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INTEGRATED OPTIMAL DESIGN OF A PHOTOVOLTAIC/WIND SYSTEM FOR ELECTRICITY AND WATER PRODUCTION

Malek ZAIBI*, **, Gérard CHAMPENOIS*, Bruno SARENI***, Xavier ROBOAM***, and Jamel BELHADJ**

* Université de Poitiers, LIAS-ENSIP, B25, TSA 41105 86073 Poitiers cedex 9, France
E-mail: {malek.zaibi};{gerard.champenois}@univ-poitiers.fr

**Université de Tunis El Manar, LSE-ENIT, BP 37, 1002 Tunis Le Belvédère, Tunisia
E-mail: Jamel.Belhadj@esstt.rnu.tn

*** Université de Toulouse, LAPLACE-ENSEEIHT, 2 Rue Camichel 31071 Toulouse Cedex, France
E-mail: {xavier.roboam};{bruno.sareni}@laplace.univ-tlse.fr

Abstract. This paper investigates the integrated optimal design of a hybrid PV/wind generator coupled with two kinds of storage i.e. electric (battery) and hydraulic (tanks) devices for the production of electricity and drinking water in remote areas. Taking account wind and PV potentials in such system for assessing its performance implies its simulation over long periods of time. This can drastically increase the CPU time cost related to the design step, especially if the system energy management and sizing are sequentially integrated into a two level optimization process. In order to solve this problem and accelerate the system simulation, two complementary approaches are suggested. On one hand, metamodels are used for representing the system constraints and objectives. On the other hand, PV and wind cycles are compacted with a synthesis procedure which preserves their influence on the system performance with regard to the reference data. Those approaches are applied to the grey energy optimization of the studied hybrid system.

Keywords: System Design, Optimization, Renewable Energies, Battery Storage, Hydraulic Storage, Reverse Osmosis.

INTRODUCTION

Off-grid power supply systems based on renewable energies are of great interest for applications such as remote areas electrification, telecommunication station powering, water pumping and/or desalination for irrigation or drinking. The optimal design of such systems is a topical and challenging issue since it usually results in a two level optimization process integrating two different nested loops: a first (inner loop) for the energy management and a second (outer loop) for the system sizing [1]-[2]. Moreover, integrating the seasonal characteristics and the stochastic behaviour of the renewable energy sources as well as their time-correlation requires simulating the systems over long periods of time (i.e. at least a single year). Consequently, the optimal design of those systems is a complex problem because of the prohibitive CPU time costs resulting from both optimization steps and "long-term" simulations [2]. In order to solve this issue, two complementary approaches are investigated in our work: the first consists in using metamodels for representing the system constraints and objectives instead of a dynamic simulation; the second relies on the simplification of the intermittent profiles related to the renewable energy sources thanks to a particular process which preserves the main features affecting the system behaviour (i.e. statistical properties and correlations between stochastic sources). Both approaches are investigated on a PV/wind system with electric/hydraulic storage devoted to electricity and water production in remote areas. Such system aims at exploiting slow hydraulic dynamics with regard to the renewable energy source intermittency in order to optimize the fulfilment of load power and water demands.

SYSTEM DESCRIPTION

The present system includes hybrid Photovoltaic (PV)/Wind turbines (WT) sources with battery bank and hydraulic tanks powering electrical loads and hydraulic network loads. The latter is composed of water pumping and Reverse Osmosis (RO) desalination unit to produce permeate water. Fig. 1 (a) presents the global system architecture. The PV/WT/Battery electric subsystem consists of photovoltaic panels, wind turbines, battery bank and converters (DC/DC and AC/DC). The brackish water pumping and desalination process are composed of two motor-pumps, RO membrane, two water tanks and two (DC/AC) inverters. The different subsystems are coupled to a DC Bus. The meteorological profiles: wind speed, solar irradiation and ambient temperature of a typical region (North Tunisia) have been recorded during one year. The electrical load and the fresh water demands are defined over one week and repeated each week. The energy and water management of such system constitutes itself a difficult issue which can be solved using optimal control methods. In our study, a

simple but quite efficient water-energy management strategy developed in previous works [3] has been used. To assess the system performance, several criteria are defined among others the Loss of Power Supply Probability (LPSP) for the electric and hydraulic loads ($LPSP_E$ and $LPSP_H$ respectively). Moreover, each element of the system is represented by its grey energy (GE) on its life cycle. In addition to the fulfilment of the electric and hydraulic demands through the minimization of $LPSP_E$ and $LPSP_H$, the global grey energy of the system should also be minimized.

INTEGRATED DESIGN PROCESS WITH METAMODELS AND PV/WIND CYCLE COMPACTION

The integrated design process of the hybrid system includes two nested loops as described in introduction. The internal loop applies the water - energy management strategy and computes with the dynamic simulator of the system the $LPSP_E$ and $LPSP_H$ values from the reference data (i.e. PV/Wind cycles and electric/hydraulic demands) or from fictitious compacted profiles. The determination of those profiles with a particular process described in [4] will not be developed in this digest but explained in the full paper. The external loop resides in the optimization of the system design variables, i.e. panel surface A_{PV}, wind surface A_{WT}, battery capacity C_n, tank sections S_1 and S_2, pump power P_1, reverse osmosis membrane area DM and two variables of the energy management strategy [3]: the intermediate threshold levels in the battery SOC_u and in the fresh water tank L^2_u. This optimization is carried out using the NSGA-II [5] according to three objectives: $LPSP_E$, $LPSP_H$ and GE and two constraints imposing a $LPSP_E$ and a $LPSP_H$ less than 5%. In order to reduce the computational cost of the whole design process, all objectives are also represented with metamodels. For that purpose, 5000 configurations of the search space with regard to the 9 design variables are sampled with the Latin Hypercube method and simulated with the dynamic simulator using the reference data and the management strategy. The Matlab toolbox "Model-Based Calibration" is then exploited for building the metamodels of $LPSP_E$ and $LPSP_H$ based on the hybrid spline method [6]. Fig. 1 (*b*) compares the Pareto-optimal solutions obtained from the dynamic simulator (o) and from the metamodels (◊). It can be seen from this figure that both set of solutions are quite close in the objective space. It will be shown in the full paper that they also present the same design variables along the Pareto-front. On the other hand, the computational time of the design process of the hybrid system with metamodeling has been reduced by 330 compared with that using the dynamic simulator. Other results will be shown in the full paper combining this approach with compact renewable energy profiles in order to further reduce the computational cost of the design process.
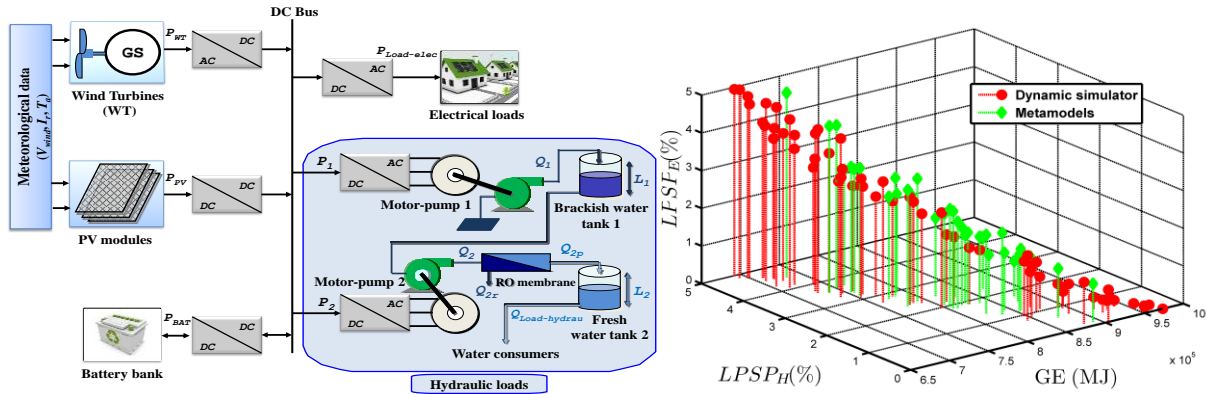

Figure 1. Three-objective optimization of the PV/Wind system with battery and two water tanks (*a*) system architecture (*b*) Pareto-optimal solutions issued from NSGA-II optimizations with the dynamic simulator and metamodels

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