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On the Simulation Tool of Autonomous Hybrid RES-Based Power Plants

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Abstract – *An extensive study is presented on the simulation, optimization and establishment of several hybrid RES-based building scale systems, designed to produce electricity to cover different electrical requirements. As fundamental case study, an already established system was simulated and optimized to be financially and energetically feasible for off-grid operation. Solar and wind resources along with several buffering technologies are proposed and related to the characteristics of such an investment. Moreover, based on a comparative feasibility study for systems simulated on several Greek islands, the role of grid connection was investigated. Finally, a laboratory-scale system was built to validate the theoretical predictions with experimental measurements, thus identifying the validity of the HOMER simulation platform.*

Keywords*: Hybrid System, Renewables, Zero Emissions, Simulation, Off-Grid*

I. Introduction

Nowadays electricity production in developed and developing countries mainly depends on conventional fossil fuels which are costly energy sources, characterized by pollutant behaviour during their use. During recent decades, RES-based technologies have been gradually integrated into everyday life. Enormous scale projects, contributing to national electrification in several countries around the world, are based on hydropower and natural gas applications, being the most preferable option able to provide almost the 19% of the planet's electricity [1], [2].

To further reduce the use of coal in electricity production, it is necessary to incorporate RES solutions into individual small-scale projects. For such an investment, it is appropriate to convince each potential user of the project's efficiency under a low budget prospect, since cost minimization is the major driving force for any investment. The construction of a local micro-grid is sometimes necessary, for such small-scale projects so they can operate either as stand-alone units in remote applications [3], or under a grid connection near urban areas [4]. Fortunately, electricity production by RES systems is unlimited because the environmental potential is endless even if characterized by huge fluctuations on an annual basis. Small-scale domestic projects can be supported by the use of solar and wind energy in combination with mature buffering technologies to optimize the micro-grid.

Although sounds feasible, the specific case of autonomous systems has to be extensively studied because there are numerous points that need further investigation, especially on energy waste and production excess.

This research studies the feasibility of several RES-based projects through a theoretical analysis arising from simulation results produced by the well-known HOMER software platform.

Firstly, an already established on-grid hybrid system was optimized from a financial and energy point of view followed by several simulations of different stand-alone scenarios on a number of Greek islands to examine the feasibility of RES technologies to produce electricity in remote locations. Finally, the operation of an established experimental laboratory-scale system is compared with that of a simulated system operating under the same conditions.

II. Optimization of an Established Hybrid System

HARI is one of the world's largest hybrid projects. It is based on renewable sources for everyday life and installed at West Beacon Farm, Leicestershire, England. Although this project involves numerous different RES and non-RES technologies, is designed to use power through the grid and the electricity from the RES devices is used as supplementary power.

Therefore the grid plays the role of the main energy source which supplies electricity power to domestic and office loads [5]. Wind turbines, photovoltaic panels and micro-hydro turbines have all been incorporated into this power plant, while buffering utilizes hydrogen technologies via electrolysis along with a battery bank. All these parts are connected to the national AC grid.

Through the HOMER simulation platform it was shown that HARI is not an optimized system because the basic electricity requirements are satisfied by the grid,

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and the established wind turbines, photovoltaic panels, and hydrogen-based devices appear to have minor influence on the coverage of the desirable load during one whole day [6]. This occurs because the system is designed to cover the peak load for each hour during a typical day without taking into account a normal daily variation as it would occur in a real-life scenario.

Therefore, the energy consumed originates from the grid although the system does have the potential to operate as a stand-alone unit under a specific timetable.

By considering the local meteorological conditions during a whole year, several alternative systems of different topologies and devices were designed and proposed, to cover the desirable electricity requirements in stand-alone mode but at significantly lower initial and net present cost than the already established system.

The most preferable RES-based scenario for this project compromises two wind turbines of 25 kW each, in combination with thirteen Zebra batteries of 20 kW each. By using HOMER simulation software, it was found that the proposed system gives the best financial (Fig. 1) and energy results (Fig. 2) when not connected to the national grid.

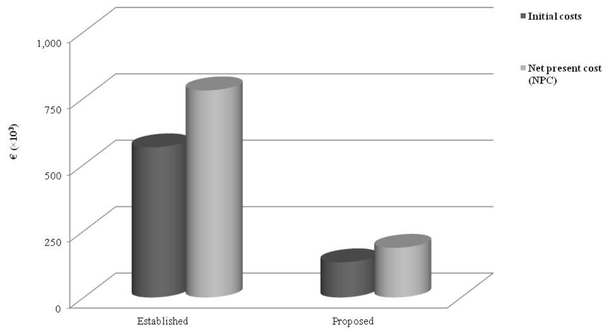

Fig. 1. Financial results

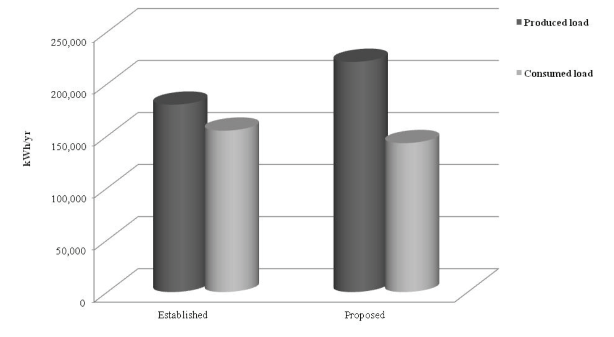

Fig. 2. Energy results

III. Theoretical Analysis of Several RES-Based Systems in Remote Areas

Following the successful optimization of the above hybrid system, a precise model on autonomous RES-based systems has been developed to describe the optimal conditions for such a system to cover electricity demands in remote areas. To start with, the simulation of several scenarios located on four Greek islands is presented to examine the necessity of the grid connection and define the financial and energy circumstances where a grid connection can be omitted.

Following an extensive study on the relative environmental potential via local meteorological stations available online [7], four Greek islands were selected for the simulations: Crete (Rethimnon), Rhodes, Skyros, and Naxos. Three different systems (a single photovoltaic, a single wind, and a hybrid photovoltaic-wind system) were designed to cover the following three different desirable loads: a typical house, a typical country house, and a small, office-based, company established in a small building. Such projects refer to small individual investors, thus the Return of Investment (ROI) is crucial [8].

All the possible scenarios were designed using HOMER software. The simulations proved that stand-alone (off-grid) systems are not financially profitable because the RES equipment is very expensive compared to its performance. Additionally, their capacity should be over-sized to ensure the system's continuous operation [7]. However, manual calculations produced a more optimistic result as the grid connection changed the above results dramatically: the consumer takes advantage of the excess electricity produced through the over-sizing, and a significant sum of money can be gained by selling the excess energy back to grid [7]. This underlines that a one-way grid connection is essential for a hybrid system from a financial point of view [7].

The best abbreviation results were produced by the hybrid pv-wind-battery system on Naxos Island where the highest combined environmental potential is found.

The above analysis demonstrates that the inevitable over-sizing of such a system is crucial for abbreviation time [7].

Figs. 3 - 4 present the abbreviation time in years for three different combinations of RES-technologies in hybrid off-grid and on-grid systems, respectively.

IV. Laboratory-Scale Experimental Power Plant

To experimentally investigate the feasibility of an off-grid system, a stand-alone hybrid RES-based power plant was constructed (Fig. 5) to simulate different small-scale projects under real-life meteorological conditions. Three loads (electricity requirements of a typical house, typical country house, and small company) were chosen to be satisfied by the hybrid system. The desirable load for each simulated scenario arises from the down-sizing of the real-scale load, a process essential for the stable operation of different AC devices that operate in different combinations [9].

The first simulation referred to the coverage of the annual electricity requirements of a typical house and resulted in the system covering 95.5% of the days of one year. This result is significant and promotes the application of stand-alone, eco-friendly systems into everyday life [9].

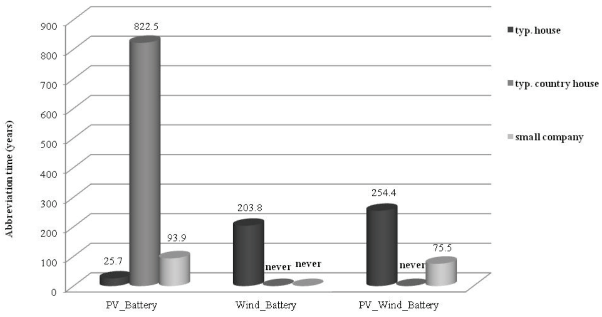

Fig. 3. Abbreviation time for off-grid systems to cover three loads on Naxos Island

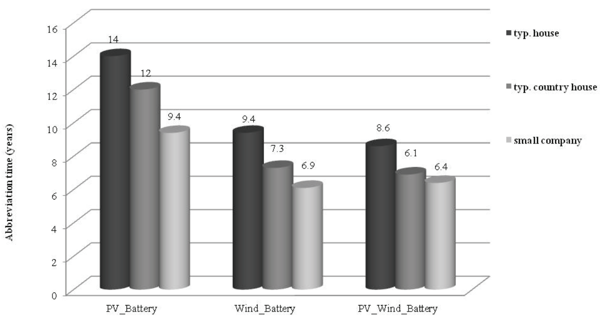

Fig. 4. Abbreviation time for on-grid systems to cover three loads on Naxos Island

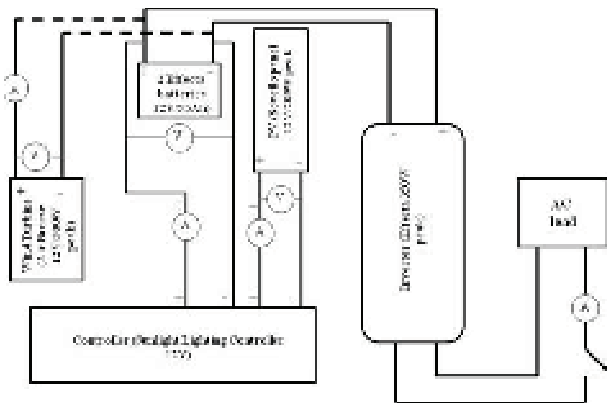

Fig. 5. The established hybrid system

The second simulated scenario of a typical country house's load produced similar results to the first simulation, and showed that the RES-based system can cover electricity demands for 87.7% of the days of one year. This efficiency rate could be improved by more precise management of the excess energy produced when the load is stable and constantly low due to the absence of the family during typical weekdays in winter, as presented by Prodromidis & Coutelieris [9]. Finally, the coverage of the small company's annual load was extensively studied to investigate if the company's primary needs could be met under different scenarios.

The simulations showed that during autumn, winter and spring, the specific load could be covered 100% of the time, while total annual coverage drops to 77.2% due to the summer period when the peak load is high enough for the established RES-based technologies to handle.

Finally, the experimental process demonstrates that the specific established hybrid system can adequately cover several scenarios and is therefore an attractive option for low-budget investors.

Real-time simulations of the three different projects, as they are presented above, were then compared to those carried out using the HOMER software tool.

This comparison revealed whether the theoretical simulation based on mathematical models can measure up to a real-life scenario. All the simulated scenarios were designed on the HOMER platform as presented in Fig. 6. For the sake of comparison, the meteorological data used for both real-time and theoretical simulations were taken from the same time period.

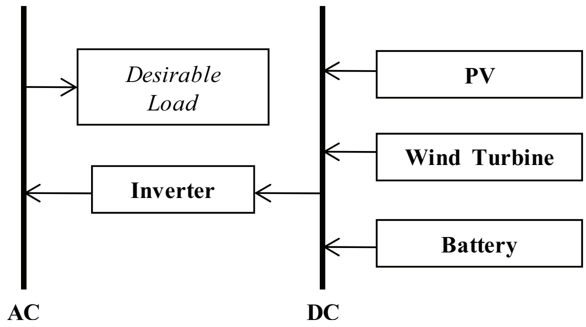

Fig. 6. The system's design in the HOMER platform

Results of the HOMER simulation showed that the capacity of the established RES-based equipment is insufficient to cover the load of a typical house, while over-sizing of the system is necessary and inevitable for a real-life project. This theoretical analysis showed that the electricity requirements of a typical house cannot be fully covered even for a single day of the year. This is in contradiction with results obtained from the real-time experiments [9], where the loads of a typical house could be covered 95% of one year [10].

A similar result was obtained from the simulation of the load characterizing the typical company. The only period where the produced energy from the RES-based equipment can meet the electricity demands of the company is typical weekends in August when the load remains very low throughout the day. This is in disagreement with the experimental process results which showed that the desirable load can be met approximately 80% of the days of one whole year.

Finally, the simulation of the typical country house seems to be in agreement with the experimental results. During weekdays from September to May, the electricity requirements can be covered but with an efficiency of less than the 78% found in the experimental procedure [9], [10].

Fig. 7 presents the final collective theoretical results arising from the HOMER simulations and shows the weaknesses of the software platform. As shown in Fig. 7, the energy produced by the system is the same in each simulated project because the laboratory-scale hybrid system was characterized by exactly the same RES devices.

From the theoretical study it was found that the established RES-based system cannot meet the electricity demands of a small-scale building project. This conclusion does not agree with the experimental (real-life) results, thus indicating the necessity for more accurate modelling approaches.

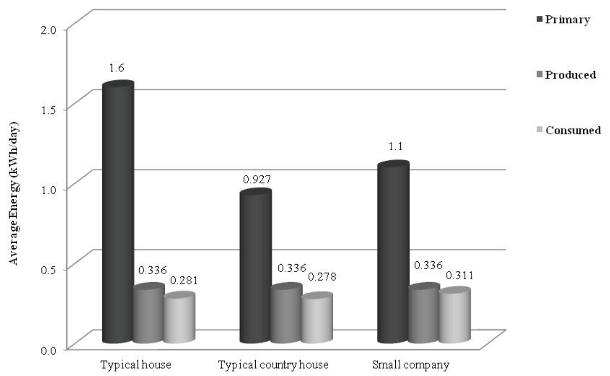

Fig. 7. Theoretical simulation results produced by HOMER

V. Conclusion

To investigate the validity of simulation on RES-based off-grid power plants, several different small-scale projects, with different combinations of RES-based equipment are presented for the coverage of several small-scale electric loads.

Optimization process was found to be one of the most important design stages before the construction of an off-grid project. Thus, for every established system that uses RES technologies, a combined study of operation, design and optimization should be performed. Specific research showed that prior to the construction of a complex, small-scale project, it is critical to perform a systematic design analysis based on several operational criteria before finally selecting the equipment to be installed.

To validate the process presented here, an already established RES-based system was simulated and optimized in terms of both energy and economics, while a laboratory-scale system was built to validate the theoretical predictions with experimental measurements.

Although experimentally the system found sufficient to successfully handle the desirable loads in annual basis, simulations produced a significant amount of days when the system cannot caver the demands.

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