Bulletin of the *Transilvania* University of Braşov
CIBv 2014 • Vol. 7 (56) Special Issue No. 1 - 2014

ANALYSIS OF USING STAND-ALONE SOLAR-WIND POWER SYSTEM IN RURAL AREAS

G. CORSIUC[1] C. MÂRZA[1] R. FELSEGHI[1]
T. ŞOIMOŞAN[1] M. ROMAN[1]

Abstract: The use of renewable can be a solution for the power supply of remote rural villages in Romania, where grid connection is impossible or very expensive to achieve. Stand-alone power systems generate power onsite with no need for a complex transportation system, while offering consumers energy independence. In this paper are analyzed and compared three types of stand-alone systems based on solar and wind power. A series of simulations were conducted in order to obtain the optimal solutions in terms of energy production, investment cost and CO_2 emissions. The first system studied is composed only of photovoltaic panels and it is feasible if there is enough space for the installation of the panels needed to cover the energy demand. The hybrid solar wind appears to be a good solution for this specific location, both in terms of energy production as well as of the cost.

Key words: *renewable energy, rural electrification, stand-alone power system, hybrid system.*

1. Introduction

In the context of durable development, a special stress is put on the use of non-conventional and unpolluting sources of energy and also on the decrease of gas pollution, which contributes to the greenhouse effect. Thus, the strategic objectives established by the European Union are to provide 20% of the total amount of energy needed from renewable sources of energy until 2020 and to decrease the CO_2 emissions by 20%.

In Romania, the rural area is a mixt space in which very small human communities, some isolated with few inhabitants, coexist with relatively large communities, with a population approaching 10,000 people. For Romania, the rural areas have an important socio-economic value, because here lies 45% of the population, 47% of the number of residential houses and 46% of the residence designed area. In the administration of communes are found 87% of the total area of the country and 91% of the agricultural area, while the average density of population is under 48 people per km^2.

Nowadays, in Romania there are some isolated villages, placed far away from communal centers and scattered throughout the country, undeveloped economically and beyond the pale of

[1] *Technical University of Cluj-Napoca, Faculty of Building Services*

civilization (some are small villages of 5-10 households) that are still not benefiting from electricity. Connection to the distribution grid of these isolated areas is a basic requirement to ensure normal living conditions today. Considering that Romania is a European Union Country is necessary to provide economic and social development in this isolated regions. Electrification is one of the biggest blessings of social life, that can not be conceived without the use of electricity.

Electrification of isolated communities can be done in three ways:

- by extending the existing electrical network - that involves issues of cost due to the low density of population and low energy consumption;
- by using the conventional diesel generators, causing environmental problems, operating costs, not guaranteeing a continuous supply, maintenance;
- or the implementation of hybrid systems using renewable energy sources.

Although the cost of electricity supplied through the grid is now inferior to that produced from renewable sources, must be emphasized the high cost of connection to the network mainly due to the relatively large distances (and often difficult) from the network, territorial spreading, small number of isolated households located in areas of interest, as well as the lower power consumption in rural areas. It should also be noted that the population in these areas have generally lower solvency. As a result, it is difficult to bear the right price for energy supplied through the network correspondig to the real value of the investment. Thus, some technical and economic studies indicate that for many punctual situations, the cases of renewable electrification can be competitive or even more advantageous than other conventional solutions such as network connection or generators.

In this paper the authors are presenting the results of the research regarding the design and sizing of some renewable sources energy systems , that supply an isolated house in the countryside. Three types of stand-alone energy systems will be presented and analyzed.

2. Renewable energy sources

In rural areas there are various forms of renewable energy that can be used in the power supply of these areas:

- biomass - which is the main fuel in rural areas being mainly used for space and water heating as well as for cooking;
- geothermal energy - which can be used for space heating and hot water;
- small hydropower - can be a basic option for supplying energy to rural areas which are not connected to the electricity network, only that is dependent upon the existence of a constant flow water source;
- solar energy - used for water heating and electricity production;
- wind power - also can cover the electricity needs of hard to reach rural areas.

Choosing a solutions one must take into account the following criteria:

- the location of the consumer compared to the existing conventional sources, namely the distribution network;
- the existence in the area of some non-conventional energy resources;
- dynamics of the area development respecting the declared energy consumption;
- the existing technology, materials, switchgear and equipment;
- the size and shape of the geographical area occupied by isolated consumers which can decide if the solution is either the conection to the distribution network or from local unconventional sources;
- the shape and geomorphology of the land determines if is favorable or not the use of

renewable energy resources.

For the simulations presented in this paper was considered that the energy system uses renewable energy sources as solar and wind power and is located in a village in the county of Cluj, having the coordinates: latitude 46°25'N, longitude 23°38'E, at an altitude of 609m. For this area we used the official meteorological data of solar radiation intensity and wind speed according to the months of a year [7].

Simulations were performed during a year of the operating system, and the weather conditions are considered constant for the remaining years of the system functioning. Thus, in Table 1 are given the average values of solar irradiation and wind speed during a year while in Figure 1 and Figure 2 are shown the corresponding output graphics.

Monthly averaged insolation and wind speed Table 1

Month	Insolation	Wind speed at 10m
	[kWh/m²/day]	[m/s]
January	1.35	3.99
February	2.16	3.82
March	3.18	3.26
April	4.01	3.18
May	4.87	2.92
June	5.32	3.22
July	5.35	3.10
August	4.93	3.56
September	3.47	3.25
October	2.37	3.36
November	1.42	3.89
December	1.08	3.38

The values of the solar irradiation on horizontal surface are considered to be :
- daily average irradiation 3.28 kWh/m^2 ;
- total annual irradiation 1197.26 kWh/m^2 .

The values of the solar irradiation on the plane of the photovoltaic pannels are :
- daily average irradiation 3.35 kWh/m^2 ;
- total annual irradiation 1225.4 kWh/m^2 .

The average wind speed for a year, measured at 10 meters altitude is considered to be 3.4 m/s.

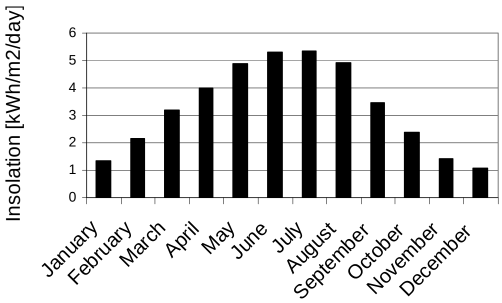

Fig.1. *Output graphic for solar radiation profile*

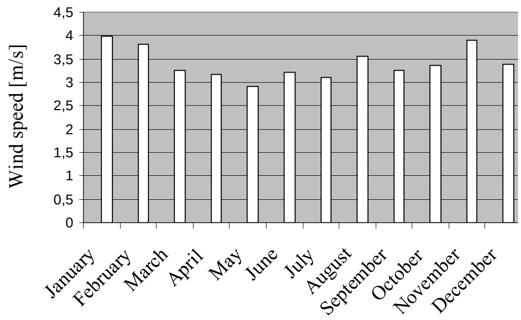

Fig.2. *Output graphic for wind speed profile*

3. Household energy load

Considering the needs of an isolated household farm but also the requirements of ensuring a typical regime of electrification for stand-alone systems, was established the energy load, considering the following consumers: indoor lighting, outdoor lighting, radio, TV, power tools and a fridge.

Based on the energy consumers, and considering the normal way of life in the countryside the following loads was considered:
- maximum load : 350 W ;
- average hourly load : 241.67W.

Further on simulations for three configurations of energy systems were performed, having as objectives reducing total system cost and optimizing the values of carbon and excess energy. The first system is based on the energy produced by photovoltaic panels, the second system produces energy using wind turbines and the last type is a solar-wind hybrid system. All three systems are equipped with batteries to store the excess energy. If the power produced by renewable sources is higher than the energy demand, the batteries will charge, the stored energy will be used when the system does not cover the energy demand of the consumers.

4. Simulations for stand-alone energy systems

In order to determine the optimal renewable energy system design that can cover the load using solar and wind power, the authors used the software HOGA (Hybrid Optimization by Genetic Algorithms), which is a simulation and optimization program based on genetic algorithms [4].

4.1. Simulation results for a solar photovoltaic system

Performing the simulations for a solar-photovoltaic energy system, the algorithms have determined the optimal configuration of the system according to the energy load required, havind the following components:

- 2 PV panels serial x 19 panels parallel of 175Wp each, with a total power of 6.65 kWp ;
- 4 batteries serial x 3 batteries parallel, having a capacity of 80Ah each ;
- inverter, 500VA ;
- battery charge regulator**.**

Considering that the minimum state of charge allowed for the batteries is 40%, the energy balance of the system for a year is shown in Table 2. For comparison, the results are graphically represented in Figure 3.

Balance of system energies for one year

Table 2

Overall Load Energy [kWh/year]	2117
Excess Energy [kWh/year]	2369
Energy delivered by PV [kWh/year]	5122
Battery Charge Regulator [A]	135.,8
Energy charged by Batteries [kWh/year]	1511
Energy discharged by Batteries [kWh/year]	1513
Total CO_2 emissions [kg CO_2/year]	298

Figure 4 shows that from the total cost of the system, the largest share is held by the price of the photovoltaic panels 46.12%, followed by the batteries price 39.81% and auxiliary equipments 14.07%.

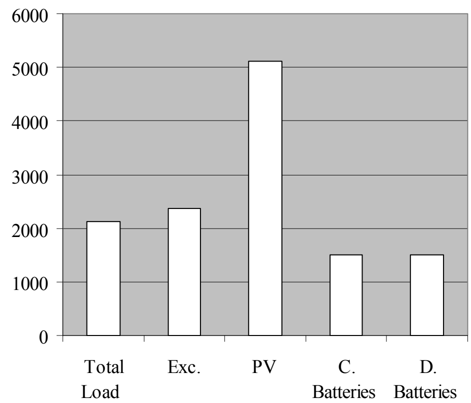

Fig.3. *Electrical energy production of the solar photovoltaic system*

4.2. Simulation results for a wind turbine system

Performing the simulations for a wind

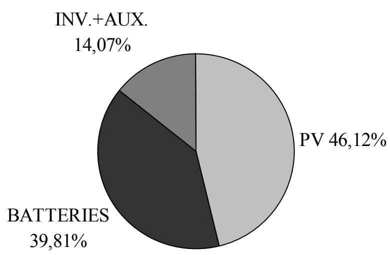

Fig.4. *Percentage cost of the proposed system equipments*

turbine energy system, the algorithms have determined the optimal configuration of the system according to the energy load required having the following components:

- 1 DC wind turbine, 6500 W ;
- 4 batteries serial x 2 batteries parallel, Cn = 444 Ah;
- inverter, 500 VA;
- battery charge regulator.

In Table 3 is shown the energy balance of the wind power system for a year. The results are graphically represented in Figure 5.

Balance of system energies for one year

Table 3

Overall Load Energy [kWh/year]	2117
Excess Energy [kWh/year]	4165
Energy delivered by Wind Turbines [kWh/year]	6767
Battery Charge Regulator [A]	107.6
Energy charged by Batteries [kWh/year]	841
Energy discharged by Batteries [kWh/year]	845
Total CO_2 emissions [kg CO_2/year]	439

Figure 6 shows that from the total cost of the system, the largest share is held by the price of the batteries 51.55%, followed by the price of the wind turbine 41.51% and

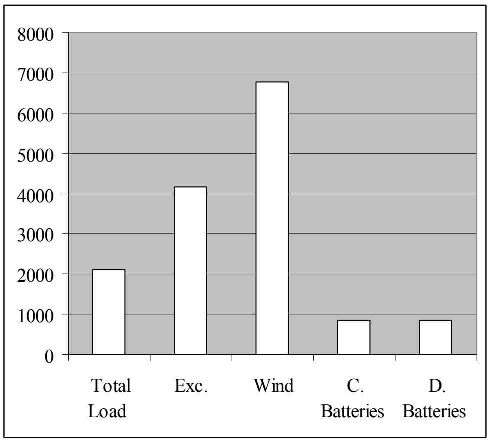

Fig.5. *Electrical energy production of the wind energy system*

the price of the auxiliary equipments 6.95%.

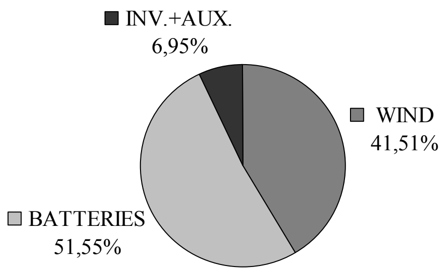

Fig.6. *Percentage cost of the proposed system equipments*

4.3. Simulation results for a hybrid solar-wind system

After performing simulations for solar-wind hybrid stand-alone energy system has resulted the following design - as in Figure 7:

- 2 PV Panels serial x 9 Panels parallel, 175 Wp;
- 4 Batteries serial x 4 Batteries parallel, Cn = 80 Ah each, E_{total} = 15.3 kWh;
- 1 DC Wind Turbines, 1760 W;
- Inverter, 500 VA;
- Battery Charge Regulator.

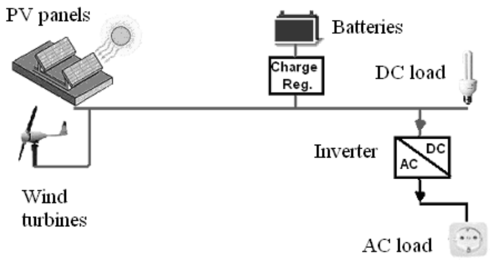

Fig.7. *Solar-wind hybrid energy system*

The energy balance of the solar-wind hybrid system for a year is shown in Table 4. For a better comparison, the results are graphically represented in Figure 8.

The percentage values for the proposed solar-wind hybrid system equipments cost are shown in Figure 9. It is noted that in this case too the highest percentage is held by the cost of batteries.

Balance of system energies for one year

Table 4

Overall Load Energy [kWh/year]	2117
Excess Energy [kWh/year]	1603
Energy delivered by PV generator [kWh/year]	2426
Energy delivered by Wind Turbines [kWh/year]	1779
Battery Charge Regulator [A]	64.3
Energy charged by Batteries [kWh/year]	839
Energy discharged by Batteries [kWh/year]	839
Total CO_2 emissions [kg CO_2/year]	255

5. Results and discussions

Comparing the values obtained from the simulations of the three types of systems we note that in terms of investment cost (Figure 10) solar photovoltaic system has the lowest price, but has a large number of panels which implies a large area required for their installation. It seems a good solution if the necessary space is available.

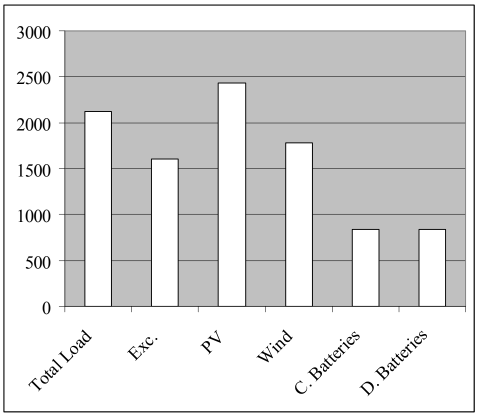

Fig.8. *Electrical energy production of the solar-wind hybrid system*

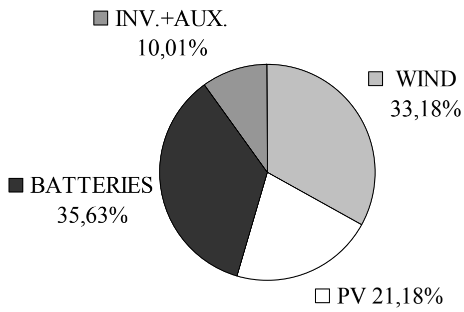

Fig.9. *Percentage cost of the proposed system equipments*

Analyzing the results it is observed that every time from the total cost of the system the highest percentage is held by the cost of the batteries. This demonstrates the importance of energy storage in dimensioning a stand-alone system and also the need to solve the storage problem.

Even if the cost (Figure 10) of the solar-wind hybrid system is 3% higher then the solar photovoltaic system we note that is composed of a much lower number of photovoltaic panels, resulting the need for a smaller area for installation. Also, in Figure 12 is noted that it is the energy system with the lowest CO_2 emissions. The calculated CO_2 emissions are resulting both from the operation of the equipments in the lifetime of the system as well as from the process of manufacturing them.

Figure 11 shows that the wind turbine system produces the greatest amount of energy, 60% more than the solar-wind hybrid system.

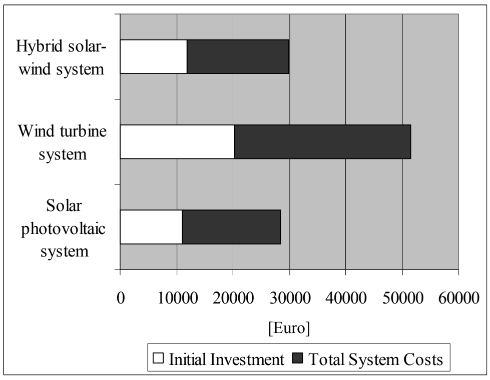

Fig.10. *Economic comparison of simulation results*

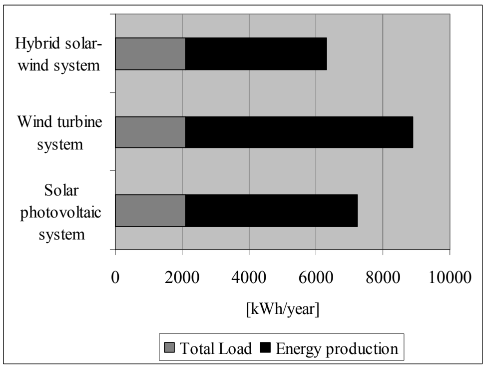

Fig.11. *Annual energy production by different systems*

In terms of reducing the excess energy is shown in Figure 13 that also the solar-wind hybrid system has the lowest values.

The results presented above demonstrate that when solar and wind power are combined in a hybrid system, we obtain a much more reliable system, with a stable performance, lower CO_2 emissions and also the lowest level of excess energy.

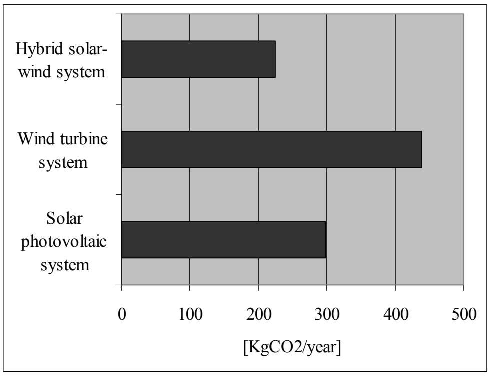

Fig.12. *Annual CO_2 emissions for the studied systems*

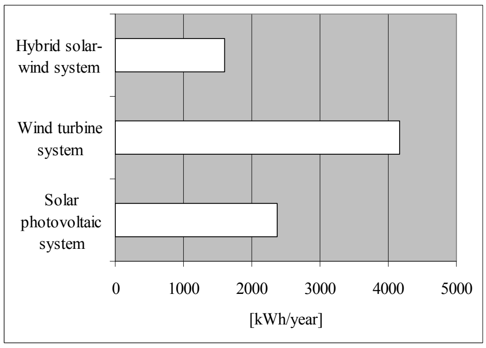

Fig.13. *Annual energy excess*

6. Conclusions

In the context of sustainable development, renewable energy resources are the optimal alternative to solve energy issues and protection against environmental degradation.

The problem of ensuring energy in isolated rural areas presents certain peculiarities caused in principle by the lack of networks or by the existence of some damaged national systems of energy distribution. In this context, to obtain energy on a local level using unconventional and clean energy sources represents a reliable solution, which is in agreement with the sustainable development policy.

Renewable energy resources, particularly solar and wind power, are considered as the basic components in the sustainable development of human communities whose energy demand continues to grow. The development of the renewable industry is considered to be a possible answer for both consumers connected to national electricity grids as well as for those isolated ones.

Unfortunately, solar power and wind power are, in most cases, intermittent sources (solar radiation, wind speed), which is their main disadvantage. For this reason, renewable energies are generally highly dependent on energy storage systems or be supported by continuous energy generation technologies like hydro, biomass or diesel/biogas generators. Thus, a solution would be the combination of solar and wind energy, this way contributing to alleviate the deficit in power supply and, at the same time helping to reduce the amount of energy that needs to be stored.

Stand-alone energy systems, unlike grid-connected systems, are much more complex and expensive because it must ensure the independence of the consumers operations, for which an important role is occupied by the storage of excess energy in batteries.

Acknowledgements

This paper was supported by the project „Inter-University Partnership for Excellence in Engineering - PARTING - project coordinated by the Technical University of Cluj-Napoca" contract no. POSDRU/159/1.5/S/137516, project cofounded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

References

1. Azurza O., Arranbide I., Zubia I.: *Rural electrification based on* renewable energies. A rewiw, International Conference on Renewable Energies and Power Quality, Santiago de Compostela, Spain, 2012.
2. Bernal-Agustín JL, Dufo-López R.: Simulation and optimization of stand-alone hybrid renewable energy systems, Renewable and Sustainable Energy Reviews, Volume 13, Issue 8, 2009, p. 2111–2118.
3. Díaz P., Peña R., Muñoz J., Arias CA., Sandoval D.: Field analysis of solar PV-based collective systems for rural electrification, Energy. The International Journal, Volume 36, Issue 5, 2011, p. 2509–2516.
4. Dufo-López R., Bernal-Agustín J.: Software and HOGA User Manual, Faculty of Engineering, University of Saragossa, Spain.
5. Huang R., Low S., Topcu U., Chandy M.: Optimal design of hybrid energy system with PV/wind turbine/storage: a case study, Smart Grid Communications, 2011 IEEE International Conference , Brussels, p. 511 – 516.
6. Vani N., Khare V.: Rural electrification system based on hybrid energy system model optimization using HOMER, Canadian Journal of Basic and Applied Sciences, Vol. 01, Issue 01, 2013, p. 19-25.
7. https://eosweb.larc.nasa.gov
8. http://www.lpelectric.ro
9. http://www.minind.ro/