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CASE STUDY REGARDING THE CONFIGURATION OF A STAND-ALONE HYBRID SYSTEM FOR ELECTRICITY PRODUCTION

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Abstract: *Even if electricity is currently accessible in most of the country, there are still some isolated areas without access to the national power grid. In this case, a solution can be the implementation of some systems that produce electricity using the available resources on site such as solar or wind power. Thus, besides providing the necessary energy it complies with the European directive on the use of clean energy sources. But due to the fact that solar and wind power are not uniform and constant is recommended to use both of them in a hybrid system. In this paper the authors present a case study on the configuration of an autonomous solar-wind hybrid system that supplies electricity to a consumer from rural areas located in different wind regions.*

Key words: *solar, wind, energy, renewable, electricity, hybrid system.*

1. Introduction

Energy is the driving force of the civilization and of the economic and technical-scientific evolution.

Making a retrospective analysis in history, we find that the most powerful countries or empires that have played an important role in the geopolitical and strategic configuration in various time periods were characterized by a flourishing economy. In the contemporary period we can conclude that the economic development is directly connected to the possession or access to energy resources [4].

With the identification of current issues related to energy and the environment, we have established principles that underpin sustainable development. Thus, it places great emphasis on the use of renewable and clean energy sources, characterized by low CO_2 emissions [4].

If a few years ago, the idea to provide the electricity demand using renewable energy in residential buildings seemed a distant goal in terms of technological, economic and even psychological, now it has become achievable.

On one side energy conversion equipment were produced at affordable prices and, on the other side, the widely publicity of the need to use renewable energy led to optimistic results. Thus, in rural areas or in areas adjacent to large cities, where the national energy systems

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have not expanded, more residents are choosing solutions that involve autonomous energy production systems.

To encourage the use of renewable, energy special programs are created by the European Union which finances part of the investment.

Because renewable energy sources are usually characterized by unevenness it is necessary to implement hybrid systems, namely the use of at least two sources that can work alternative or complementary and storage systems [1].

In this paper the authors present a study on the configuration of some autonomous hybrid systems for electricity production using solar and wind energy.

Simulations were performed for two villages located in the III respectively in the IV wind areas, because these cover large part of our country surface.

The zone III is characterized by a wind speed of 4.5 m/s in the cities and 6m/s outside the city and the zone IV shows an average wind speed of 4m/s independently of class exposure.

Moreover, zones I and II, are characterized by higher wind speeds (zone I - between 8 and 10 m/s and zone II - between 5 and 7 m/s) is well suited for on grid energy systems by using high power wind turbines.

Following are presented the results of simulations carried out in order to determine the optimal configuration for a autonomous hybrid system that supplies electricity in rural areas.

2. Mathematical Modelling of the Hybrid System

To determine the system configuration iHOGA software was used (Hybrid Optimization by Genetic Algorithms), which is a simulation program based on genetic algorithms. It is used for the generation of electrical energy and can simulate or optimize stand-alone or grid-connected systems. The program is based on the mathematical model created for the used equipment.

- **The photovoltaic panels**

During the simulation iHOGA calculates the power generated by the photovoltaic panels P_{PV}, as a function of irradiation and shortcut current [3]:

$$P_{PV} = \frac{I_{sc} \cdot G \cdot V_{PV} \cdot N_{PVs} \cdot N_{PVp}}{LF} \quad (1)$$

where I_{sc} is the shortcut current [A];
G – solar irradiance on the surface of the panels [kWh/m2];
V_{PV} – voltage generated by the PV panels [V];
N_{PVs} – number of PV panels in serial;
N_{PVp} – number of PV panels in parallel;
LF – loss factor caused by errors on the orientation of the panel or by the dust on the panels.

- **The wind turbine**

The power generated by the wind turbine in an hour "i", is calculated based on wind speeds and power curves of each turbine provided by manufacturers, according to the formula [3]:

$$P_T = v_i \frac{\ln \frac{z_{hub}}{z_0}}{\ln \frac{z_{data}}{z_0}} \quad (2)$$

where P_T is the power generated by the wind turbines (kW);
v_i – the wind speed measured to “i” hour (m/s);
z_{hub} - the level difference of the turbine rotor axis relative to the ground (m);

z_0 - the length of elements with irregular surfaces (m);
z_{data} – the level difference of the anemometer relative to the ground (m).

- **Energy storage batteries**

The lifetime of the batteries ($Life_{bat}$) is calculated with the following formula [3]:

$$Life_{bat} = \frac{1}{\sum_{i=1}^{m}\left(\frac{N_i}{CF_i}\right)} \text{ [years]} \qquad (3)$$

where N_i is the number of cycles depending on the discharge rate of the batteries;
CF_i - the number of cycles until the complete exhaustion of the storage capacity.

3. Case Study

3.1. The Energy Demand

Considering the needs of households from the rural environment, and also the requirements to ensure a typical electrification autonomous system, was established an energetic endowment considering the following consumers: indoor and outdoor lighting, radio, TV, refrigerator, power tools.

The simulations presented in this paper were made considering, each time, the same energy demand.

Based on the energy consumers, was considered an average energy consumption of 6.49 kWh/day and the following:
- average hourly AC load: 151 W;
- maximum hourly AC load: 339 W;
- frequency: 50Hz;
- voltage: 230V;
- cos ρ = 0.9.

3.2. The Hybrid System Located in the Wind Zone III

- **The potential of renewable resources on site**

The analysed hybrid system has the following geographical coordinates:
- latitude: 44º29 'North;
- longitude: 28º38 'East.

For this area, based on the geographical position of the system were used the daily average values of solar radiation and wind speed according to the months of the year, presented in Table 1 [5].

The simulations were performed during one year of operation considering the same weather conditions for the remaining years of the system functional. The system lifetime is considered to be 25 years.

Average daily values Table 1

Month	Daily average irradiation	Wind speed at 10m
	[kWh/m^2]	[m/s]
January	1.48	5.8
February	2.28	5.7
March	3.24	6.4
April	4.39	5.5
May	5.58	4.5
June	6.03	4.6
July	6.22	4.0
August	5.41	4.1
September	4.16	4.5
October	2.65	6.1
November	1.58	5.5
December	1.20	5.9

The average values of the solar irradiation on the plane of the photovoltaic panels are [3]:
- daily average irradiation 3.78 kWh/m^2 ;
- total annual irradiation 1380.08 kWh/m^2 .

• **The simulation results**

Simulations were conducted having as main objective the finding of an optimal solution in terms of ensuring the energy demand with a minimum initial investment and maintenance costs over the lifetime of the system.

To provide the energy demand, the system includes a wind turbine, photovoltaic panels and batteries as a backup system.

Performing the simulations for the autonomous energy system [3], the algorithms have determined the optimal configuration of the system according to the energy demand, having the following components:

- 4 PV panels of 100 Wp each, with a total power of 0.4 kWp ;
- 1 DC wind turbine, 1660 W ;
- 24 batteries, having a capacity of 816Ah each, E_{total} = 39.1 kWh;
- inverter, 4000VA.

Simulation results Table 2

Indicators	Unit	Value
Overall Energy Demand	[kWh/year]	2369
Percentage of Renewable Energy	%	100
Excess Energy	[kWh/year]	2080
Energy delivered by PV	[kWh/year]	460
Energy delivered by Wind Turbines	[kWh/year]	4504
Energy charged by Batteries	[kWh/year]	623
Energy discharged by Batteries	[kWh/year]	621
Batteries Lifetime	years	18
SOC min. batteries	%	20
Total CO_2 emissions	[kg CO2/year]	192

Considering that the minimum charging rate of the batteries is 20%, the simulation results for the solar-wind hybrid system are shown in Table 2, for a year of operating [3]. One can see that to cover the energy demand of 2369 kWh/year from renewable sources only, the system produces more than double. In Figure 1, the energy balance of the system for one year is graphically represented.

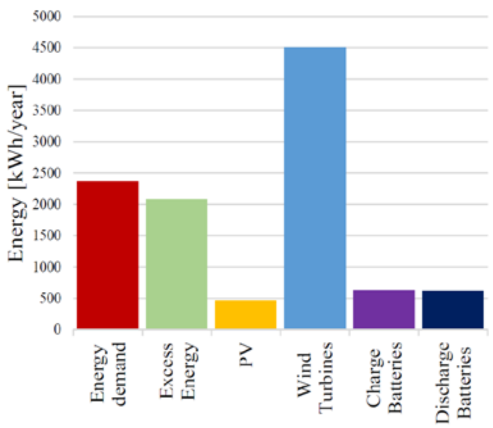

Fig. 1. *Balance of system energies*

In Figure 2 is presented the percentage costs of the equipment of the system [3]. It can be seen that the batteries hold the highest share of the total cost 42.69 %, as these have a lower lifespan than the other components of the system and must be replaced after a certain number of charge/ discharge cycles.

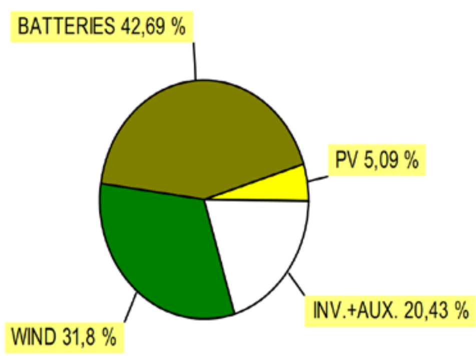

Fig. 2. *Percentage cost of the equipment[3]*

3.3. The Hybrid System Located in the Wind Zone IV

• The potential of renewable resources on site

The geographical data regarding the location of the system from zone IV are: 46˚25' North and 23˚38' East.

The solar and wind potential of the site can be seen in Table 3, which presents the daily average values of the solar radiation on the horizontal surface and wind speed at 10 m altitude [5].

Average daily values Table 3

Month	Daily average irradiation [kWh/m^2]	Wind speed at 10m [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 average values of the solar irradiation on the plane of the photovoltaic panels are [3]:
- daily average irradiation 3.36 kWh/m^2 ;
- total annual irradiation 1228.31 kWh/m^2.

The simulation results

Performing the simulations for the autonomous energy system located in the wind zone IV, it resulted that the optimal configuration of the system having the following components [3]:

- 8 PV panels of 135 Wp each, with a total power of 1.08 kWp ;
- 1 DC wind turbine, 3471 W ;
- 24 batteries, having a capacity of 686Ah each, E_{total} = 32.9 kWh;
- inverter, 900VA ;
- battery charge controller of 149A.

In Table 4 are presented the results of the simulations regarding the total energy production, excess energy, and CO2 emissions [3]. It may be noted that the energy demand is covered entirely by renewable energy.

Simulation results Table 4

Indicator	Unit	Value
Overall Load Energy	[kWh/year]	2369
Renewable Energy	%	100
Excess Energy	[kWh/year]	2149
PV	[kWh/year]	808
Wind Turbines	[kWh/year]	4112
Energy charged by Batteries	[kWh/year]	789
Energy discharged by Batteries	[kWh/year]	798
Batteries Lifetime	years	18
SOC min.batteries	%	20
Total CO_2 emissions	[kg CO2/year]	245

The energy balance of the hybrid system is graphically represented in Figure 3.

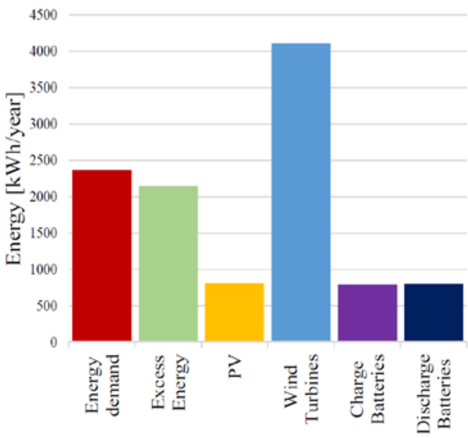

Fig. 3. *Balance of system energies*

Figure 4 presents the percentage cost of the equipment of the hybrid system [3].

In this case the highest percentage of the cost is held by the wind turbine 41.47 %, followed by the energy storage system 29.66%.

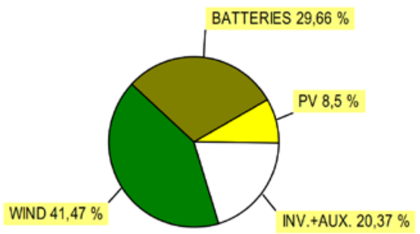

Fig. 4. *Percentage cost of the equipment[3]*

4. Conclusions

From the conducted study one can highlight the importance that wind power holds in a hybrid power system. As can be seen in Figure 5, in both cases, the highest percentage of the total energy is produced by wind turbines. Note that an increase of the average wind speed by 1.8 m/s involves a decrease in the total cost of the investment by approximately 17% for the same consumer (Figure 6). In this regard, should be considered in the future ways to increase the wind speed in the rotor section by using wind energy concentrators, as casing turbines [4].

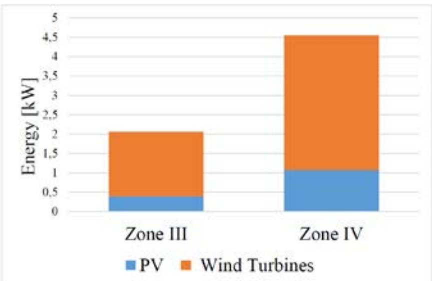

Fig. 5. *Energy generated by the system*

Also, the use of a higher number of photovoltaic panels, and a higher power wind turbine increases the negative environmental impact by increasing the amount of CO_2 produced by the equipment.

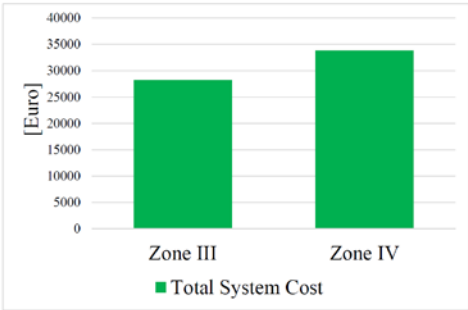

Fig. 6. *Economical comparison*

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