HSU_60 (maximum surface is 60 m^2), HSU_70, HSU_80 and HSU_90. Figure 3 shows solar insulation and outdoor air temperature in °C used in all *HSUs*

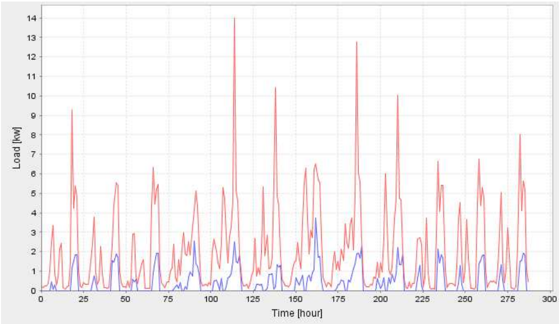

Figure 2 Load curve (red: all over load, blue: controllable load)

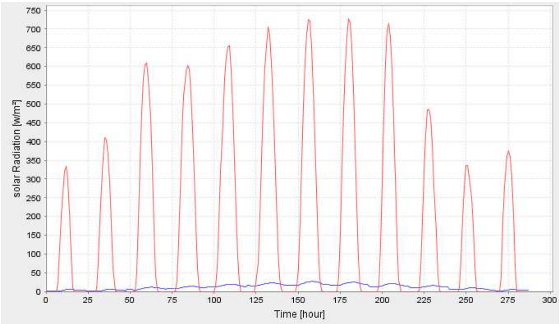

Figure 3 Meteorological data (red solar radiation, blue temperature)

In fact, the most varying hypothesis is the *HSEM*, because it depends on the energy politic of each country, and the strategic planes of energy producers. Therefore end user is interested to have an estimation of the impact of *HSEM* over the sizing variables and profitability index, in this study two *HSEMs* was applied, the first one *HSEM_1* for the impact of varying energy prices, and the second one *HSEM_2* for impact of subsidies given to end user to install his/her *PVGs*.

HSEM_1: in this hypothesis the price of purchase energy from grid (pg) and one's of sell energy to grid (surplus) (ps) were varied, and the subsidy is fixed to zero.

HSEM_2: The energy prices are fixed to tariffs published by (EDF *Energy de France* [6]), while subsidies were varied from 0% to 30% of PV module initial cost, so three hypotheses were taken into the account *HSEM_2_0*, *HSEM_2_15* and *HSEM_2_30* respectively.

Table 1 represent the combination of all hypotheses during the sensitivity analysis.

Study number	HSU	HSEM	HSS
1	HSU_60	HSEM_2_0 HSEM_2_15 HSEM_2_30	HSS
2	HSU_70	HSEM_2_0 HSEM_2_15 HSEM_2_30	HSS
3	HSU_80	HSEM_2_0 HSEM_2_15 HSEM_2_30	HSS
4	HSU_80	HSEM_1	HSS
5	HSU_90	HSEM_2_0 HSEM_2_15 HSEM_2_30	HSS

Tableau 1 Studies and correspondents Hypotheses

V. Sensitivity analysis for sizing variables

This paper focused on the impact of recently mentioned hypotheses over sizing *PVGs* from economic point view (maximize the incomes of the installation throughout 20 years, by encouraging selling surplus to grid, and in the same time minimizing the subscription with the grid operator.

Study 4:

For reason of simplicity results of study 4 (*HSU_80* and *HSEM_1*) have been presented firstly, figure 4 shows module number variation, then capacity of the battery and the subscription level are represented in figure 5 and 6 respectively, while figure 7 show the PI variation. As can be seen from figure 4 if price of surplus is more than 0.2 [€/kWh] the variation has no impact on module number.

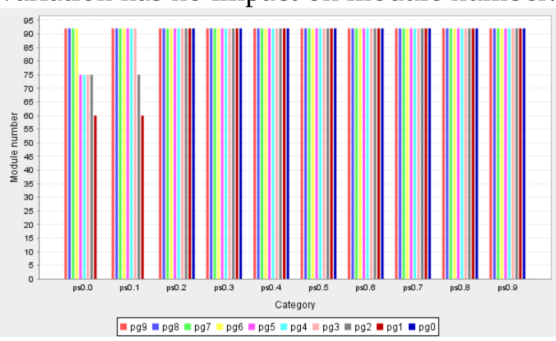

Figure 4 Optimal module number for study 4

That means for ps≥0.2 [€/kWh] it is recommended to use 64 m² (92 x surface of one module) of PV modules, and also increase the subscription with grid operator for low *pgs* (0.1 up to 0.4[€/kWh]), then the big capacity of the battery will ensure reliability, because it will be used later when the solar production sold as surplus to grid (ps is high), at this moment grid energy is kept to supply load directly or by charging the battery (selling and purchase can not happen at the same moment for system design issues). We can see this effect from PI in figure 7, PIs for low *pg* are greater than ones for higher pg when ps is high (ps≥0.5).

A pre-intermediate conclusion of study 4 is that varying energy prices have no big impact on sizing variables but on PI of the *PVGs*.

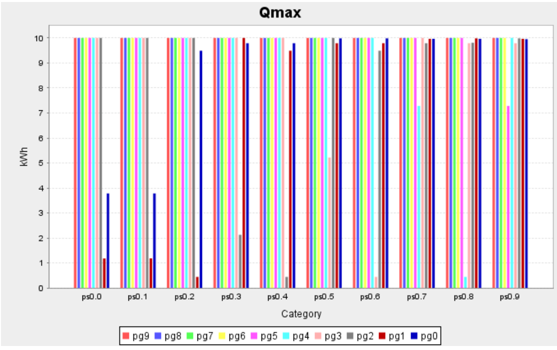

Figure 5 Optimal capacity of the battery study 4

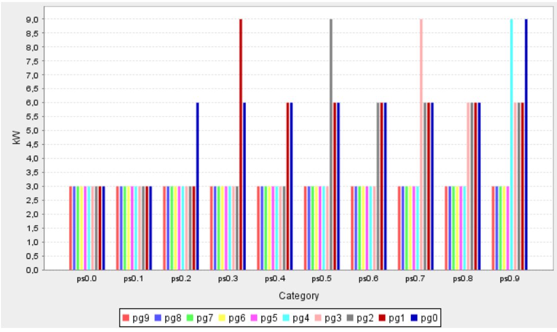

Figure 6 Optimal subscription level with grid operator for study 4

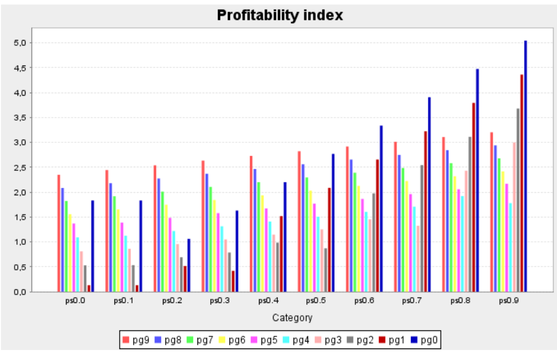

Figure 7 Profitability index for study 4

Studies 1,2,3,5:

In these studies the *HSU* and *HSEM* have been varied as clarified in table 1. Energy prices are fixed to (pg = 0.15 and ps =0.4 [€/kWh]). The Optimizing results had been arranged in one figure for simplicity of interpretation. As can be seen from figure 8, module numbers vary depending on applied *HSU* but it is not changing with different *HSEM_2*.

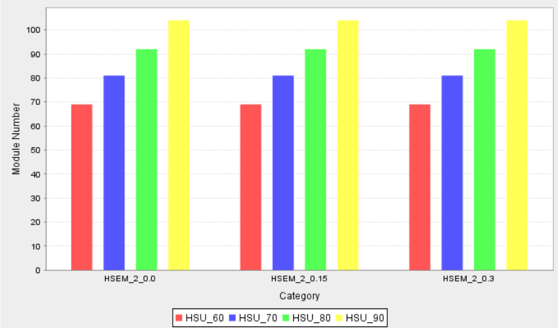

Figure 8 Optimal modules Number with different hypotheses

Same impact was found on battery capacity presented in figure 9:

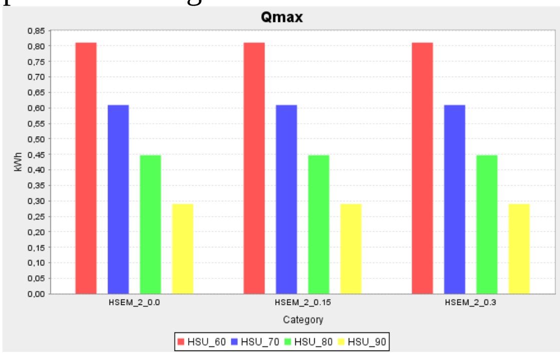

Figure 9 Optimal battery capacity with different hypotheses

In contrast grid subscription is the less sensitive to applied hypothesis as figure 10 shows:

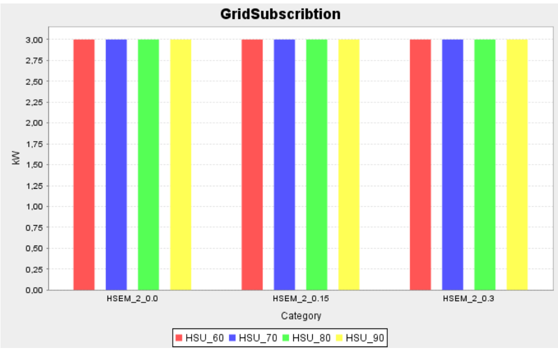

Figure 10 Optimal grid subscription with different hypotheses

The most sensitive to applied hypotheses is PI, as can be seen from figure 11, PI increases when user increase the useful surface, this is justified by the fact that with more surface there will be more panels resulting in more surplus.

From these studies a pre-intermediate conclusion can withdrawn: that sizing is more sensitive to *HSU* than to *HSEM*, while the opposite is true for PI, as represented ing figure 11 for *HSU_80* with *HSEM_2_0.0* installation is not so profitable PI~1 while for *HSEM_2_0.15* and *HSEM_2_0.3* PI is greater than 1 (1.12 and 1.3 respectively).

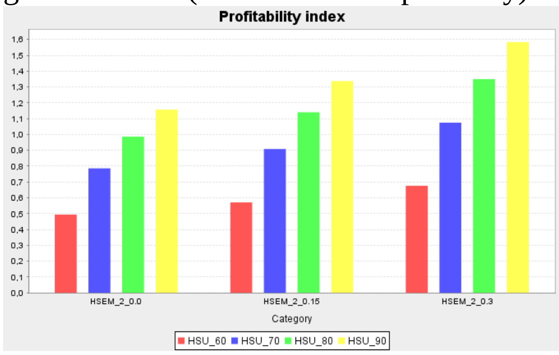

Figure 11 Profitability index PI with different hypotheses

VI. Conclusions and perspectives

This paper focus on the impact of user defined data on the optimal sizing variables in *PVGs*. User data was grouped under three major types of hypotheses, hypothesis of specific sources *(HSS)*, hypothesis of specific user *(HSU)* and hypothesis of specific energy market (*HSEM*). This categorization helps to set up the sensitivity analyses (SA) of sizing variables. The SA was started to show if there is any impact of hypotheses over the optimal solution. Due to the large possibilities in each hypothesis, conclusions can not be completely generics and more works is needed. However, according to the study case: sizing variables is more sensible to *HSU* rather than *HSEM*, in contrast to PI which showed that for same *HSU* the installation is not profitable if there is no suitable *HSEM*.

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