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# OPTIMAL SIZING INTEGRATING POWER MANAGEMENT FOR A MICROGRID WITH STORAGE

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**Abstract.** The paper presents an optimal design process for a microgrid with an industrial load associated to a photovoltaic power plant and a storage unit based on high speed flywheel. The power management is simplified with a fast linear programming algorithm which allows simulating the whole system over a long period of time integrating both operating and sizing loops. The overall design procedure is led by the Efficient Global Optimization that interpolates the objective function with a kriging technique. Then, the optimal sizes for both storage and PV production are found in a reduced number of objective function evaluations.

**Keywords:** efficient global optimization, kriging, linear programming, microgrid, optimal sizing

## INTRODUCTION

With the development of decentralized power stations based on renewable energy sources, distribution networks have progressively included meshed structures [1]. It can be considered as an association of various "microgrids" both consumer and producer that have to be run independently while granting the global balance between load and generation. Adding a storage device allows more flexible operations. The management as well as the sizing of such systems have to be optimized considering environmental (solar, wind conditions) and economic data [2]. The study focuses on a microgrid with an industrial load associated to a photovoltaic power plant (PV) and a storage unit composed of high speed flywheels (FW). In section 1 the problem is introduced and a particular attention is attached to the management procedure that is coupled with the sizing problem. Section 2 gives details about the algorithm that performs the optimal sizing and some results are presented.

## 1. INTEGRATED SIZING/MANAGEMENT OPTIMIZATION

The optimal sizing aims at finding the best values of the PV panels ( $P_{PV}$  in kW) and the flywheel ( $E_{FW}$  in kWh). Given a system configuration with its sizing, an optimal planning tries to find the best operating costs. Thus a compromise has to be found between the operating and the investment cost [2]. A fast Linear Programming (LP) approach estimates the operating cost on a large time scale (i.e. one year) [3]. It minimizes the day by day cost with corresponding prices for the purchased energy ( $C_p$ ) and the sold production ( $C_s$ ) as well as the forecasts for consumption  $P_{load}$  and production  $P_{prod}$  (that depends on environmental features). On a 24 h of time horizon (with a time step of one hour) the goal is to find the best values for the microgrid degrees of freedom  $\mathbf{P}_{ref} = [\mathbf{P}_{st} \ \mathbf{P}_{st-1} \ \Delta \mathbf{P}_{PV}]$  that determine the flows through the meters  $P_p$  and  $P_s$  and finally allow the computation of the cost  $C_i$  for the  $i^{th}$  day as in (1). Given a microgrid size, the investment cost  $C_{inv}$  is computed with prices of the PV panels (2000 €/kW) and of the flywheels (1500 €/kWh) over 20 years of life. Then, bounds for  $\mathbf{P}_{ref}$  are generated depending on the component sizes. The management loop computes the operating cost  $C_{op}$  by summing all daily optimized costs  $C_i$  as shown in Fig 1b. Finally, the Total Cost of Ownership (TCO) related to the microgrid is obtained by summing operational and investment costs.

$$(1) \quad C_i(\mathbf{P}_{ref}) = \sum_{t=0}^{t=24h} C_p(t) \times P_p(t) - C_s(t) \times P_s(t)$$

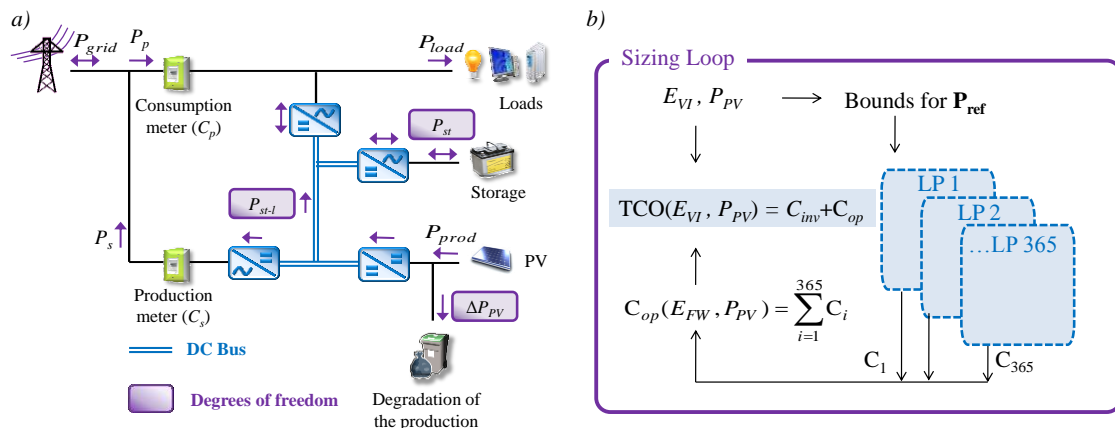


Figure 1: Studied problem - a) microgrid topology - b) integrated sizing/management optimization

## 2. MICROGRID SIZING WITH THE EFFICIENT GLOBAL OPTIMIZATION

A whole year simulation lasts less than one minute with the LP. To avoid a long CPU time and a high number of objective function evaluations the sizing loop is performed using the Efficient Global Optimization (EGO) [4]. This method is based on the interpolation of the objective function with the kriging technique that estimates the function in the unexplored points with probabilistically laws [5]. Starting from randomly chosen test points ( $E_{FW}$ ,  $P_{PV}$ ) the EGO investigates the search space and maximizes the Expected Improvement (EI) criterion (Fig. 2a). This coefficient evaluates the balance between unknown areas and spaces where the objective function appears to be the most interesting (i.e. with the lowest TCO costs). The algorithm stops when the maximum number of objective function evaluations is reached or when there is no improvement of the objective function during a given number of iterations.

Optimizations are performed according to two prices policies. Results are given in Table 1 and compared in each case with a situation "INIT" without flywheel storage and PV production where all the consumed energy is purchased from the main grid. In Scenario1, the electricity is sold at a high price ( $C_s = 10$  c€/kWh) and  $C_p$  is moderate equals to 10 c€/kWh from 10 p.m. to 6 a.m. and 18 c€/kWh otherwise. At the optimal point, there is no storage and  $P_{PV}$  is set to its upper bound (i.e. 500 kW here) to generate a maximum profit. If the purchased cost increases like in Scenario 2 ( $C_p = 16$  c€/kWh from 10 p.m. to 6 a.m. and 26 c€/kWh otherwise) and selling the production is not subsidized ( $C_s = 0$  c€/kWh) adding a storage device becomes interesting with an optimum value at 44 kWh. In the same time the PV capacity is moderate at 282 kW and the self-consumption as well as the storage management allow decreasing the annual electric bill by 13 %. Fig. 2b illustrates the EGO convergence in the case of 10 starting points randomly initialized with a Latin Hypercube Sampling and 30 iterations.

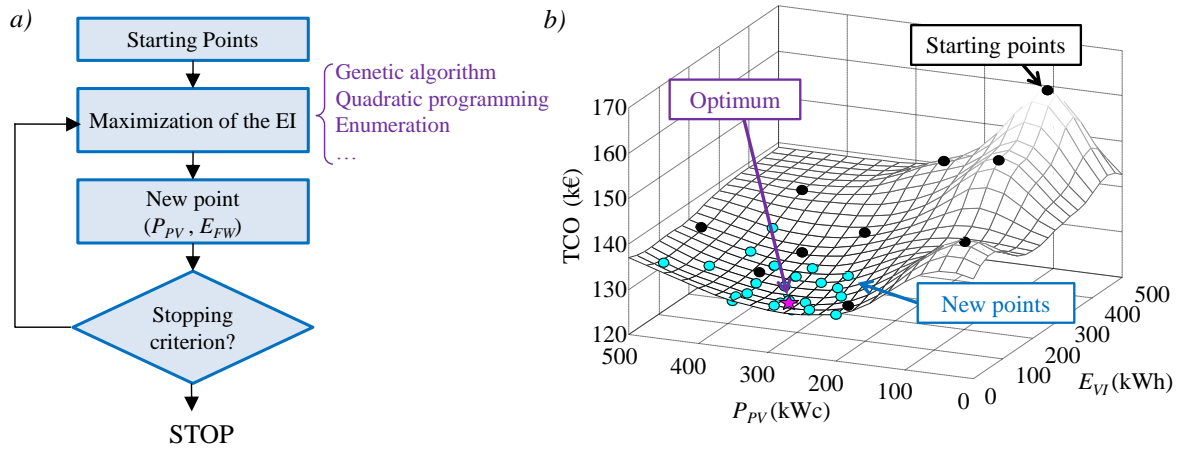


Figure 2: EGO - a) algorithm architecture - b) results obtained under the scenario 2

Table 1. Optimization results: microgrid configuration and annual costs in k€

	Optimal configuration ( $E_{FW}$ , $P_{PV}$ )	FW cost	PV cost	Purchase energy	Sold energy	TOTAL	INIT
Scenario 1	[0 , 500 kW]	0.0	50.0	64.1	24.2	<b>90.0</b>	97.0
Scenario 2	[44 kWh , 282 kW]	3.3	28.1	98.6	0.0	<b>130.0</b>	149.3

## CONCLUSIONS

Based on a simplified power management method sped up by the linear programming, this study has investigated a 2-level optimization process integrating the power flow scheduling and the microgrid sizing. The sizing algorithm based on the EGO allows finding solutions in a reduce number of evaluations (less than 50). The return results strongly depends on the considered prices policies and it appears that costs of the purchased energy should drastically increase to justify the investment in a storage unit.

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