



## DESIGN OPTIMIZATION OF A HYBRID HYDRO-WIND MICROPOWER SYSTEM FOR RURAL COMMUNITIES

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**Abstract:** Renewable energies can play an important role to provide electricity to rural communities. This work study the optimum design of a hybrid hydro-wind, micro-power system in rural area. Six case studies, including the impact of hydro head, flow rate, efficiency, and head loss for micro hydropower with wind turbine hub height were implemented based on HOMER software. The simulation results show the importance of using HOMER to assist system designers for assigning the optimum design of hybrid system components.

**Keywords:** HOMER, Renewable Energy, Micro-Power System, Hydro Power, Wind Power.

### التصميم الامثل لمنظومة قدرة كهربائية صغيرة هجينة (رياح – مياه) للمناطق الريفية

**الخلاصة:** الطاقات المتجددة يمكن ان تلعب دورا مهما في تزويد الطاقة الكهربائية للمجتمعات الريفية. يدرس البحث الحالي التصميم الامثل لمنظومة قدرة هجينة تعمل بطاقتي المياه والرياح في منطقة ريفية. تم دراسة ست حالات لهذه المنظومة اخذت بنظر الاعتبار تأثير ارتفاع منسوب المياه ومعدل جريانه وكفاءة التوربين المائي وفقد الارتفاع مع دراسة تأثير ارتفاع توربين الرياح وذلك باستخدام برنامج هومر. اوضحت النتائج لهذا البحث اهمية استخدام برنامج هومر لمساعدة المصممين في اختيار التصميم الامثل لمكونات المنظومة الهجينة

### 1.Introduction

The world today is pointing to a clean environment by reducing the hurtful emissions like carbon dioxide. One active way to achieve that is by expanding of using renewable energies. Also, these energies being the best manner to produce electric power to isolated (not grid- connected) rural communities due to its affordable, easily installed, and community ownership. Small-scale hydropower is a technique use moving water of the river to produce electricity in isolated regions with negligible environmental impact. Micro hydro system (as in Fig.1) is comprised of a number of components, the most important incorporate the intake where water is redirected from

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the natural stream, river, or maybe a waterfall. In mild climates, this structure must stand up to ice as well. As a rule miniaturized scale hydro establishment doesn't have a dam and supply, like expansive hydroelectric plants have, depending on a low stream of water to be accessible year-round. [1]

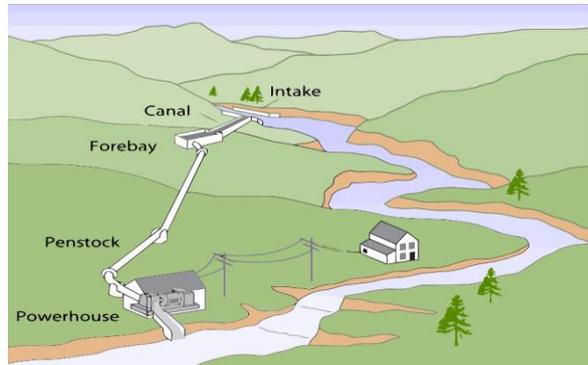


Figure 1: Typical run-of-river hydropower components

The wind is continually blowing somewhere and wind power has become a key player in the present power system. Actually, no vitality source keeps running at 100 percent limit, every minute of every day, 365 days a year .Rural communities benefit directly and indirectly from hydropower and wind power projects. Just as is the case with new jobs and additional income are created, new revenues are generated to be spent in local stores, restaurants, and services businesses, boosting the neighborhood economy and making more employments. HOMER is a micropower optimization modeling software developed by the national renewable energies laboratory (NREL) in the USA. Streamlines the errand of assessing designs of both off-grid and grid-connected power systems for a diversity of implementations. When we layout a power system, we must activate many resolutions about the arranging of the system:What combinations does it make sense to include in the system layout?How numerous and what estimate of each component ought to we utilize ? The expanding number of innovation alternatives and the variety in innovation costs and accessibility of energy assets make these choices troublesome. HOMER's optimization and affectability investigation calculations make it less demanding to assess the numerous conceivable system setups. The renewable energy as well as conventional power generating technologies can be modeled through HOMER. Many research works have been done in the field of design optimization for a hybrid micro power system, including micro hydro power units based on HOMER ,for example Deepark et al(2011) proposed a hybrid system consist of wind turbine,PV panels ,diesel generator ,and hydro power, to supply power of 3 MWh/day to an isolated area in India [2].

Niharika et al (2013) present the sizing of hybrid system contain solar,wind,hydro,biomass,diesel generator,and battery banks,to supply many neighboring villages in Malaysia of total power of 720 MWh/year [3]. Onojo et al (2013) used HOMER to simulate a combination of hydro,solar,an d biomass to supply a backup power of 493 kW /day to a building in Nigeria [4]. Luis et al (2015) study the

optimization of PV-hydropower system to supply a peak power of 287 kW ,installed on a small river dam in Brazil [5]. Getnet and Getachew(2016) discuss the optimization of 10 kW PV and 4 kW hydro on rural area lie on a river in Ethiopia [6].The aim of this work is to study the effects of hybrid hydro-wind considerations on the design optimization of stand-alone micro-power system.

## 2. Study Area

The sight which taken as a study area in this work (as in Fig. 2) is Beria village (19° 45' South , 43° 45' East) lay in the Pungwe river in Mozambique.



Figure 2: The map of the study area

## 3. System Modeling by HOMER

The proposed micro-power system for this work (as in Fig. 3) consist of three parts .The first part is the electrical load which is specified in Fig. 4. The second part is the wind turbine type PEG 20/25 which declared in Fig.5 and the average speed of study area is shown in Fig. 6 [ 7 ] .The third part is the mini hydro power generator which its resource inputs are demonstrated in Fig.7.

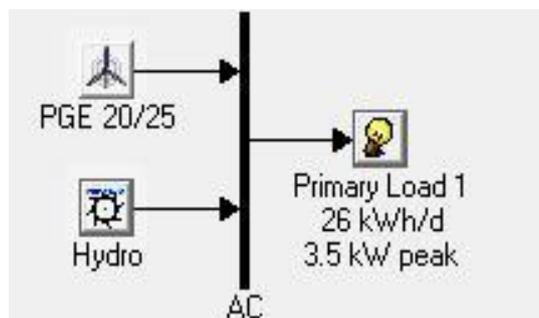


Figure 3: System configuration

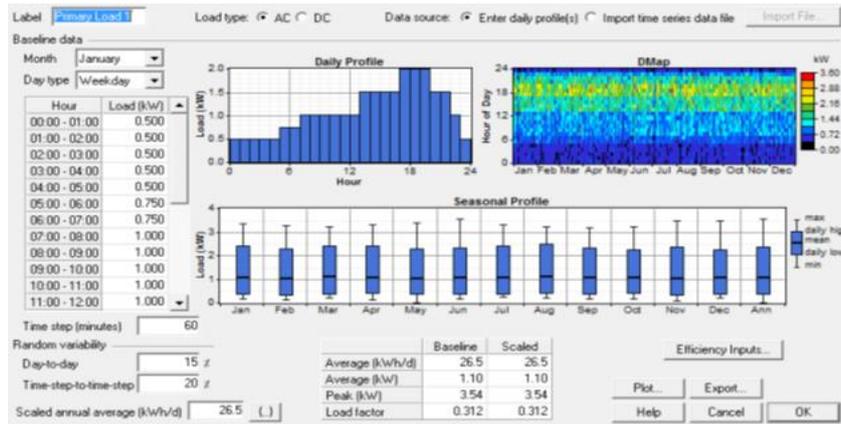


Figure 4 : The proposed load profile.

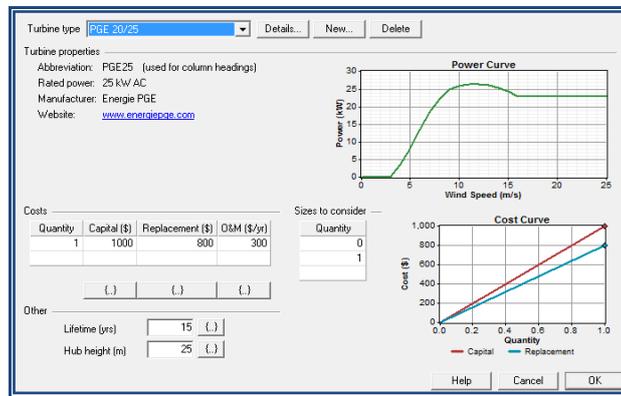


Figure 5: Wind generator specifications.



Figure 6 : Average wind speeds in Beira , Mozambique.

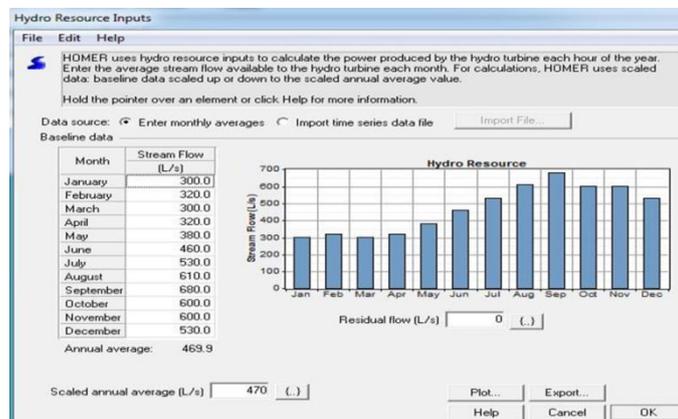


Figure 7: Hydro resources inputs.

## 4. Theoretical Background

In order to visualize this research work, the terms used in it were identified as follows[8]:

### 4.1. The Capacity Shortage Fraction ( $F_{cs}$ )

A capacity shortage is a decline in electric power that take place between the desired operating capacity and the existing quantity of operating capacity that can be provided by the system. The capacity shortage fraction is equal to the total capacity shortage divided by the total electrical demand. HOMER sees a system workable (or agreeable) only if the capacity shortage fraction is lower than or equal to the maximum yearly capacity shortage. HOMER employs equation 1 to calculate the capacity shortage fraction:

$$F_{cs} = E_{cs} / E_{demand} \quad (1)$$

Where

$E_{cs}$  = total capacity shortage [kWh / yr]

$E_{demand}$  = total electrical demand (primary and deferrable load) [kWh/yr]

HOMER keeps track of such shortages and calculates the total amount that occurs over the year.

### 4.2. The Pipe Head Loss ( $F_h$ )

It is the frictional loss within the hydropipeline, communicated as division accessible head. Water (like every goeey liquid) streaming through a pipe encounters a loss in pressure due to friction. We can express this pressure loss in terms of a loss of head, where the head is the vertical drop through which the liquid streams. In HOMER, we indicate the pipe head loss as a rate of the accessible head. Little high-head, low-flow hydro systems regularly encounter pipe head losses of between 10% and 20%. With low-head systems, pipe head losses are regularly as it were a couple of percent.

### 4.3. Available Head ( $h$ )

The full accessible vertical drop between the intake and the turbine. Frictional losses in the pipeline between the intake and the turbine make the effective head slightly lesser than the obtainable head. HOMER uses the obtainable head to estimate the titular hydro power and the effective head. It utilizes the effective head to estimate the power output of the hydro turbine.

#### 4.4. Wind Turbine Hub Height ( $z_{hub}$ )

It is the height over ground at which the rotor sits. Hub heights typically range between 25m (for smaller wind turbines, 50 kW or less) and 100m (for large, multi-megawatt wind turbines). Wind speeds resort to rise with height over ground, so if the hub turbine is not similar to the anemometer height, HOMER regulate the wind speed data appropriately.

#### 4.5. Hydro Turbine Flow Rate ( $Q'_{turbine}$ )

It is the amount of water passing through the hydro turbine .HOMER estimates this value each time step using equation 2:

$$\begin{aligned} Q'_{turbine} &= 0 && \text{if } Q'_{available} < Q'_{min} \\ &= Q'_{available} && \text{if } Q'_{min} \leq Q'_{available} \leq Q'_{max} \\ &= Q'_{max} && \text{if } Q'_{available} > Q'_{max} \end{aligned} \quad (2)$$

Where

$Q'_{available}$  is the flow rate obtainable to the hydro turbine

$Q'_{min}$  is the minimum flow rate of the hydro turbine

$Q'_{max}$  is the maximum flow rate of the hydro turbine

#### 4.6. Design Flow rate ( $Q'_{design}$ )

The design flow rate is the flow rate for which the hydro turbine is designed.This is also typically the flow rate at which the turbine works at its maximum efficiency ,although HOMER suppose the turbine efficiency is constant. HOMER utilizes the design flow rate to estimate the hydro turbine flow rate and the nominal hydro power.

#### 4.7. Nominal Hydro Power ( $P_{hyd.nom}$ )

Is the power generated by the hydro turbine given the obtainable head and stream flow equal to the design flow rate of the hydro turbine. The estimation of the nominal hydro power contains the efficiency of the hydro turbine ,but not the pipe head loss. HOMER uses this value only to characterize the size of the hydro system, and to permit easy rapprochement with the sizes of other parts of the power system. HOMER estimates the nominal hydro power using equation 3:

$$P_{hyd.nom} = \frac{\eta_{hyd} * g * Q_{design} * \rho_{water}}{1000 \text{ W/kW}} \quad (3)$$

Where

$\eta_{hyd}$  is hydro turbine efficiency [%]

$g$  is acceleration due to gravity [9.81 m/s<sup>2</sup>]

$Q_{design}$  is the design flow rate of the hydro turbine [m<sup>3</sup>/s]

$\rho_{water}$  is density of water [1000kg/m<sup>3</sup>]

#### 4.8. Cost of Energy (COE)

HOMER defines the leveled cost of energy as the average cost per kWh of useful electrical energy produced by the system .

#### 4.9. Net Present Cost (NPC)

The net present cost (or life-cycle cost) of a component is the present value of all the costs of constituting and operating the component over the project existence, minus the present value of all the revenues that it earns over the project existence. HOMER estimates the net present cost of each component in the system, and of the system as a whole.

### 5. Case Studies

Six case studies were implemented in this work. Case study 1 take the impact of hydro head on optimization when uses hydro power only, case study 2 take the impact of water flow rate on optimization when uses hydro power only, case study 3 take the impact of hydro turbine efficiency on optimization when uses hydro power only, case study 4 take the impact of hydro head loss on optimization when uses hydro power only, case study 5 take the impact of wind turbine hub height on optimization when uses wind power only, and case study 6 take the impact of hydro head on optimization when uses both hydro and wind power .

### 6. Simulation Results and Discussion

HOMER gave 8400 simulation results for the proposed system of this work cover all six case studies .Tables 1 to 6 show some of these results with respect to each case study.Figure 8 shows the optimum design in case studies 1 ,5, and 6 when wind turbine hub height= 15m, hydro head= 12m, design flow rate= 100L/s, hydro turbine efficiency= 95%, hydro head loss= 30% and maximum annual capacity shortage= 60%.

Table 1. Effect of hydro head (Case study1)

Hydro Head [m]	Output Power [kW]	COE [\$/kWh]	Capacity shortage [%]
4	3.7	0.081	0.00
6	5.6	0.081	0.00
8	7.5	0.081	0.00
10	9.3	0.081	0.00
12	11.2	0.081	0.00

Table 2 . Effect of flow rate (Case study2)

Flow rate [L/s]	Output Power [kW]	COE [\$/kWh]	Capacity shortage [%]
50	5.6	0.081	0.00
100	11.2	0.081	0.00
150	16.8	0.081	0.00
200	22.4	0.081	0.00

Table 3. Effect of hydro turbine efficiency (Case Study3)

Turbine efficiency [%]	Output Power [kW]	COE [\$/kWh]	Capacity shortage [%]
75	8.8	0.081	0.00
80	9.4	0.081	0.00
85	10	0.081	0.00
90	10.6	0.081	0.00
95	11.2	0.081	0.00

Table 4.Effect of hydro head loss (Case Study 4)

Hydro head loss [%]	Output Power [kW]	COE [\$/kWh]	Capacity shortage [%]
5	1.8	0.082	2
10	1.8	0.082	2
15	1.8	0.082	3
20	1.8	0.082	5
30	1.8	0.084	8
40	1.8	0.087	14
60	1.8	0.102	35

Table 5 . Effect of wind turbine hub (Case Study 5)

Wind turbine height [m]	Output Power [kW]	COE [\$/kWh]	Capacity shortage [%]
10	4.6	0.174	56
15	5.4	0.163	52
20	5.9	0.157	49
25	6.3	0.153	46

Table 6 . Effect of hydro head (Case Study 6)

Hydro Head [m]	Output Power [kW]	COE [\$/kWh]	Capacity shortage [%]
4	3.7	0.183	0.00
6	5.6	0.183	0.00
8	7.5	0.183	0.00
10	9.3	0.183	0.00
12	11.2	0.183	0.00

PGE25 Hub Height (m) 15		Hydro Head (m) 12		Design Flow Rate (L/s) 100				
Max. Annual Capacity Shortage (%) 60		Hydro Turbine Efficiency (%) 95		Hydro Head Loss (%) 30				
Double click on a system below for simulation results.								
	PGE25	Hydro (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage
		11.2	\$ 7,500	200	\$ 10,057	0.081	1.00	0.00
	1		\$ 8,000	359	\$ 12,594	0.163	1.00	0.52
	1	11.2	\$ 15,500	559	\$ 22,651	0.183	1.00	0.00

Figure 8: The overall system design.

From above results we see that ,the case study 1 is the optimum one, since it gave energy cost COE= 0.081 \$/kWh and the total NPC= 10, 057\$ which are the lowest, and the load is provided with the complete energy requirement, and there is no capacity shortage in feeding the load. While when using wind power only in case study 5 ,it is seen that according to COE and total NPC of this design categorized, the load couldn't be provided with total energy requirement and the capacity shortage depends upon the wind turbine hub height, for 15 meters height, the capacity shortage is 52%. Total NPC and COE are 12, 594\$ and 0.163\$/kWh respectively. According to COE and total NPC of design for case study 6, the load is provided with complete energy requirement and there is no capacity shortage in feeding the load ,and the value of total NPC and COE are 22, 651\$ and 0.183\$/kWh respectively.

## 7. Conclusions

The design optimization of a hybrid hydro-wind , micro-power system for rural community were investigated. Six case studiess were implemented using HOMER software and taking into account the consideration of hydro head,flow rate,efficiency ,and hydro loss for micro hydro power with wind turbine head.The optimun design were extracted from 8400 of HOMER simulation ressults.We can get the optimum design by using a hydropower turbine only with choosing some characteristics of it .Designers of micropower system with using renewable energies must implement HOMER software as a first stage for their design to guide them to have the right descions in planning and constructing such systems.Also it was concluded that the devolping hybrid micropower system using HOMER will encourage the private investors to expand their projects in isolated rural places using available renewable energies.

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