ASSESSING THE FEASIBILITY OF USING THE SOLAR RESOURCE TO POWER A REMOTE AGRICULTURAL CONSUMER IN BIHOR COUNTY

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Abstract - This paper aims to evaluate the possibility of using the solar resource in Bihor County in order to supply electricity to a water pumping system, to cover the needs of an agricultural consumer with annual water demands, such as a horse farm. The use of the Homer software for this evaluation involved the consideration of the pumping system as a deferrable load, and it was necessary to determine how to calculate the parameters that describe it: peak load, storage capacity, average load and minimum load ratio. Data on the solar resource available on the NASA website and a minimum of data for the hydraulic characteristics of the water source were used. Following the running of the program, it was necessary to refine the initial design so that the system also included an electricity storage subsystem in batteries. With the new data obtained it was possible to evaluate the feasibility of extending the electricity network to the pump site, and finally the conclusions were presented.

Keywords: water pumping systems, load profile, deferrable load, cost of grid extension

1. INTRODUCTION

Water supply to meet the most diverse demands is a universal requirement throughout the world, knowing that water is one of the most basic need for the development of human communities.

Due to the fact that the demand for water is constantly increasing and the rainfall is decreasing in many areas of the world due to climate change, surface water sources are becoming increasingly problematic, especially for isolated rural areas [1]. Consequently, groundwater sources appear to be the most desired solution for consumers in this type of locations [1].

Regardless of the available water source, water pumping systems powered by renewable resources tend to be more attractive than the classic ones powered by national power grids or unconventional energy sources. This is also due to the fact that agricultural areas, where the need for water is high, are mostly far from the points of connection with the energy system and/or the constant supply of fuel is problematic, not to mention the fact that maintenance staff are limited [1].

Due to the development and growth of the market for photovoltaic systems, their use for powering the water pumping systems is growing and is of increasing interest, both for small users of residential type and agricultural associations, as well as for large users of farm type or important agricultural producers.

This makes the study of the feasibility of implementing systems to harness renewable resources to power water pumping systems becomes significant, especially in the context of the rising price of electricity and fuels.

2. THE CASE STUDY

It is considered as a case study, a rural consumer who requires water supply throughout the year, a good example being the water supply to a horse farm and the solar resources to power an associated pumping system.

The demand for watering of a live stock is usually estimated as a product between the number of animals using the water supply system and the per capita water consumption Table 1.

Table 1 - Daily consumption of water per head [1]

Type of stock	Daily consumption per capita $D_{cons/capita}$ [l/day]
Dairy cows	80
Beef brood cows	50
Horses and mules	50
Calves	30
Pigs	20
Sheep and goats	10
Chickens	0.10

Considering, as a case study, a horse farm with an optimum capacity of N_{capita} =70 heads (according to Table 1, it is noticed that the water requirement per capita (R_{water}) can be obtain with the relation:

$$R_{water} = N_{capita} \cdot D_{cons/capita} = \\ = 70 \cdot 50 = 3500 \frac{l}{day} = 3.5 \text{ m}^3/\text{day} \quad (1)$$

Given that this water requirement is a critical component for our example, the animals not being able to be deprived of water for more than one day of the winter season, the farm will be provided with additional water tanks to ensure the necessary for at least 4 days of bad weather. Thus, the volume of water accumulated in the tanks will result as the product of the water requirement and the considered storage days, for 4 days of storage (DS), resulting in a total of:

$$V_{water} = R_{water} \cdot DS = = 3.5 \cdot 4 = 14 \text{ m}^3/\text{day} \quad (2)$$

For this reserve volume, 3 standard tanks of 5000 liters will be used, so the total volume of the farm's water reserve will be 4 · 5000 = 15000 liters ($V_{rez} = 15$ m^3), sufficiently to cover the farm's needs.

Due to the fact that the study refers to Bihor County, data on the available solar resource are needed. These data can be obtained from various sources, for this paper we have chosen those provided by the HOMER (Hybrid Optimization of Multiple Electric Renewables) software which, depending on the GPS coordinates of the place, downloads from the NASA database, the Global Horizontal Irradiation (GHI) values for flat solar panels were used. This indicator is calculated by the software as the sum of the direct solar irradiant perpendicular to the photovoltaic panel (DNI), the diffuse radiation and the radiation reflected from the ground, and is used to calculate the power generated by the photovoltaic panel when running the software.

In the case of the present study, it was considered a possible location for the horse farm a few kilometers from Oradea in Bihor County, which can be viewed using the virtual map provided by HOMER, Fig. 1.

Fig. 1 - Location of the horse farm

For these GPS coordinates, through the software downloaded from the NASA website, the characteristics of the solar resource, systematized in tabular and graphic form are obtained, as can be seen in Fig.2.

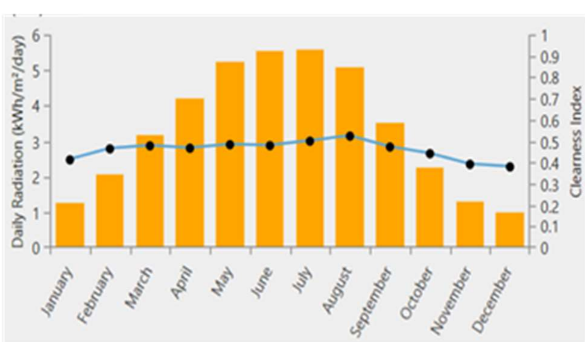

Fig. 2. Solar resource on site

Figure 2 shows that the lowest values of solar irradiance are in the winter months, this being the month we will consider peak sun hours for system PV based pumping system design. As shown in Table 2, for this month solar insolation will be 1,8 kWh/m^2 per day [2].

Table 2 - Average solar irradiance for winter months

Month	S_{sun} [h/d]			
Tilt angle	35	45	50	57
January	1.97	2.03	2.06	2.1
February	2.95	3.07	3.1	3.11
March	4.14	4.21	4.21	4.18
April	4.85	4.73	4.63	4.45
May	5.76	5.49	5.31	5.02
June	6.28	5.91	5.68	5.31
July	6.64	6.31	6.08	5.72
August	6.19	6.01	5.87	5.6
September	5.02	5.04	5	4.9
October	4.23	4.39	4.43	4.43
November	2.33	2.46	2.5	2.53
December	1.63	1.73	1.77	1.8

We considered a 57° PV tilt angle to maximize power for the lowest irradiance month of the year for this location thus, for the considered rural consumer, the following data summarized in Table 3 were obtained.

Table 3 - Preliminary input data

Parameter from the preliminary analysis of the consumer on chosen site	Value [units]
Daily water requirement	3.5 [m^3/day]
Volume of the water reservoir	15.0 [m^3]
Solar insolation (Peak sun hours)	1.8 [h/day]

These data resulted from the preliminary analysis of the horse farm type consumer and are necessary for the next phase of analysis.

3. ASSESSING FEASIBILITY WITH HOMER

The HOMER software was used, because it allows a quick evaluation of the most economically feasible solution for the production of clean and safe electricity, which represents precisely the purpose pursued in this work.

It was also taken into account that the software allows the modeling of electricity generation subsystems, including solar based on photovoltaic panels, consumer loads (both isolated and connected to the grid) and storage subsystems of various types, including batteries of accumulators [3].

3.1. The load profile

The load of the consumer is simulated, taking into account the economic efficiency and demand side management, the possible variants and configurations being ranked by the optimization engine of the software [3].

In our case, the load is the water pumping system that has to supply the horse farm. These systems have the characteristic that they require a certain amount of energy in a certain period of time, but the exact timing is not important [3]. HOMER classifies such loads as *deferred* when associated with storage. In the case of pumping systems, there is some flexibility as to when the pump actually operates, provided that the storage tank does not dry out [3]. Thus, the pumping systems are introduced by HOMER as *deferred load*, marked by "D" in Fig. 3.

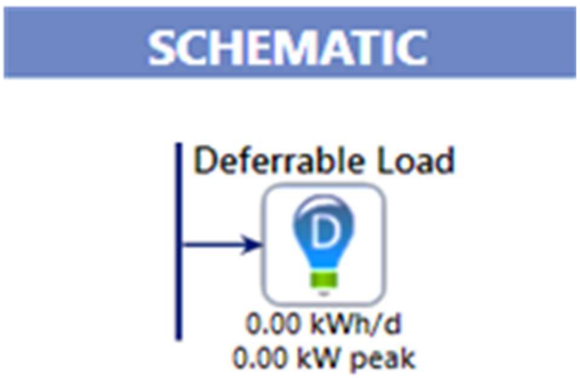

Fig. 3 - Pumping system as deferrable load

In the window corresponding to the deferrable load, the following variables is necessary to be calculated: storage capacity, peak load, minimum load ratio and average load, Fig.4.

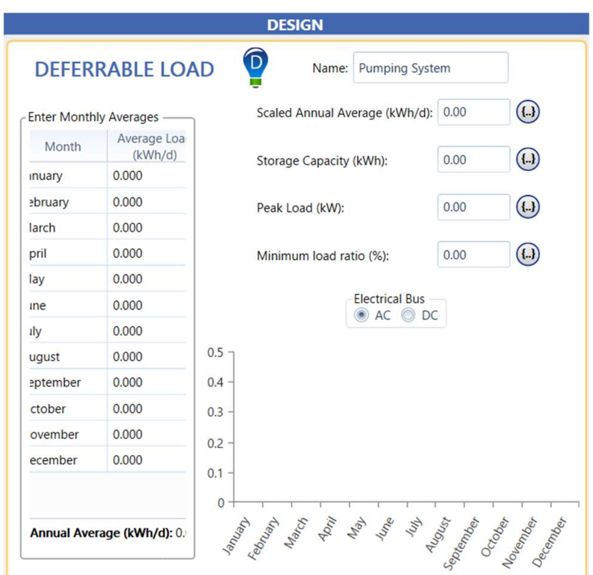

Fig. 4. The variables of the deferrable load

Since the peak load represents for pumping systems the nominal value of the power consumption of the pump [3], this value will be calculated first. To this end, the type of pump to be used must be determined, the following steps are necessary to complete:

a) Peak load: since, for pumping systems, HOMER considers it "is equal to the rated electrical consumption of the pump" [3], this parameter will be calculated first. For this purpose, the type of pumps that will have to be used for our system must be determined.

Typically, the choice of the type of pump for a pumping system is made taking into account [4]:

- Solar insolation in the site;
- The volume of the source required daily;
- The total dynamic level;
- Length of pipes used;
- Handbooks of various types of pumps provided by manufacturers.

In this paper, because only a rough approximation is required for our system, the type of pump will be chosen from three sources:

- Required daily pumping rate;
- Solar insolation (peak sun hours) S_{Sun};
- Handbook of pump manufacturers.

The daily pumping rate shall be calculated, according to [6], with the expression:

$$Q_{pump} = R_W / T_{Pump} / S_{Sun} = 3500 / 1.8 / 1.8 = 1080 \text{ l/h} \tag{3}$$

Where:

$R_W = 3500$ l/day
$S_{Sun} = 1.8$ h/day
$T_{Pump} = 1.8$ h/day

The values for the *water requirement* and *solar insolation* are calculated in the previous paragraph.

Pumping time represents the number of hours of operation of the pump in a day. If no battery storage subsystems are used, according to [6], it is taken as the default value equal to the value of the solar insolation, in our case of 1.8.

For a pumping rate of 1080 liters per hour, using the manufacturer's handbook, a pump with the nominal data presented in Table 4 is chosen, which provides a sufficient flow rate to cover the daily requirement.

Table 4 - Characteristics of the pumps chosen [7]

Pump type	DANKOFF
Flow rate ($D_{DANKOFF}$)	1080 [m^3/h]
Rated power ($P_{nDANKOFF}$)	0.380 [kW]
Rated voltage (U_n)	30 [V]
Rated current (I_{opt})	8.4 [A]

Table 4 shows that the pump power of 380W, is the value sought for the peak load and entered in the corresponding box from Figure 5.

b) Storage capacity (SC): according HOMER software engine, represents "the hydraulic energy necessary for the pumping system to complete filling of the water tank" [3] and we calculated this value with the following formula:

$$SC = P_{nDANKOFF} \cdot T_{full} / 1000 = \\ = 0.380 \cdot 13.8 / 1000 = 5.2 \text{ kWh} \quad (4)$$

Where:

$P_{DANKOFF}$ = the rated power of the pump chosen from the manufacturer's handbook;

T_{full} = the necessary time to fill the reserve tank(s) when the pump is running at optimum flow, calculated taking into account of the power of the pump chosen from the manufacturer's handbook ($D_{DANKOFF}$):

$$T_{full} = V_{rez} / D_{DANKOFF} = 15 / 1.080 = 13.8 \text{ h} \quad (5)$$

It is noticed if the filling time exceeds the number of daylight hours of the days in the winter season, in a subsequent refinement of the project, the following measures can be taken into account to reduce this value:

- Depending on the capacity of the water source and the hydrodynamic characteristics of the well, pumps with high-flow will be chosen;
- If the number of pumping hours still remains high, it is necessary to design a battery storage system.

The value of 5.2 kWh was entered in the corresponding box of the deferrable load data, Fig. 5.

c) Average load per day (W_{day}): is considered by HOMER as "the amount of power required to keep the level in the storage tank constant" and represents the baseline data for all the 12 months of the year [3]. To calculate these input data we determined the following formulas:

$$W_{day} = P_{optDANKOFF} \cdot T_{Oper} / 1000 = \\ = 252 \cdot 3.21 / 1000 = 0.7 \text{ kWh/day} \quad (6)$$

Where:

$P_{optDANKOFF}$ = the optimum power of the pump at nominal voltage and optimum current draw, values which is chosen from the manufacturer's handbook, Table 4;

$$P_{optDANKOFF} = U_n \cdot I_{opt} = 30 \cdot 8.4 = 252 \text{ W} \quad (7)$$

T_{Oper} = the operating time of the pump, representing the duration of operation of the pump at optimum flow to cover the daily water requirement. It is calculated with the relation:

$$T_{Oper} = R_W / D_{DANKOFF} = 3.5 / 1.080 = 3.21 \text{ h} \quad (8)$$

Because HOMER assumes that the deferable load is constant every month, the value obtained for the average daily load of 0.7 kWh/day will be entered in the corresponding table as the same for each month of the year, see Fig. 5.

d) Minimum load ratio (MLR): is defined by HOMER as "the minimum amount of power that can serve the deferrable load, expressed as a percentage of the peak load" [3]. In our case, the pump operates at minimum 8.4 A to serve the deferrable load, which corresponds at 30 V DC bus to a minimum power of P_{min} = 0.253 kW. It results that the minimum load rate can be calculated with the relation determined as:

$$MLR = P_{min} \cdot 100 / P_{DANKOFF} = \\ = 0.252 \cdot 100/0.373 = 66 \% \quad (9)$$

e) Electrical bus: according to Fig. 4, one we tick to specify "whether the deferrable load must be served by alternating current (AC) or direct current (DC) power." [3]. There may be two situations:

- The water pump is with ac motor;
- The photovoltaic system is on the bus of alternating current.

All photovoltaic systems generate in direct current, so when we check the AC box, we consider that the photovoltaic system has its own embedded inverter or it is taken together with a properly sized inverter. For this study, HOMER optimization engine opted for the photovoltaic system solution with the corresponding inverter.

f) Scaled annual average: if no exact data is available, "the default value for the scaled annual average is the baseline annual average" (W_{base})[3].

$$W_{scaled} = W_{base} = W_{day} = 0.8 \text{ kWh/day} \quad (10)$$

For our case, the baseline annual average is equal to baseline deferrable load entered each month due to the fact that these data are equal in every month. This value was also entered in the corresponding box of the deferrable load data, Fig. 5.

For this Study, following the calculations made so far, the view window for de deferable load results, Figure 5.

Fig. 5 - Screenshot with the deferrable load results

g) Dispatch strategy: for the pumping system considered it is chosen as a strategy the load following (LF). This is because "under the load following strategy, HOMER serves the deferrable load only when the system is producing excess electricity or when the storage tank becomes empty" [3], which corresponds to the purpose and configuration of the system considered, in our case study: water pump - storage tank.

3.2. The components of the system

As components HOMER considered any power generation systems that supply the load. In our case, the solar resource is used, so the component we are going to add is the photovoltaic system.

a) Photovoltaic system

Adding a generic component of 1 kW photovoltaic system on AC bus is considered by the software, both from a technical and cost point of view, that the system is composed of: PV panel, mounting hardware, cable, tracking system and inverter, Fig. 6.

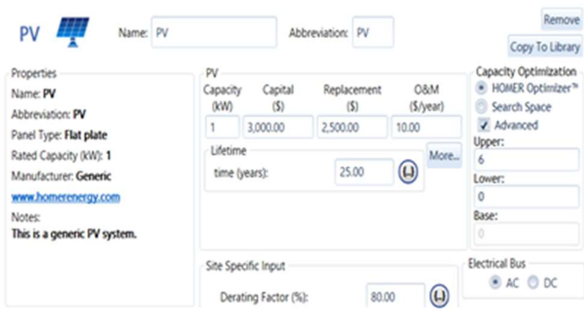

Fig. 6 - PV component tab

Replacement costs refers to photovoltaic panels and inverter, the rest of the hardware do not need to be replaced during the lifetime of the system.

The derating factor of 80 % is considered by HOMER as the "scaling factor applied to the PV array power output to account for reduced output in real-world operating conditions compared to operating conditions at which the array was rated." [3].

For further refinement of his design, the desired price values can be entered from the catalogs available at manufacturers.

b) The electricity grid

This component is added due to the fact that it is necessary to compare the costs of the PV – water pumping as a remote system with the costs of extending the electricity grid from the connecting point to the point of consumption.

The grid is added and treated by the HOMER as any other component of the hybrid system [3], the variables required to be completed being: capital cost, operation and maintenance and the price of energy, Figure 7.

The prices listed in the components table from figure 7 are at the RON/USD parity from 06.05.2022.

The final configuration of the photovoltaic system for pumping water in HOMER will be the one shown in Fig. 8.

Fig. 7 - The grid component tab

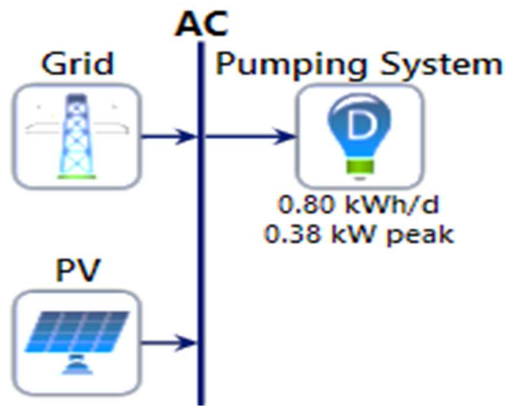

Fig. 8 - PV-water pumping system architecture

The dispatch strategy chosen is load following (LF), because as mentioned in point (g), it is most suitable for water pumping systems.

3.3. Simulation and results

After running HOMER, it results that in order to serve this load, a photovoltaic system with an installed power of at least 1.28 kW is required, all at the initial capital of 3827 $, Fig. 9.

The total costs of the system incur during 25 years lifetime considered, namely the net present cost (NPC) is calculated by HOMER at 3992 $.

Architecture				Cost	
			PV (kW)	NPC ($)	Initial capital ($)
			1.28	$3,992	$3,827

Fig. 9 - PV-water pumping system simulation results

This system is also sufficient to provide 5.2 kWh of energy for storing water in the reserve tanks with a total volume of 15 m³ of water, designed to cover the water requirement for at least 4 days of inclement weather.

In order to extend the grid to the horse farm, the pumping site would need to be within 0.14 km from the grid connection point to breakeven, Fig. 10.

From the renewable resource point of view, from the simulation made it resulted that the system has a high degree of PV penetration and this can cause stability problems. For this reason, it is preferable to use a storage system, either in inertial flywheel or in batteries [6].

In order to obtain the stability in operation, batteries with shallow cycle discharge can be used, in this case they have the role only to stabilize the current and voltage at the terminals of the pump motor and are not intended to be operated at night or days with clouds [6]. In this case, the charge controller must be set to limit the BA discharge to less than 20 % [6].

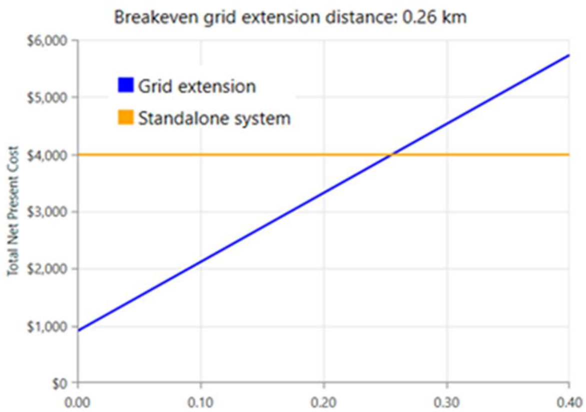

Fig. 10. PV power system electrification costs

In choosing the battery type, usually there are used units based on lead acid due to the fact that they are cheap and have high energy density. But it comes with the disadvantage of a service life of only 5 to 7 years, depending on the number of charging/discharging cycles so, for a project with a lifetime of 25 years, it is necessary to made 4-7 replacements.

In the latest period Lithium-based battery storage technology for insolated systems has entered on the market. These have a higher charging/discharging number of cycles (more than 4000) a lifespan of more than 10 years, so for a project with a lifetime of 25 years it is necessary to made one, maxim 2 replacements [8].

For this reason, we choose a Lithium iron phosphate (LFP) battery, HOMER software being capable to model this type of storage system, Fig. 11.

Fig.11 - Generic LFP battery tab

It results a new configuration of the pumping power system, consisting in a PV-BA with appropriate inverter, configurated by HOMER optimizer engine, Fig. 12.

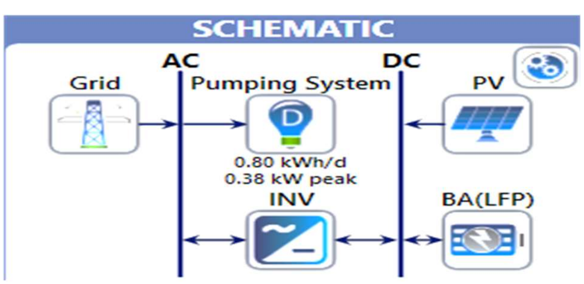

Fig.12 - Pumping system with LFP battery storage-based technology architecture

By running the software for the 2nd time, the following results are obtained:

In terms of system architecture, it follows that in order to serve the pumping load under the conditions of the solar resource profile obtained for the chosen site, an 1.13-kW installed PV and a single LFP based battery are required, together with a 0.5-kW inverter, Fig. 13.

Architecture			Cost	
PV (kW)	BA(LFP)	INV (kW)	NPC ($)	Initial capital ($)
1.34		0.343	$4,462	$4,244
1.13	1	0.417	$6,480	$5,135

Fig. 13 - PV-water pumping system simulation results

In terms of power, as can be seen from the Table5, the PV production is 1292 kWh/year with an excess electricity of only 987 kWh/year and 0.028 kW unmet load. The storage system provides an autonomy of 28.8 hours for the pumping system, sufficient both to cover the electricity needs and to ensure the stability of the current and voltage at the terminals of the pump motor.

Table 5 - Electricity results from simulation

Parameter	Value [units]
PV annual production	1292 [kWh/year]
Excess electricity	987 [kWh/year]
Unmet electric load	0.028 [kWh/year]
Battery autonomy	28.8 h
Battery expected life	10 years

As a dispatch strategy, HOMER's optimization engine automatically opted for the new system architecture, the cycle charging (CC), unlike architecture without storage, where load following (LF) dispatch strategy was chosen.

In terms of costs, as it shows in screen capture from Fig. 13, the initial capital and the net present const is higher than the previous system, due to additional replacement cost of the BA and INV. Ten years expected life of the LFP battery results in needing of two replacements along the 25 years of project life and the inverter only one, Fig. 14.

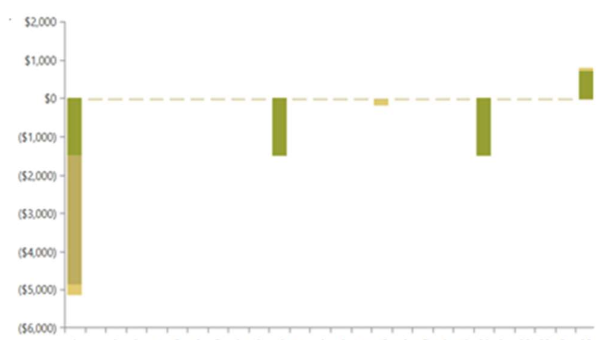

Fig. 14 - Screen capture of the system cash flow

In terms of electrification costs, in order to extend the grid to the horse farm type agricultural consumer, the pumping site would need to be within 0.45 km from the grid connection point to breakeven, Fig. 15.

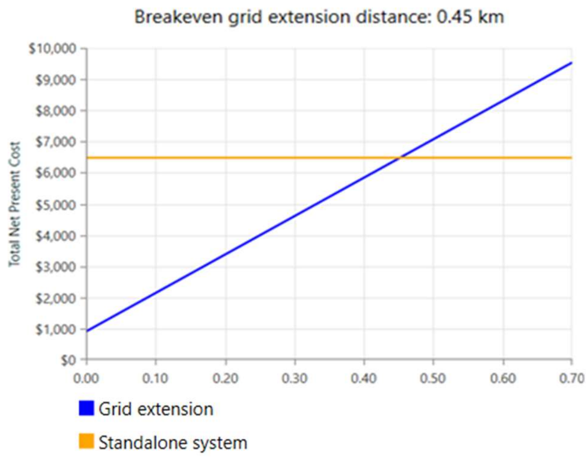

Fig. 15 - The PV-BA power system electrification costs

4. CONCLUSIONS

One of the most challenging problems encountered in the design of hybrid systems is the assessment of the feasibility of supplying water pumping systems from renewable resources to power remote agricultural consumers. This is due to the correct sizing of these systems requires knowledge of the exact hydraulic data of the water source used. Data of this kind are not known every time, especially when an assessment has to be carried out for a new location where does not exists study on the local water source.

With the help of the HOMER program, a gross economic and technical assessment was made for such a pumping system and for such a location, using a minimum available data: water demand of the consumer and the profile of the renewable resource, in our case, of the solar resource. This could be achieved thanks to a load parameter that the HOMER software engine uses, namely the "deferrable load".

In this paper were established the calculation formulas both for the water requirement and the estimated water reserve of a consumer for a horse farm type and for the parameters of the deferrable load: storage capacity, peak load, minimum load ratio and average load.

With these data, the architecture of the photovoltaic system could be made and after running the program were found that, for Bihor County, with the solar resource profile established for the chosen location of the farm, a purely remote photovoltaic system is feasible if it is located at a distance of more than 0.31 km from the connection point with the electrical network.

It has also been underlined that, due to the high level of renewable penetration, the voltage and current stability problems may occur at the pump motor terminals, HOMER suggesting the addition of an energy storage system in inertial flywheels or batteries. This led to a first refinement of the initial project by adding an inverter and a battery storage system. LFP-based batteries were chosen due to zero operating and maintenance costs and the number of higher charge cycles than the cheapest lead-acid ones.

After running the HOMER program, with the new system architecture, it was found that for a daily water consumption of 14 m³ per day and a water reserve of 15 m³, a 1.13-kW photovoltaic system with a single battery is sufficient both to cover the required load and to ensure the stability of the voltage and current at the terminals of the pump motor.

At the same time, it is found that the total lifetime costs of the system are justified only if the consumption point is located over 0.45 km from the connection point with the electricity grid. However, this can change if the design is subsequently refined by using accurate measurements and data of the hydraulic parameters of the water source, leading to an increase in net present cost (NPC) and therefore moving further the breakeven connection point.

It should be emphasized that for all the simulations performed, HOMER makes the calculations only for the electrical system, not including the costs with the works for the access to the water source (channels, drillings, etc.), which must be added later. Therefore, the NPC will grow even more, resulting in the further move of the breakeven connection point. This calculation is not part of the proposed objective for the present paper, being left for a future study.

To power an agricultural remote consumer using solar resource is a feasible solution for Bihor County region, a gross evaluation of the project can be made with minimal data using the HOMER simulation and optimization program, the project can be refined subsequently with exact hydraulic data according to the measurements on site. The accuracy of the design calculations is substantially improved if a water source is already available for the remote consumer, its parameters being measurable. Also, the total costs of the system will be lower, due to lack of access works to the water source.

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