# OPTIMAL ENERGY STORAGE CAPACITY FOR A GRID CONNECTED HYBRID WIND – PHOTOVOLTAIC GENERATION SYSTEM

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**Abstract - Taking into account the directives of the European Union concerning the increasing role of renewable power sources for supplying loads and reduction of $CO_2$ emission, this paper presents details of the technical and economic characteristics for a hybrid solution generation power system used to supply remote consumers and determining the optimal storage capacity. The goal of this micro power system is to supply residential electrical load that consist in 60 consumers of 5 kW each. Yet, considering the different variability of the most important renewable resources, wind and solar, the hybrid solution is investigated to found the optimal mix solar-wind for a maximum founding option. The investigation is realized using the NREL HOMER package.**

**Keywords:** energy mix, wind power, solar energy, energy storage.

## 1. INTRODUCTION

Recent IEA and other scenarios [1] have demonstrated that a large basket of sustainable energy technologies will be needed to address the challenges of moving towards clean, reliable, secure and competitive energy supply. Renewable energy sources and technologies can play an important role in achieving this goal. Many countries have made progress in promoting renewables in their energy mix, but obstacles remain and greater efforts are needed.

Some renewable energy technologies are close to becoming commercial and should be the first to be deployed on a massive scale. Other, which has a large potential, are still less mature and impose to consider them only for long-term visions. Reducing their costs will require a combined effort in research, development and demonstration, and technology learning resulting from marketplace deployment.

Wind power seems likely to remain the main new renewable energy source for the renewable new projects given the large offshore and on land resource and its relatively good economics [1]. However a promising and large available renewable resource remains the solar. The main issue in implementation of photovoltaic panels is the large capital cost. Starting from the observation that the wind generation is more accessible financial, but have larger and different variability, the authors has investigated in present work the possibility to find for and concrete application an optimum mix for rated power of wind generation, PV, grid and storage batteries.

For all the remote consumers which cannot be connected to any grid or the connection requires important investments, energy storage solutions must be provided, due to the uncertain character of the renewable energy sources.

In this paper, the authors propose a solution to supply remote consumers using a mix of renewable energy sources (wind and photovoltaic) and also providing the continuity of supplying using batteries for energy storage.

## 2. MARKET ASPECTS IN RENEWABLE TECHNOLOGIES IMPLEMENTATION

As we mentioned above, the investment costs of PV systems, which represent the most important barrier to PV deployment, are still high. Since only 1% of the realizable potential had been exploited by 2005, the actual average policy effectiveness levels for PV are lower by a factor of ten than for a more mature renewable technology such as wind energy. The development of PV in terms of absolute installed capacity is dominated by Germany and Japan, followed at some distance by the United States. These three countries were responsible for roughly 88% of the globally installed capacity at the end of 2005.

Incentive mean such as feed-in tariffs (complemented by the easy availability of soft loans and fair grid access) have been very effective in Germany, even though at a high cost (USD 0.65/kWh) [2].

For many years, PV installations in the United States have benefited from federal tax incentives, but these have been insufficient to motivate PV installations. Therefore, more recently, California (which alone represents nearly 80% of the USA inventory), Arizona and New Jersey established aggressive incentive policies for PV, including tax rebates for residential and commercial installations and quota obligation systems with a solar-specific set-aside. Net metering, favorable retail rate structures and streamlined interconnection rules have also been enablers of sizable PV markets [2]. These measures may become important triggers for PV market take-off in other countries as well.

A wide variety of incentive schemes in place can be effectively applied depending on the specific technology and country. However, to date non-economic barriers have significantly hampered the effectiveness of renewable support policies and driven up costs in many countries, irrespective of the type of incentive scheme.

## 3. HYBRID ENERGY SYSTEMS

Hybrid power systems are considered as combinations of two or more energy conversion devices (including storage) or two or more fuels for the same device [3], [4], that when integrated, can improve the system performances or get over limitations that may be inherent in either.

Hybrid systems are potentially very cost-effective solutions to overcome the handicap of low predictability of renewable resources. For low load applications about 10 kWh/day, wind-PV hybrid systems appear to be already attractive considering the environment aspects too [5].

The authors investigated to find a reasonable mix between wind an PV such that the equivalent cost of energy be comparable even for greater load applications. Also, the optimum of storage capacity was determined in order to preserve the feasibility of the hybrid energy source solution even in the absence of grid connection.

Each system component is considered having an enough large domain of rated power available: the studied hybrid renewable energy source consists of a 10 to 60 units of 25 kW rated power for wind generation and 1 to 50 kW (peak) PV array as primary energy sources. The excess energy with respect to the load requirement has considered to be stored in a high capacity battery capable to provide power supply even for a few days absence of wind and/or solar source.

## 4. NUMERICAL SIMULATION

To model and simulate the large number of possible combinations of sizes for the four elements considered (wind, PV and storage) the authors used free available specialized software, HOMER from NREL.

The HOMER Micropower Optimization Model is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) [5] to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER can model grid-connected and off-grid micro power systems serving electric and thermal loads, and comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, reciprocating engine generators, micro turbines, fuel cells, batteries, and hydrogen storage.

Figure 1 presents the system structure without considering grid connection. The wind generation component, the PV generation component, the load, the battery and the converter are considered.

In order to make a good sensitivity analysis were considered for wind generation were considered the rated power between 10 and 60 units of 25 kW each, in step of 5 units.

As concerning the PV generation were considered the rated power between 10 and 100 kW, by steps of 5 kW.

Figure 2 shows the considered wind speed ranging between 4 and 6 m/s with an average value of 5 m/s. Figure 3 gives the photovoltaic irradiance level of the panels whose average value is around between 200 and 800 W/m² with a year average of 4 kWh/m$^2$/d.

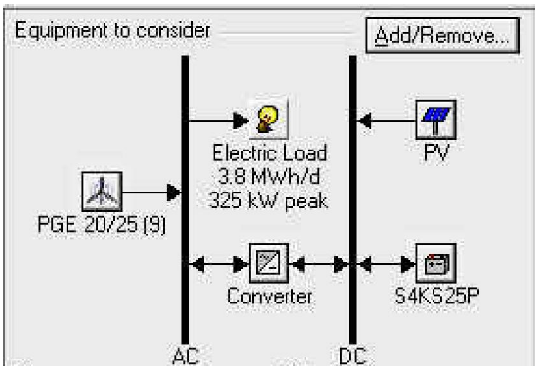



**Fig. 1. The hybrid system scheme with storage batteries**

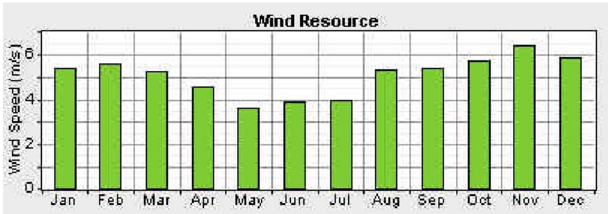



**Fig. 2. Monthly average wind speed**

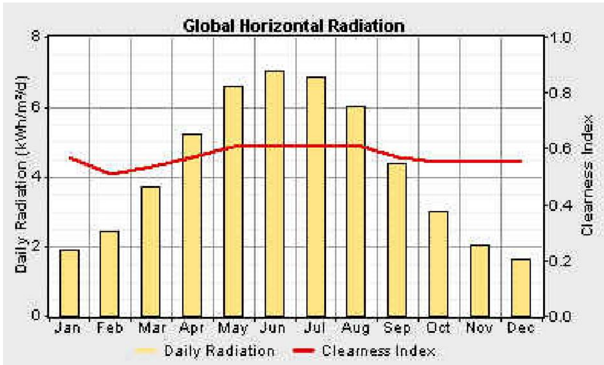



**Fig. 3. Monthly average daily radiation**

Synthetic results for the hybrid system with storage baterries identified two solutions: a hybrid wind-PV solution which determines a COE of 0.15 $/kWh and a wind solution with a COE of 0.154 $/kWh (COE -levelized cost of energy). The optimal solution is the hybrid one which considers an optimal combination of 80 kW of PV generation, 35 units of 25 kW wind generation and a battery of 4060 units. The battery is made of strings of 58 units (a total of 70 strings). A string dimension is considered to provide a voltage of 230 V (232 V more exactly), each battery have a 4 V rated power and a capacity of 1900 Ah (7.6 kWh).

The results were obtained in the following conditions: the study time period was 20 years, maximum annual capacity shortage 1 %, annual real interest rate 6 % and capacity shortage penalty 1 $/kWh.

In figure 4 are presented the results considering the cost of investments in wind and solar energy conversion equipments and in figure 5 was considered a cost reduction to 85% for solar converters and to 90% to wind converters. As it can be observed, in the second scenario, COE values decreases to 0.141 $/kWh. In both scenarios the price of the energy supplied to the consumer is lower than the actual price for residential consumers (about 0.2 $/kWh).

Sensitivity Results | Optimization Results

Sensitivity variables

PV Capital Multiplier 1 PGE25 Capital Multiplier 1

Double click on a system below for simulation results.

| PV (kW) | PGE25 | S4KS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage |
|---|---|---|---|---|---|---|---|---|---|
| 80 | 35 | 4060 | 400 | $ 1,901,000 | 44,520 | $ 2,411,642 | 0.150 | 1.00 | 0.00 |
| | 40 | 4640 | 500 | $ 1,874,000 | 51,935 | $ 2,469,689 | 0.154 | 1.00 | 0.01 |

**Fig. 4. Synthetic results, hybrid system without batteries**

Sensitivity Results | Optimization Results

Sensitivity variables

PV Capital Multiplier 0.85 PGE25 Capital Multiplier 0.9

Double click on a system below for simulation results.

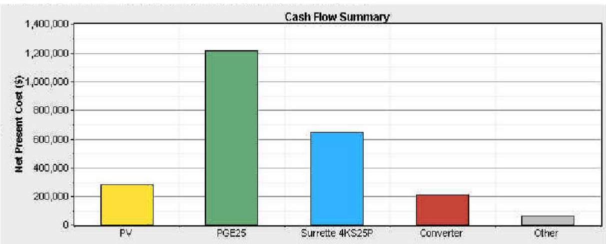
| PV (kW) | PGE25 | S4KS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage |
|---|---|---|---|---|---|---|---|---|---|
| 80 | 35 | 4060 | 400 | $ 1,757,500 | 44,520 | $ 2,268,142 | 0.141 | 1.00 | 0.00 |
| | 40 | 4640 | 500 | $ 1,758,000 | 51,935 | $ 2,353,689 | 0.147 | 1.00 | 0.01 |

**Fig. 5. Sintetic results, hybrid system with batteries**

Figure 6 present the investments, the replacement and the maintenance costs repartition for each component of the micro power system.

Figure 7 present the monthly generated power mix. It can be observed the small contribution of the PV but also the complementarity of the PV source vs. the wind source.

Figure 8 presents the battery state of charge for a year.




| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| PV | 280,000 | 0 | 1,835 | 0 | 0 | 281,835 |
| PGE 20/25 (9) | 1,015,000 | 0 | 200,724 | 0 | 0 | 1,215,724 |
| Surrette 4KS25P | 406,000 | 181,593 | 93,136 | 0 | -37,978 | 642,751 |
| Converter | 200,000 | 0 | 9,176 | 0 | 0 | 209,176 |
| Other | 0 | 0 | 62,157 | 0 | 0 | 62,157 |
| System | 1,901,000 | 181,593 | 367,028 | 0 | -37,978 | 2,411,643 |

**Fig. 6. Costs summary**

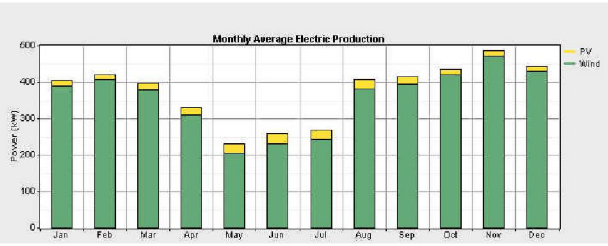



**Fig. 7. Seasonal component share, hybrid system includes batteries**

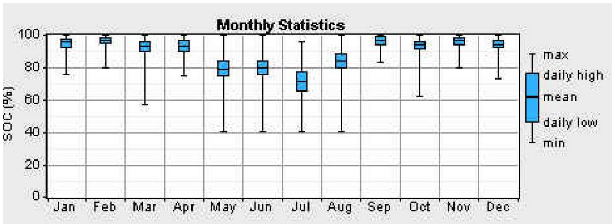



**Fig. 8. Battery state of charge**

In figure 9 is presented a period when the continuity of energy supply is provided by the battery, the renewable resources being unavailable. It must be pointed out that the hybrid power system solution is not feasabile without the storage capacity. It must provide sufficeint capacity to supply the consumer for 8 days. In the absence of the PV source, this interval grows to 9 days.

Figure 10 shows how much the solar source supplyes the load.

Figure 11 shows how much the wind source supplyes the load. As can be seen, in some time intervals, the power production excedes the consumption, but the power excess is not uses in any way. For one year, the energy excess is 1631 MWh, but because the micropower system is not not connected to the grid, the excess cannot be explited.

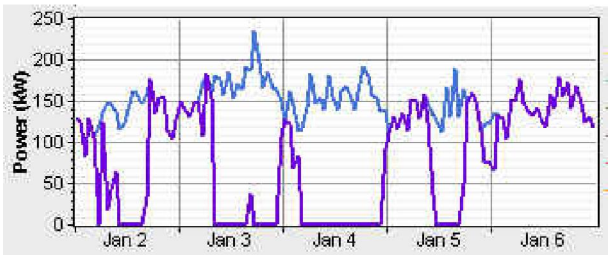



**Fig. 9. Example of period when the battery supplyes power: blue – the consumer; purple – battery**

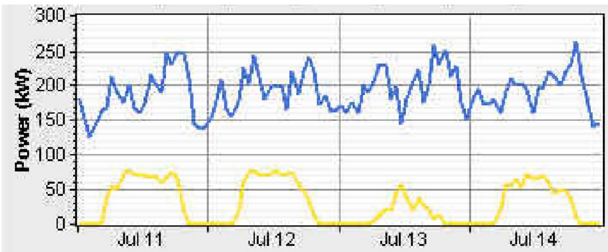



**Fig. 10. Example of period with PV energy production: blue – the consumer; yellow – PV**

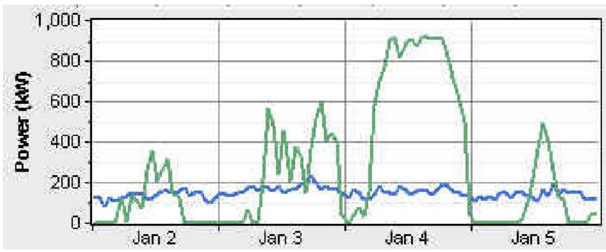



**Fig. 11. Example of period with wind production: blue – the consumer; green – wind turbine**

Considering the grid and obtaining benefits by selling the excess power, the value of COE is –0.238 $/kWh at a sell price of 0.2 $/kW which makes the return of investment in a very short period. It was limited to zero the possibility of buying power from the grid.

Considering the grid (Fig. 12) and obtaining benefits by selling the excess power, the value of COE is –0.238 $/kWh at a sell price of 0.2 $/kW which makes the return of investment in a very short period. It was limited to zero the possibility of buying power from the grid (Fig. 13).

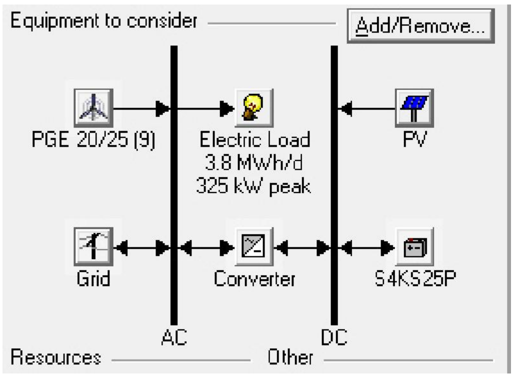



**Fig. 12. Micro power system and grid**

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

| | PV (kW) | PGE25 | S4KS25P | Conv. (kW) | Grid (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 80 | 35 | 4060 | 400 | 0 | $ 1,901,000 | -365,184 | $ -2,287,629 | -0.142 | 1.00 | 0.00 |

**Fig. 13. Results considering the grid**

## 5. CONCLUSION

The optimal mixture seems to be when wind power produces about 95% of the total electricity production from renewable resources and PV contributes (as energy) with about 5%. So, the PV share rest lower and strongly dependent of capital multiplier.

Such hybrid system can permit to respect some important principles of sustainability in energy systems: for renewable resources – make use of local biomass, geothermal, hydro, solar and wind energy – and strategic use of grids – optimize the use of energy within the grid.

The storage capacity must supply the consumer for a long period of time. For our case study, this period is at least a week. When the wind source is constant and with a higher intensity, this time period decreases and the capacity is smaller.

The cost for the storage capacity is almost a quarter of the total system cost. The storage capacity makes feasible the proposed solution in the absence of the grid.

The capacity of installed power in the wind and solar generators depends by the capacity factor for each source, for this case these are 40.6% and 24%. The average power supplied by the wind generators is correlated with the average consumed power, being twice its value.

The COE value for the micro power system is below the energy price supplied by the distribution companies: 0.15 $/kWh to 0.2 $/kWh,

The maximum benefit is obtained when the excess power is sold to the grid.

Although the PV system is more expensive, the best solution considers the mix of the wind and solar sources.

## ACKNOWLEDGMENTS

This work was supported by the Romanian National Council of Academic Research CNCSIS – UEFISCU, through the research Grant PNII – IDEI code 485/2008.

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