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# Design of Solar–Wind Hybrid System for Rural Electrification in Rwanda

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***Abstract* - Renewable Energy has become an attractive solution to electrify rural communities where to connect on national grid is expensive. For these areas that are far from the grid connection; off-grid solutions that includes both isolated distribution grids (mini-grids) with central power generation and individual stand-alone systems are more preferred. This is the same case in Rwanda due to its geographical situation with many hills. Therefore, this paper presents the development of an effective approach of design, simulation and analysis of a wind-solar hybrid system for a typical rural village in Kayonza District, Rwanda. This district has been chosen because is where we found the strongest wind speed in the country.**

**The main power of this hybrid system comes from the photovoltaic panel, wind turbine, batteries / inverter system, while the diesel generator is used as backup units and the optimization software used for analyzing is HOMER. The average daily load demand of the selected village is 265.14kWh/day where an approximate maximum demand of 29.2 kW has been observed during the evening hours between 18– 21PM; and the village has 200 households with average of five persons per household.**

**The optimal dispatch strategy of the diesel generator has been found to be Load following and the total net present cost of each system configuration has been calculated for 20 years of lifetime of system to examine the lowest energy cost option. It has been found that the combination of wind turbines, PV system, a battery bank and a diesel generator creates the optimum hybrid system.**
**The obtained results show that the required initial capital investment for this project is $ 268,000. Then, the NPC needed for this project is $ 850,480 with total O&M cost of $ 21,376 for the whole system which is mainly increased by O & M of the diesel generator, batteries and wind turbine. This system can satisfy the demand at a LCOE of 0.339 $/kWh with renewable fraction of 56% as found in simulated results.**

***Key words: Hybrid System, HOMER, Techno-Economics Analysis***

## I. INTRODUCTION

Nowadays, the increasing of energy consumption causes the development of different forms of energy, around the World. This demand has been supplied mostly by wood biomass especially for rural communities, in developing countries and this is unfriendly to the environment. In Rwanda, the electricity is mainly supplied through transmission lines, therefore some of remote areas have no access to national grid due to different factors such low generation capacity, difficulties of power system expansion because the country is made up of so many hills. Some remote area in Rwanda are basically powered by isolated generator set systems or photovoltaic system; and the challenge of using these technologies is that they cannot provide reliable electricity due to the daily maintenance and irregular nature respectively [3].

Reliable access to electricity is a basic requirement for improving people's lives for enhanced healthcare, education and for increasing the economy of a country. At present, more than 77% people in Rwanda do not have access to electricity and almost all of these people live in rural areas [1]. The Rwandan Government tried to increase national electrification by installing Photovoltaic system in schools locate far from the national grid, this is for a purpose of implementing also the program of "One Laptop per Child" [2].
Hence, the aim of this paper is to study the feasibility of a Wind-PV hybrid system for local electricity production in order to power rural communities; this addresses technical and economic viability for a specific site in rural Rwanda.

## II. METHODOLOGY

The research methods used to achieve our objectives are: to get wind and solar data of the selected village; and these data have been collected in our previous study, where it has proven that the best place in Rwanda for Wind-Solar hybrid system is in Kayonza District; due to its strongest wind. The wind and solar data found for the selected village are respectively the following: Direction of wind varies from 11 to 16° and Wind speed varies from 2 to 5.5 m/s; the daily insolation is ranging from 4 to 5.5 $KWh/m^2$ and peak sun hours of approximately 5 hours per day [4] [10] with an average of 5.13 $kWh/m^2$.
The other data need for this system design include the determination of the village load profile, studying component characteristics and costs to get the input parameters to our used tool HOMER for modeling and simulation; hence for economic viability the Levilized Cost of Energy (LCOE) and Net Present Cost (NPC) of the system have been calculated.

### *A. Village Load Profile*

Rwanda is among the countries with highest population density so the electric load considered at this point is to satisfy the demand of 200 households that are classified

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into 3 categories; 10 rich families, 140 medium income families and 50 low income families.

The village studied contains 200 households with the following institution in addition to house electric appliances which demand a supply of electric load: One school (primary and secondary school) which has 1-8 grades, 7 mini-shops including 2 barbers, 1 Health poste with 4 rooms, 1 milling house and 1 Government building which is used for office).

The village load demand profile is categorized in DC charges for water pumping with a scaled annual average of 3.25kWh/d; a peak load of 0.65 kW and AC charges for the remaining load with total scaled annual average of 265.14 kWh/d and a peak of 29.2 kW, that profile demand is presented in Figure 1.

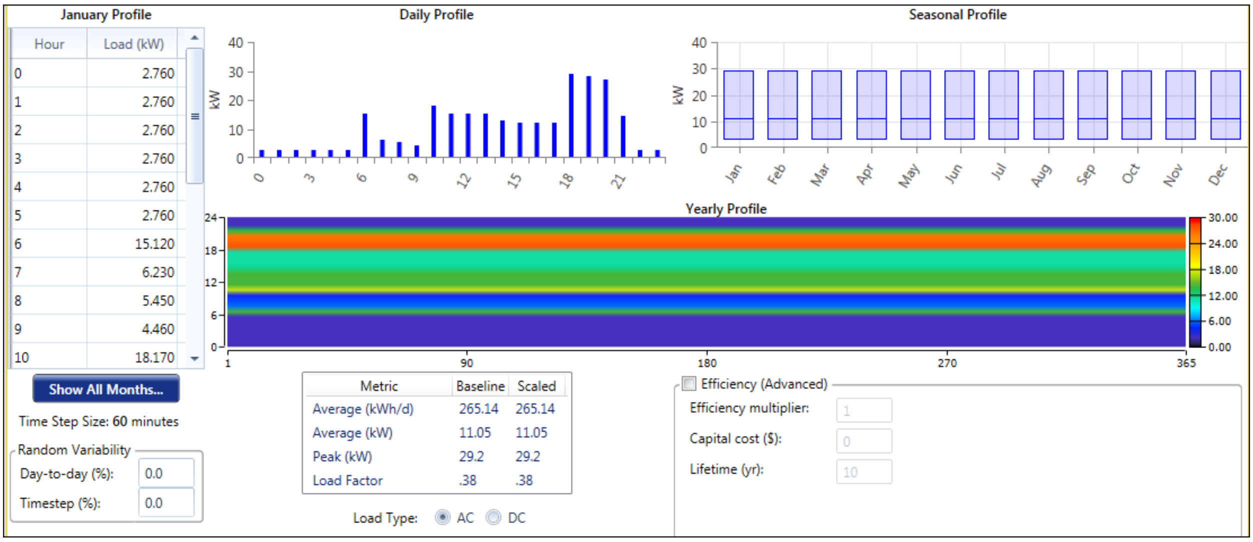


Figure1: Load profile for Kinyana Village located in Kayonza District

### B. *Homer Software*

International Renewable Energy Project Analysis Software called Hybrid Optimization Model for Electric Renewables (HOMER) is most widely used for carrying out quick prefeasibility, optimization and sensitivity analysis in several possible system configurations.

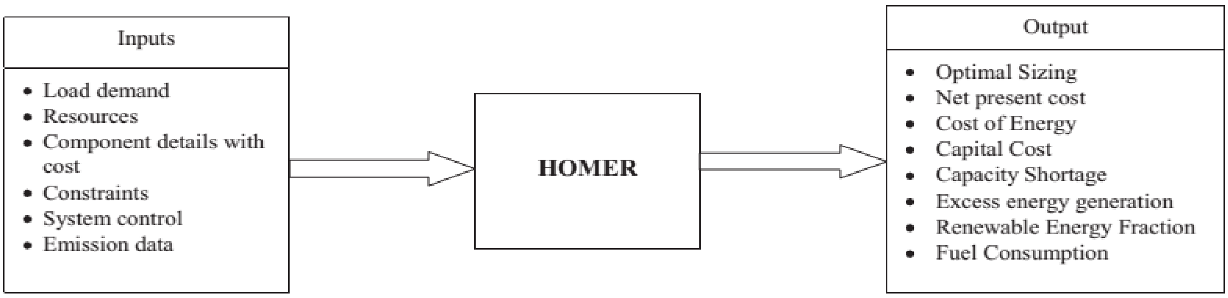


Figure 2: Schematic representation of HOMER

In this paper, PV array system, wind turbine, diesel generator with battery and converter are the components chosen for the analysis. It then determines the best feasible system configuration which can sufficiently serve the electric demand. HOMER simulates the system based on the estimation of installing cost, replacement cost, operation and maintenance cost, fuel and interest rate, it also displays a list of configurations sorted based on the Net Present Cost (NPC) and Levilized Cost of Energy (LCOE) [5][9].

Then, the list of various configurations of hybrid renewable energy will be tabulated from the lowest to the highest NPC and LCOE. The optimal solution of hybrid renewable energy system is referring to the lowest NPC and LCOE.

## III. SYSTEM MODELING

Figure 3 presents the configuration of overall component of the designed system and its model in HOMER. The program set-up includes all the simulations and possible arrangements that were tested for solar PVs and wind turbines, for several sensitivity value ranges of generation capacity, financing costs, wind speed and solar irradiation as described in previous chapters.

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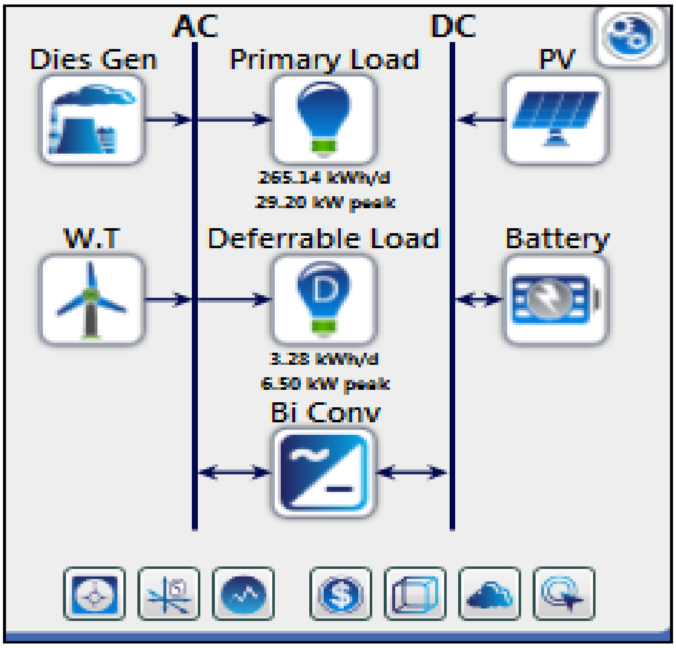



Figure 3: Configuration of the system in HOMER

*Homer Input Parameters*

Table I gives the summary of the costs, other technical details of the components and other required parameters which are given as the inputs to the HOMER hybrid model [6][8].

| Components | Size (kW) | Capital cost $ | O&M Cost $ | Replacement Cost $ |
|---|---|---|---|---|
| PV System | 10 | 35,000 | 20/year | 30,000 |
| Wind turbine | 10 | 20,000 | 500/year | 18,000 |
| Battery | 1156Ah | 1,200 | 10/year | 1,200 |
| Generator | 10 | 7,000 | 0.5/hour | 5,000 |
| Converter | 5kW, 48V | 550 | 5/year | 550 |

Average load demand is 11.05 kW with peak load demand of 29.2 kW and daily average demand of 265.14 kWh/d and the load factor of 0.38;

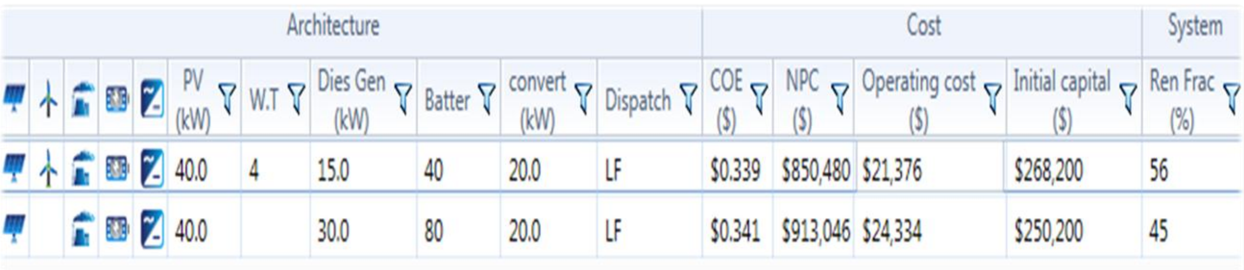
- ✓ Solar irradiance is 5.13 kWh/m$^2$/d with the clearness index of 0.513 and the average temperatures of 22.7°C;
- ✓ The battery is Surrette 6CS25P of 6V, 1,156 Ah (6.94 kWh);
- ✓ Diesel generator with a lifetime of 15,000 operating hours is used;
- ✓ Efficiency of 98 % for converter.

HOMER can model two dispatch strategies for the operation of the generator. These are “cycle charging” and “load following”. In cycle charging strategy, the generator is always operated at its rated capacity when it is required to operate and the excess energy is used to charge the batteries. In load following strategy that has been used in this study, the generator generates only the required amount of power when it operates [9].

## IV. RESULTS OBTAINED

### *A. OPTIMIZATION RESULTS*

HOMER simulations are done for several hybrid system configurations, which are the combination of PV/wind/Battery/ Diesel Generator system with different capacities. Homer calculates the total net present cost of all feasible systems and displays them in the optimization results by ranking them in ascending order of total net present cost. The system is having the lowest total net present value is optimum hybrid configuration Figure4.



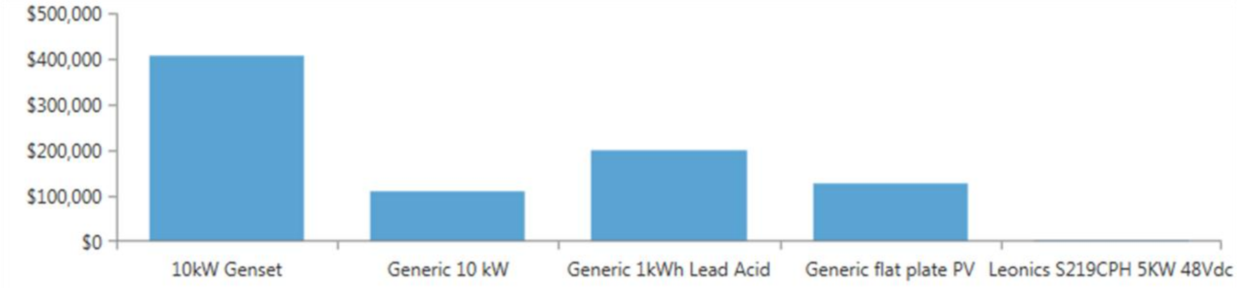
| PV (kW) | W.T | Dies Gen (kW) | Batter | convert (kW) | Dispatch | COE ($) | NPC ($) | Operating cost ($) | Initial capital ($) | Ren Frac (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 40.0 | 4 | 15.0 | 40 | 20.0 | LF | $0.339 | $850,480 | $21,376 | $268,200 | 56 |
| 40.0 | | 30.0 | 80 | 20.0 | LF | $0.341 | $913,046 | $24,334 | $250,200 | 45 |

Figure 4: HOMER optimization results

As shown in the optimization results, PV/wind/Diesel Generator/ Battery hybrid system is the optimum system composed by 40 kW PV panels, 4 wind turbines with 10 Kw rated capacity each; 15 kW diesel generator; 40 batteries of 1, 156 Ah each and inverters of 20 kW. With simulated results, this has the best cost of energy which is $0.339 comparing to the remaining ones.

### A. *Economic Analysis*

Economic details of the selected hybrid system scenario are presented in Figure 5.3, this scenario has low costs of O&M, LCOE and NPC compared to others.




| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| 10kW Genset | $6,000.00 | $25,421.63 | $43,066.41 | $337,737.16 | ($6,197.52) | $406,027.68 |
| Generic 10 kW | $72,000.00 | $0.00 | $39,225.57 | $0.00 | $0.00 | $111,225.57 |
| Generic 1kWh Lead Acid | $48,000.00 | $205,701.66 | $10,895.97 | $0.00 | ($63,166.89) | $201,430.74 |
| Generic flat plate PV | $140,000.00 | $0.00 | $21,791.98 | $0.00 | ($35,133.31) | $126,658.67 |
| Leonics S219CPH 5KW 48Vdc | $2,200.00 | $2,915.86 | $21.80 | $0.00 | $0.00 | $5,137.66 |
| System | $268,200.00 | $234,039.15 | $115,001.73 | $337,737.16 | ($104,497.72) | $850,480.32 |

Figure5: Cost summary for the proposed system scenarios

### B. *Technical Analysis*

Moreover, SC1 has been chosen for this project due to its larger amount of excess of electricity and its lowest LCOE compared to other scenarios. The renewable contribution for the selected system has 56%.

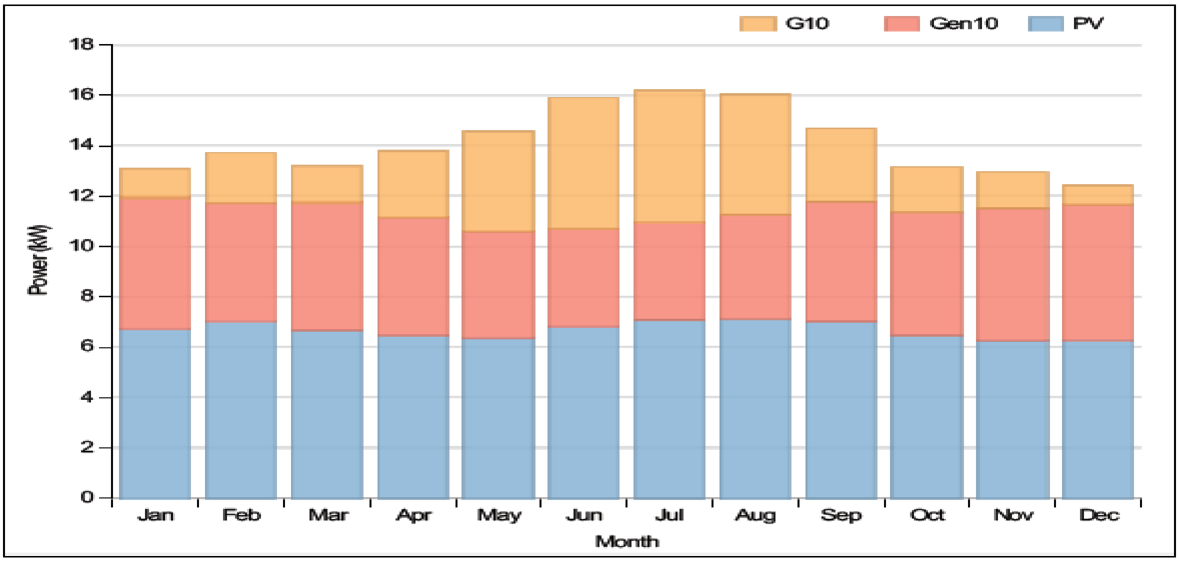



Figure 6: Technical Analysis of the selected system

So, as it is seen with Figure 6 the highest share of power production is from PV panel which contributes 58,597 kWh/year equivalents to 47.32% of the total electric production; while diesel generator is the second that contributes in the system with capacity of 40,923 kWh/year (33.04%) and the remaining is for Wind turbine with 24,323 kWh/year (19.64%) i.e. the total Electricity production for this system is 123,842 kWh/year. With the simulation results show, capacity shortage per year for this system is 9.9%; with excess electricity of 22.4% and unmet electric load is found to be 6.3%.

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## V. CONCLUSION

Nowadays, electrifying rural areas has continued to remain a challenging assignment for developing countries like Rwanda. In Rwanda the current COE is lower than the value obtained from the off-grid hybrid system considered in this study ($0.339/kWh) for the reason that the main source of energy in the country is hydro-power.

For developing this power production system in Rwanda, it requires government supports. The present cost for domestic user of national grid electricity is in range of 0.24-0.3 $/kWh, this depends on monthly energy consumption. Therefore, by considering the Government to fund 40% of the capital investment for this project the energy cost can be minimized up to an approximately of 0.2 $/kWh and the local people involve in maintaining and controlling this power system. So, the cost of energy obtained in this study (0.2 $/kWh) with the national grid users, the cost of Hybrid system is less than the price for using the national grid electricity.

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