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Optimal Sizing of Grid Connected PV/Wind Hybrid System Using Homer Software

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Abstract: ***The renewable energy sources have increased significantly due to environmental issues and fossil fuels elevated cost. Integration of renewable energy sources to utility grid depends on the scale of power generation. Large scale power generations are connected to transmission systems whereas small scale distributed power generation are connected to distribution systems. Conventionally a battery bank is used as the backup system in standalone Hybrid Renewable Energy Systems (HRES) while in grid-connected systems the grid performs as the backup during power shortage periods. For the latter, different prices of electricity during peak and off-peak hours raises a question about the cost effectiveness of using the grid as a backup this paper focuses on the design of an optimized grid connected small-scale HRES, The performance of the proposed design method is evaluated based on a case study for a typical Village in Ethiopia***.

Keywords: Wind energy, solar energy grid-connected hybrid systems

1. Introduction

Ethiopia has a lot of small hydropower, solar and wind energy potentials convenient for rural electrification. It is conceivable that a hybrid system has the advantage of improved reliability and therefore gives better energy service when compared to any particular (wind, solar, etc.) type of stand-alone supply system. What this means is that in the absence of one type of energy (example: solar energy during nighttime) another could be available (example: wind) to carry out the service. Hence, hybrid systems are found to be more appropriate than single stand-alone resources. Conventionally the balance between demand and HRES is obtained by grid in grid-connected systems and overproduction is sent into the grid. In these systems, the grid performs as the storage system with infinite capacity which makes the HRES reliable at any time. However different grid electricity prices in peak and off-peak hours could become an economical challenge in maintaining power shortage in peak hours from the grid. The generated power by wind turbine and PV arrays are depended on many parameters that the most effectual of them are wind speed, the height of WTs hub (that affects the wind speed), solar radiations and orientation of PV panels. In certain region, the optimization variables are considered as the number of WTs, number of PV arrays, and installation angle of PV arrays, number of storage batteries, height of the hub and sizes of DC/AC converter. goal of this work is optimal design of hybrid system for the one village in southern part of Ethiopia. The data of hourly wind speed, hourly vertical and horizontal solar radiation and load during a year are taken from some secondary data centers.

1.1 Current status of energy Development in Ethiopia

Table 1: Indigenous energy resources in Ethiopia (Report on Ethiopian Energy Sector [1])

Resource	Unit	Exploitable reserve	Exploitable percent
Hydro power	MW	45000	<5%
Solar /day	KW/m^2	Av 5.5	<1%
Wind power : Speed	GW m/s	1350 > 6.5m/s	<1%
Geothermal	MW	7000	<1%
Wood	Million tones	1120	50%
Agriculture Waste	Million tones	15-20	30%
Natural gas	Billion m^3	113	0%
Coal	Million tones	300	0%
Oil share	Million tones	253	0%

Renewable energy resources like solar and wind offer clean and economically competitive alternatives to conventional power generation where high wind speed and high solar radiation are available. For meeting the energy demand, PV wind hybrid power generating systems can be beneficial in enhancing the economic and environmental sustainability of renewable energy systems. Hybrid power systems are designed for the generation of electrical power using number of power generation devices such as wind turbine, PV, micro hydro and/or other conventional generators. In addition, it includes power electronics and electricity storage bank. Some of the advantages of using RESs are gain an immediate access to reliable electricity at any time; reduce the dependency from oil price fluctuations and the transportation costs of fuels; increase economic productivity and fight climate change.

1.2 Importance of the Hybrid System

Hybrid power supply systems consist of different energy sources in order to have more secured supply of electrical loads with increased reliability and durability of the system. The hybrid systems take advantage of the strengths of the subsystems to overcome the weaknesses of the individual systems. The features of the hybrid systems are mainly more reliable and less expensive than the conventional systems, because the solar sources are available during the day while the wind energy is 24 hours a day. It should be noted that wind and solar energy sources are practically free after the installation of their infrastructure. An efficient management or control system can determine the power flow to the loads from various components of the hybrid system during the period of operation. Note that in a hybrid system, the individual power sources are operating like a team supporting each other in a highly reliable manner. It is obvious that when the energy is drawn from the solar subsystem, the other subsystems can be viewed as standby systems.

1.3 Components the Hybrid System

A typical hybrid power generation system consists of various components as shown in Figure 1. The components can be summarized and described as follows

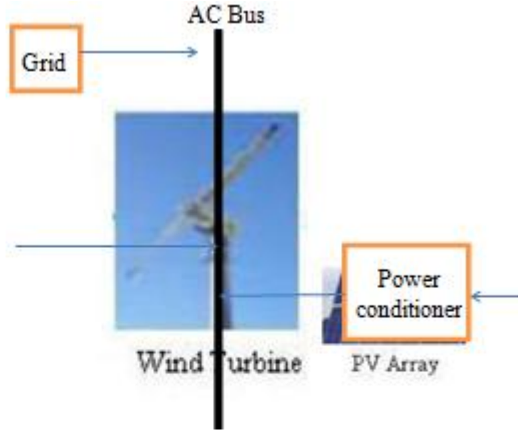

Figure 1: Concept diagram of PV/Wind hybrid system connected with grid

2. Solar and Wind Energy resource in Ethiopia

Ethiopia receives 4.55 to 6.5 kWh/m^2/day annual average of solar insolation throughout the country [1 - 6, 10]. This varies significantly during the year, ranging from a minimum of 4.55 kWh/m^2 in July to a maximum of 6.55 kWh/m^2 in February and March. Other literatures describe the yearly average radiation to be in the range from 4.25 kWh/m^2 in the areas of Itang in the Glabella regional state (western Ethiopia), to 6.25 kWh/m^2 around Adigrat in the Tigray regional state (northern Ethiopia) [8,9].Wind energy is another potential source of renewable energy. Winds are the motion of air caused by uneven heating of the earth's surface by the sun and rotation of the earth. It generates due to various global phenomena such as air-temperature difference associated with different rates of solar heating. Since the earth's surface is made up of land, desert, water, and forest areas, the surface absorbs the sun's radiation differently. Locally, the strong winds are created by sharp temperature difference between the land and the sea [7, 10].Ethiopia has exploitable reserve of 1350 GW wind energy with an average speed of 5.5 m/s, flowing for 6 hours/day. There are two basic zones with homogenous periodicity separated by the rift valley. In the first of these, covering most of the highland plateaus, there are two well-defined wind speed maximal occurring, respectively, between March and May and between September and November. In the second zone, covering most of the Ogaden and the eastern lowlands, average wind velocity reaches maximum values between May and August [7, 9, 10, 11, 13]. Currently two projects are being constructed, one Ashegoda wind park (near Mekele) of 120MW and the other Adama Wind Parks of nearlyAdama51MW and 153MW

3. System Modeling

The proposed possible modeling is used to design a grid connected HRES for a village in Ethiopia. Inputs of the design are load profiles and hourly average of wind speed and solar irradiance data for12 months of the year as a case study.

3.1 Load Estimation

Electric load in the rural villages of Ethiopia can be assumed to be composed of lighting, radio and television, water pumps, health post and primary schools load. In this study, electricity for cooking and for flour mills is added to the load together with home radio and a TV set. Water pumps are considered as deferrable loads while the others as primary loads. There are about 5,166 people without electricity now or even in the near future in this village. Assuming an average of 6 members in a family, there would be a total of 861 household. Assuming one elementary school and one health center per 320 families, a total of 3 primary schools and 3 health centers are required for the community.

Table 2: Load profile of home appliance

Appliance	Power	No	Time(h)	Energy (Wh/day)
CFL	15	4	4	240
TV	60	1	4	240
Refrigerator	80	1	8	640
Mitad	800		0.285	228.5
recorders	20	1	4	80
chargers	10	2	1	20
Others	50	2	1	100
Total Energy				1548.5

The total primary and deferrable load of the village is summarized in table below

Table 3: Summary of load on village

Load Type Category	Demand (kWh/day)	Jan-May	June	Jul & Aug	Sep	Oct-Dec
Deferrable		25	23	20	28	28
Primary	Household	1047.48	1047.48	1047.48	1047.48	1047.48
	Health Posts	16	16	16	16	16
	Primary Schools	18	18	18	18	18
	Mills	27	27	27	27	27
Total		1133.48	1131.48	1128.48	1136.48	1136.48

3.2 PV System Design

3.2.1 Solar resources of the area

Table 4: Solar data from NASA

Month	Ja	Fe	Ma	Ap	Ma	Ju	Jul	Au	Se	Oc	No	D	Av.
Clearness Index	0.601	0.653	0.661	0.649	0.66	0.59	0.58	0.62	0.59	0.59	0.58	0.66	0.62
Daily solar radiation (KWh/m²/d)	6.050	6.780	6.950	6.620	6.34	5.50	5.43	6.11	6.09	6.09	5.82	6.49	6.2

3.2.2 PV generator sizing

The peak power (Wp) of the PV generator (P_{PV}) is obtained from the following equation. [11]

$$P_{PV} = \frac{E_L}{\eta_R \eta_V PSH} S_f \qquad 2.1$$

Where

E_L is energy consumption per day = 1136,48KWh/day

PSH is the peak sun hours. 6.2

η_R is efficiency of charge regulator = 0.92

η_V is efficiency of inverter = 0.9

S_f is the safety factor, for compensation of resistive and PV-cell temperature

Losses = 1.15,

P_{PV} = 296KW$_P$

To obtain this peak value, we select to install multicrystalline-36 rectangular cells module type KC 130 GHT-2 of a 0.929 m² area, rated at 12 VDC , and P_{mpp} = 130 W. The number of necessary PV modules ($PV_{No.}$) is obtained as

$$No_{PV} = \frac{P_{PV}}{P_{mmp}} = \frac{296KWp}{130W} = 2,276 \text{ Module} \qquad 2.2$$

3.3 Wind Turbine System Design

3.3.1 Wind resource data

Table 5: Wind data at 70m height

Month	Ja	Fe	Ma	Ap	Ma	Ju	Jul	Au	Se	Oc	No	De	Av.
Speed at 70 m (m/s)	8	9.5	10	11	8	8	9	11	9	8	8	8	8.95

3.3.2 Wind Turbine Size Design

The wind power generated by a wind turbine can be obtained by:

$$P_{WT} = \frac{1}{2} \rho C_P V^3 A_{WT} \qquad 2.3$$

Where:-

$P_{WT}$is wind turbine power in *W*.

ρ1.225*kg* /*m*3 is the air density.

$C_p$is the wind turbine power coefficient

A_{WT} is the rotor disk area in *m*2 and

Vis hourly average wind velocity in *m s* at the hub elevation.

The performance of the whole system is then simulated with the equations of 2.4 and 2.5

$$P_{Total} = P_{PV} + P_{WT} \qquad 2.4$$

$$P_{Total} = P_{PV} + P_{WT} + P_{grid} \qquad 2.5$$

(2.4) if total power generated by wind turbine and PV is sufficient to cover the load demand otherwise

(2.5) where $P_{WT}$and $P_{PV}$is not sufficient during off-peak hours

4. Simulation result and Discussion using Homer Software

The main objective of the overall work is to propose the optimal combination of wind and PV together with grid systems in a form of a hybrid system, which will improve the system reliability and investment costs. HOMER simulates all the possible system configurations based on the combinations of the components specified to it as input data and discards the infeasible system configurations that do not adequately meet the suggested load with the available resource and/or specified constraints. Hence, only feasible combinations are displayed according to the total net present cost (NPC) in an increasing order. The optimization results are given out in an overall form and in a categorized form. For a particular set of sensitivity variables (solar radiation, average wind speed, diesel price, etc.), the overall table displays all feasible system configurations according to cost effectiveness. The categorized table displays only the most cost effective configuration from each possible hybrid system types.

4.1 Inputs data to the Homer

1) Monthly solar radiation

The graphical data shown below is the monthly solar radiation data for this specific area

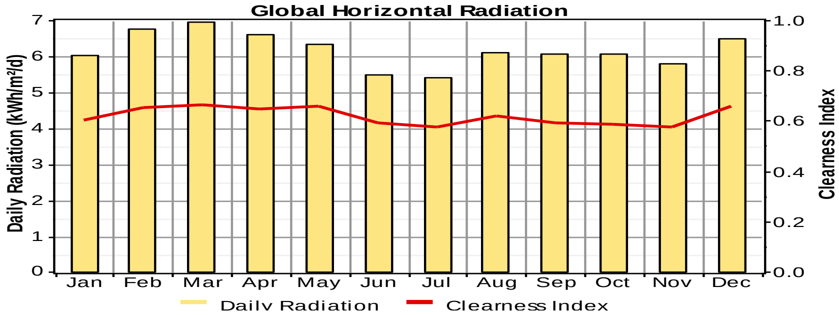

Figure 2: Monthly solar radiation data

2) Monthly wind speed

The graphical data shown below is monthly wind data for selected area at 70m height

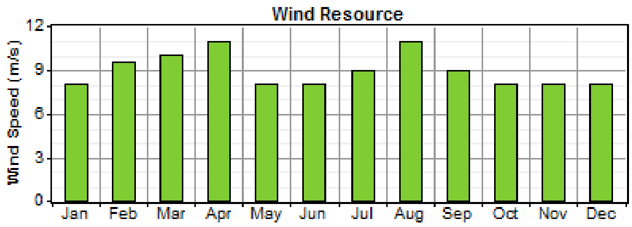

Figure 3: Graphical representation of wind resources

3) Primary load

The following data is the primary load input to the homer

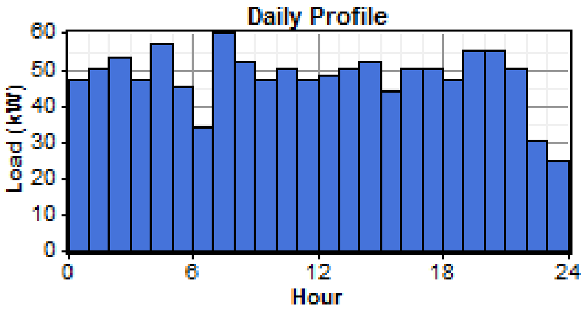

Figure 4: Daily primary load profile

4) Deferrable load

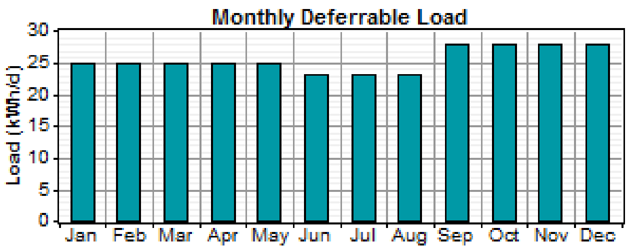

Figure 5: Daily deferrable load profile

5) Selected wind turbine

FL100 wind turbine is selected

Table 6: Characteristics FL 100 wind turbine

POWER		ROTOR	
Rated power:	100.0 kW		
Cut-in wind speed:	2.5 m/s	Diameter:	21.0 m
Rated wind speed:	13.0 m/s	Swept area:	346.0 m²
Cut-out wind speed:	25.0 m/s	Number of blades:	3
Survival wind speed:	67.0 m/s	Rotor speed, max:	46.0 U/min
Rated power:	100.0 kW	Tip speed:	51 m/s

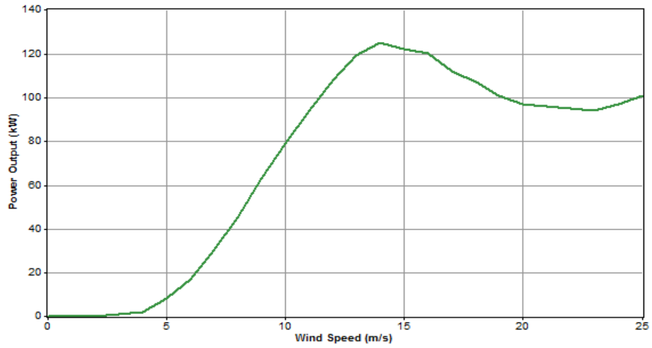

Figure 6: Power curve for FL100 wind turbine

6) Grid Electric Price in Ethiopia

Table 7: Grid price of Ethiopia

Grid	Off Peak Price BIRR/KWh	Peak Price BIRR/KWh
First 900KWh	0.3933	0.5085
Consumption after first 900KWh	0.58995	0.76275
Selling electricity to grid (birr/Kwh)		

4.2 Result and discussions

The results are displayed in an increasing order of the total net present cost (NPC). A given system type may have many different configurations based on the size combination of constituent elements. The categorized table displays only the most cost effective configuration from each system type. The overall optimization table displays all feasible system configurations (for any possible system type) ranked in their cost effectiveness. From the details of the optimization analysis the following can be observed: size of different components in each system, electric production of each component, capital, replacement and operating and maintenance cost of each system, annualized cost, excess and shortage of capacity, cost of energy (COE), renewable fraction, unmet load, amount of emission for each of greenhouse gas, consumption of diesel, operating hour and number of starting of diesel generator, life time of generator and battery, throughput of battery and fuel cost. Renewable fraction cost of energy (COE), unmet load and total NPC values can be used as a parameter of selecting a given configuration among the many candidates.

a) First scenario with 500KW purchase capacity of the grid with Small Cost of energy

(Less renewable penetration)

Within this scenario the following optimization result is obtained. The graph shown below cash flow summary of the first Scenario

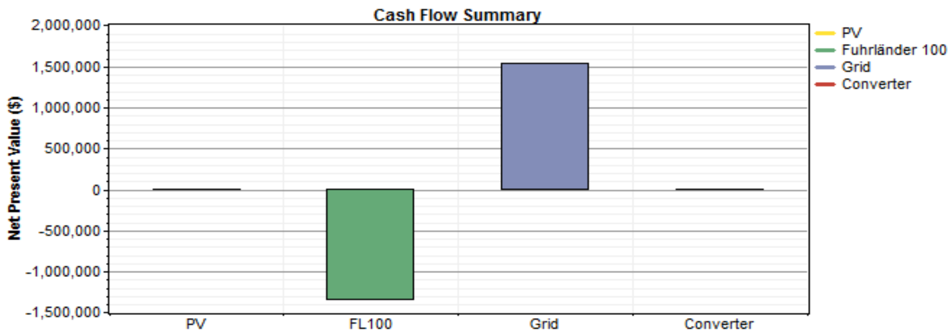

Figure 7: Cash flow summary for the least optimal value

According to this result large amount of cost is wind and grid purchased cost because most the capacity is covered by grid and Wind turbine. Total Electrical productionof this scenario described below

Table 9: Total electrical production of the system and percentage share

Production	KWh/day	%
PV array	1,702	0
Wind turbines	4,399,120	99
Grid purchases	59,503	1
Total	4,460,325	100

i) Production from PV

Table 10: Electrical production from PV

Quantity	Value	Units		Quantity	Value
Rated capacity	1.00	kW	Minimum output	0.00	kW
Mean output	0.19	kW	Maximum output	0.88	kW
Mean output	4.66	kWh/d	PV penetration	0.411	%
Capacity factor	19.4	%	Hours of operation	4,380	hr/yr

ii) Production from Wind turbine

Table 11: Electrical production from Wind Turbine

Quantity	Value	Units		Quantity	Value
Total rated capacity	1,000	kW	Minimum output	0	kW
Mean output	502	kW	Maximum output	1,250	kW
Capacity factor	50.2	%	Wind penetration	1,062	%
Total production	4,399,150	kWh/yr	Hours of operation	8,395	hr/yr
			Levelized cost	0.0238	$/kWh

iii) Production from grid

Table 12: Electrical production from grid

Month	Energy purchased (KWh)	Energy sold (KWh)	Net purchase (KWh)	Peak demand (KW)	Energy Charge ($)	Demand Charge ($)
January	6,082	191,673	-185,591	91	-9,280	297
February	3,344	210,366	-207,021	71	-10,351	353
March	4,022	242,753	-238,731	73	-11,937	365
April	3,122	252,212	-249,090	67	-12,455	246
May	5,827	191,541	-185,714	91	-9,286	314
June	6,199	185,341	-179,142	84	-8,957	282
July	4,558	220,267	-215,708	72	-10,785	275
August	3,933	260,418	-256,485	81	-12,824	392
September	5,111	213,065	-207,955	71	-10,398	298
October	5,746	190,939	-185,193	67	-9,260	325
November	5,581	185,237	-179,655	85	-8,983	268
December	5,977	190,921	-184,944	83	-9,247	381
Annual	59,503	2,534,733	-2,475,230	91	-123,762	3,796

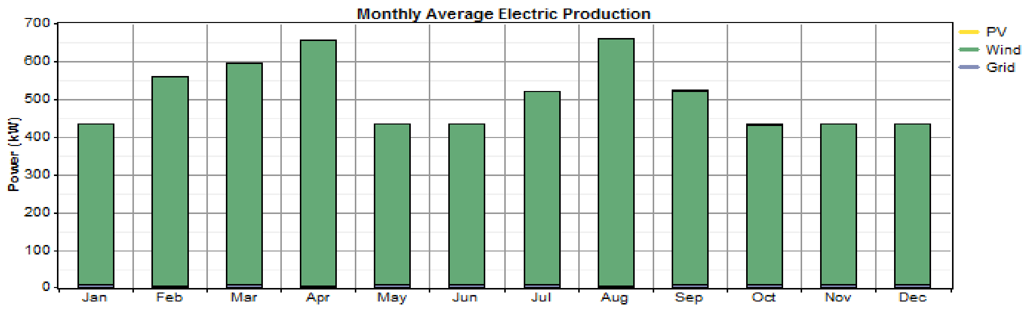

Figure 8: Graph data of monthly electric production

b) 2nd scenario with 500KW purchase capacity of the grid with increase Cost of energy (High renewable penetration)

Within this scenario the following optimization result is obtained .The graph shown below cash flow summary of the first Scenario

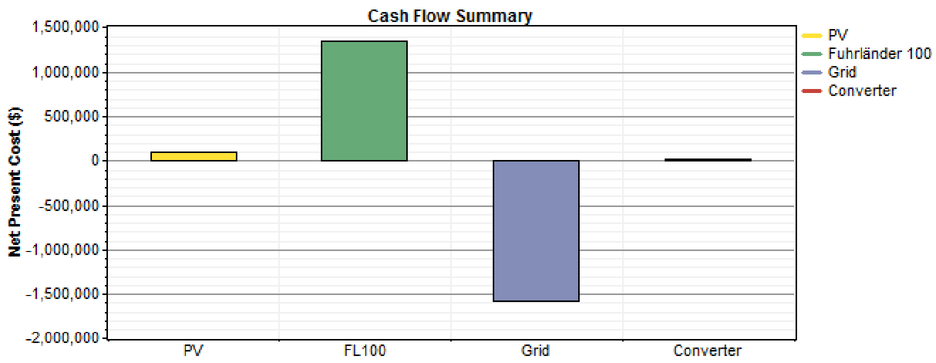

Figure 9: Cash flow summary for this scenario

According to this result large amount of cost is wind and grid purchased cost because most the capacity is covered by grid and Wind turbine.

Table 13: Electrical productions this scenario

Production	KWh	%
PV array	170,201	4
Wind turbines	4,399,120	95
Grid purchases	47,656	1
Total	4,616,977	100

i) Production from PV

Table 14: Electrical production from PV

Quantity	Value	Unit	Quantity	Value	Unit
Rated capacity	100	kW	Minimum output	0.00	kW
Mean output	19.4	kW	Maximum output	87.6	kW
Mean output	466	kWh/d	PV penetration	41.1	%
Capacity factor	19.4	%	Hours of operation	4,380	hr/yr

ii) Production from Wind turbine

Table 15: Electrical production from Wind Turbine

Quantity	Value	Units	Quantity	Value	Units
Total rated capacity	1,000	kW	Minimum output	0	kW
Mean output	502	kW	Maximum output	1,250	kW
Capacity factor	50.2	%	Wind penetration	1,062	%
Total production	4,399,150	kWh/yr	Hours of operation	8,395	hr/yr
			Levelized cost	0.0238	$/kWh

iii) Production from grid

Table 16: Electrical production from PV

Month	Energy purchased (KWh)	Energy sold (KWh)	Net purchase (KWh)	Peak demand (KW)	Energy Charge ($)	Demand Charge ($)
January	5,254	196,409	-191,155	91	-9,558	297
February	2,752	214,176	-211,424	71	-10,571	353
March	3,151	246,408	-243,256	73	-12,163	365
April	2,481	254,696	-252,216	67	-12,611	246
May	4,489	197,375	-192,887	73	-9,644	314
June	4,682	191,220	-186,538	73	-9,327	282
July	3,652	223,870	-220,218	72	-11,011	275
August	3,400	262,246	-258,846	78	-12,942	392
September	4,224	216,150	-211,926	71	-10,596	298
October	4,581	195,915	-191,335	66	-9,567	325
November	4,616	189,388	-184,772	85	-9,239	268
December	4,478	196,764	-192,286	76	-9,614	381
Annual	47,760	2,584,619	-2,536,859	91	-126,843	3,796

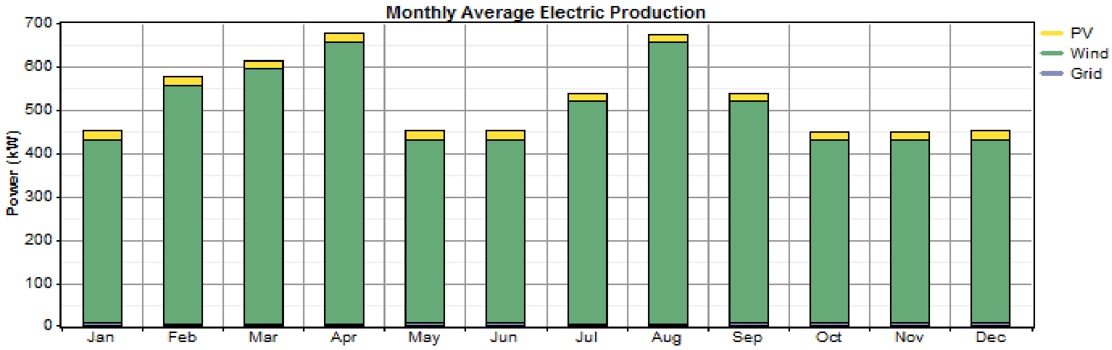

Figure 10: Graph data of monthly electric production

5. Conclusion

In this sample study of Grid connected PV/wind hybrid system for electrification of small community in Ethiopia is carried out.. HOMER is used for optimization the system. Finally I would conclude that grid connected PV/Wind Hybrid system optimization depends on two basic issues. The first issue is based on less amount of cost of energy if our optimization mostly focused on cost of energy the first scenario is the best one, But in first scenario the amount of PV penetrated to the system is very small almost negligible. The second optimization consider ofcapacity of renewable penetration to the grid. When the capacity of renewable penetration to the grid the second scenario is best. However based on these two scenarios it is possible to see further technical issue like Power quality problem, performance analysis and so on.

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