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Evaluation Of The Viability Of Solar And Wind Power System Hybridization For Safaricom Off-Grid Gsm Base Station Sites

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ABSTRACT: People no matter where they are need to communicate with the rest of the world. To enable those in remote marginalized areas communicate it has been increasingly important for the telecommunication network providers to install transmitting base stations in these regions. The study focused on the use of a hybrid system consisting of diesel generator, the solar panels and wind turbine generator. Diesel generators provide energy all the time, whereas PV and wind are dependent on solar radiation and wind speed, respectively. Load demand and renewable resources (wind speeds and solar radiation) are the major problems that face power generation using hybrid systems. The major concern therefore is the accurate choice of system components that economically satisfy the load demand. The study looked at Safaricom Limited. Safaricom Limited was formed in May 2000 as a joint venture between Telkom Kenya and Vodafone UK. It enjoys countrywide network coverage of over 80% of the Kenyan population estimated at 46 million people in the 2016 UNESCO population estimate. It provides voice and data services that include GPRS, EDGE, HSPDA and WiMAX. Safaricom has about 2,500 base stations with a mix of 2G, 3G, 4G and WiMAX technologies, most of which are powered from the grid with diesel generator as back up. However, 10% of the sites are solely on diesel-powered generators on a 24-hour basis. Additionally, 3% of the BTS are on renewable energy hybrid systems.

KEYWORDS: **Hybid**, Photovoltaic, Homer, Renewable energy, Green energy sources.

I. INTRODUCTION

Telecommunication network providers have no alternative but to install Base Transmitting Stations in far remote and marginalized areas to enable those living in these parts communicate with the rest of the world. The however have to contend with the fuel costs since these areas are remote and the cost of grid extension are majorly prohibitive. Alternative sources of energy such as solar, small hydroelectric generation and wind offer a realistic a substitute. (Nandi and Ghosh, 2009; Dihrab and Sopian, 2010).

The amplified interest in environment and inflated costs of obtaining electrical energy from conventional sources have accelerated the interest in alternative energy sources. The conventional electrical generation has often used coal, oil, gas, water or fissile nuclear material as the main fuel source. Geothermal power generation has elicited interest. There are problems facing development of methods of generating power based on conventional fuels. Generation of hydro-power is restricted to geographically appropriate areas in that it is influenced by the area's topography and its rainfall patterns. Coal reserves on the other hand are limited and not sustainable. The conceivable perils of atomic power have been generally advanced, especially those concerning the capacity and military utilization of atomic waste material. By and by, to help keep up with electrical energy demand it is necessary to expand the use of atomic power.
Wind and photovoltaic sources are major alternative source of future power. They are available in remote areas where the main grid power is not available. Wind and solar energy have attracted a lot of attention over the last couple of years (Bekele, 2009). There are distinctive arrangements of sustainable and traditional vitality sources that have been conveyed for media transmission purposes. Different configurations have incorporated Diesel-Battery; Solar-Diesel-Battery; Wind-Diesel-Battery; Solar-Wind-Diesel-Battery; Solar-Hydro-Diesel-Battery, among others. The decision of unlimited power selections is somewhat dictated by the area of installation. The use of sunlight based and wind vitality frameworks be they independent or in a mix will ultimately depend on the climatic conditions at the place, whereas the hydroelectric designs are dependent on geography and precipitation designs of the area (Bekele, G., Palm, B, 2010)

The GSM Association speaking to the interests of the overall portable correspondences industry gauges that "almost 639,000 off-framework base station bits of gear giving cell organize scope were taken off by 2012 crosswise over South and South East Asia, The Middle East and Africa where lattice accessibility is among the most minimal on the planet" (Ashok, 2007). Vitality represents up to 60% of the system working costs and corporate arrangements are currently set up to decrease the carbon impression, Ashok, (2007).

II. HYBRID POWER SYSTEMS

A power generation framework whose supply comprises of a mix of two or more sources can be described as a hybrid powered system (HPS) these may include sources like sun oriented photovoltaic boards, wind turbine generators, hydro plants, and additional fuel generators.

III. HYBRID POWER SYSTEM CONFIGURATION

The major problem faced in power generation using the hybrid system is the variation in load demand and renewable resources (solar radiation and wind speeds). Therefore, the major concern in the design of an electric power system that utilizes renewable energy sources is the accurate selection of the combination of system components that can economically satisfy the load demand, (Peterson, 1999). Based on the cost of components, fuel, labour, transportation and maintenance, it was desired to evaluate the most cost-effective size of all components to meet the predicted peak loads. In this optimization problem, hybrid system sizing is done with the aim of minimizing net present costs while meeting a given demand reliably and cost-effectively. One method of doing this is to incorporate computer simulation models for hybrid power systems (Elsholz, 1999).

IV. FINDINGS FROM THE BTS IN SEKANANI

THE HYBRID POWERED BTS AT SEKANANI IN MASAI MARA

The study site is located at Mara Siana conservancy, directly bordering the Masai Mara game reserve, on the premises of Mara BushTops game lodge. The exact coordinates of the site are: Latitude; 02° 17’ 51.45” S and Longitude; 035° 02’ 34.81” E.

PHOTOVOLTAIC PANELS

There are two arrays of four 250 W photovoltaic panels manufactured by Sanyo. It was observed that the photo-voltaic panels were mounted on the ground. It was further noted that there was a photovoltaic controller/regulator that links the photovoltaic cells to the battery bank. This controller is built for outdoor application and is used to regulate solar energy flow to the storage battery bank.

THE WIND GENERATOR

The wind generator on the site is a Bergey EXCEL 10 model rated at a maximum power output of 8.9kW. The Bergey EXCEL 10 is an upwind horizontal-axis wind turbine designed for distributed generation application and, where possible can be connected to the power grid. It has a rotor system that consists of three fiberglass blades. The blades convert the energy of the wind into rotational forces that drive the alternator.

Wind speeds vary heavily and therefore there is need to have stronger blades that can be able to withstand the changes. The generator is mounted on a mast of lattice type at a height of 24 m. The rotor of the EXCEL 10 begins to rotate when the wind speed reaches approximately 3.6 m/s. Once started, the rotor may continue to turn in winds below 2.2 m/s, but the system will not be producing power below this wind speed. During periods of high wind speeds, the AutoFurl system will automatically protect the wind turbine. The generator is designed for a maximum wind speed of 54 m/s, and therefore at any wind speed above this the generator will definitely need protection and AutoFurl suits the best candidate for this. Furling means that the rotor is turned away from the wind. When furled, the power output of the turbine will be reduced. In winds between 15 m/s and 20 m/s it is normal for the turbine to repeatedly furl and unfurl.

A Powersync II inverter that converts the “variable AC” from the Bergey EXCEL 10 turbine into utility grade electricity so that it can be connected to the wiring in the BTS. This conversion is electronic and is designed to operate automatically. The Powersync II has a digital display that provides information on the status of the system, its current output power, and its cumulative energy production. The Powersync II inverter is connected to the BTS circuit through a dedicated 70 A breaker.

SEALED VALVE REGULATED LEAD ACID BATTERY BANKS (VLRA)

The batteries are sealed Valve Regulated Lead Acid Battery Banks (VRLA). The VRLA batteries are batteries whose electrolytes are captive preventing any spill over even when punctured. These have electrolyte mixed with silica dust to form an immobilized gel. These types of batteries do not require maintenance or additional electrolyte or water.

The batteries have a charge regulator that controls the rate at which the batteries are charged or discharged. This prevents overcharging the batteries and may also help keep the batteries safe in case an overvoltage condition occurs which can reduce battery life.

These batteries are described as high capacity sealed VRLA gelled batteries 48V DC. The batteries are designed to withstand high temperatures. The battery bank is rated at 2000 Ah of two banks each of 1000 Ah. The number of cycles for the battery banks is at least 1000 at a depth of discharge of 80%.

There is an inverter used to convert the available DC power supplied by the rectifier and battery systems to a nominal 240 volt AC power for loads.

DIESEL GENERATOR OPERATION

The diesel generator operates only during charge drought from green sources. It boosts battery charge via an appropriately sized rectifier. During its operation, AC power loads are supplied directly, while DC loads are supplied via the rectifier. As soon as the battery is fully charged, the system reverts to battery operation with both green sources being default choices for battery charging.

The diesel generator running sequence is controlled in such a way that once it comes into operation, it must run until such a time that the battery bank is fully charged as compared to short and erratic intervals. The generator is started by a low battery voltage but stopped using a timer to ensure that the battery bank is fully charged.

This way, the battery bank is fully charged thus managing the cyclic life of the battery banks. The average generator running hours do not exceed four hours in each 24-hour period.

SIMULATION AND OPTIMIZATION FINDINGS

PROJECTED AND ACTUAL MONTHLY FUEL CONSUMPTION AT THE SITE

Monthly fuel consumption was obtained from the available records at the site, every time maintenance is done a data sheet is filled out and a copy of the data sheet is left at the site. These helped the researcher compile the annual fuel consumption. Figure 1 presents the monthly fuel consumption at the Safaricom BTS site in Sekanani. It is evident from the data that the fuel consumption differed each month. The month of February had the highest fuel consumption and highest generator operation hours, while the month of June had the lowest fuel consumption and generator operation hours. June is the month with high wind speeds and low solar isolation and therefore more power charge to the batteries from wind can take longer hours in day and night hours while solar only prevails during the day. February and September have lower wind speeds but higher solar isolation but experience higher fuel consumptions and longer generator operation hours. This due to shorter hours of charge compared to periods with higher wind speeds.

With HOMER projections, fuel consumed by the Diesel Gen set was highest during the months of January and December which was 195 liters for both months.

During the months of February, July and August fuel consumptions were 142, 147 and 160 litres respectively as portrayed in Figure 2.

Actual fuel consumption shows that February has the highest fuel consumption values of 2000 liters which is an exact opposite of HOMER values. There was further reduction of consumption to the month of June when the lowest fuel consumption of about 480 liters was experienced. Again, there is a steady rise in consumption to September of 1000 liters and a drop in October to 480 liters. November and December experience higher fuel consumptions which show a little conformance with the HOMER values. This difference between the HOMER and Actual values can also be attributed to environmental factors and fuel losses on transit as claimed by the Safaricom CEO.

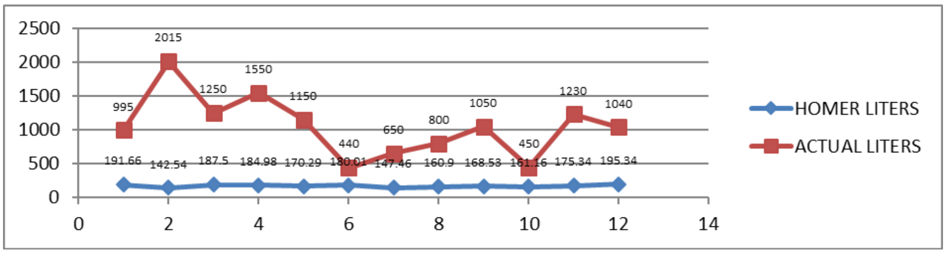

Figure 1: Monthly fuel consumption actual and Simulated from HOMER.
Source: Monthly Safaricom maintenance records

The following Table 1 illustrates the manufacturer's fuel fuel consumption rating of the engine. It indicates the amount of fuel the diesel engine would consume at any given speed.

Table 1: Manufacturer fuel consumption rating of the engine

	1500 rev/min		1800 rev/min		3000 rev/min	
	L/kWh	L/hr	L/kWh	L/hr	L/kWh	L/hr
At Standby Power	0.305	6.2	0.303	7.3	0.305	10.4
At Prime Power	0.292	5.4	0.294	6.4	0.310	9.5
At 75% of Prime Power	0.292	4.0	0.297	4.8	0.323	7.5
At 50% of Prime Power	0.319	2.9	0.323	3.5	0.376	5.8

Reading from the generator meter reading indicated that it did 3840 hours which proves the fact that the generator was running at 50% of its prime power of about 3.3 liters per hour having consumed a total of 12,620 liters yearly.

At 50% prime power the generator uses an average of (.319+.323+.376)/3 = 0.34 liters to generate 1KWh of power and therefore for actual annual power that could be generated by the generator consuming 12,620 liters is about 37.2 MWH. The annual requirement of power from the generator in this hybrid architect is about 6 MWH and therefore only about 2000 liters of diesel will be consumed on annual basis.

Diesel charging hours annually =3840 hours
Simulated annual energy requirement from diesel generator = 6 MWH
The recommended size of the prototype generator therefore should be = 6 x 1000/3840 = 1.56 kVA approximately 1.6 kVA

A critical look at the data on the site, reveals that the diesel engine at the site would consume between 2.02 litres per hour and 5.5 litres per hour. The Perkins Engine 400 series at the site has the capacity to consume up to 10.4 litres per hour, on maximum load as shown in Table 1. It is apparent that the engine is not put to maximum capacity, possibly due to the existence of the other sources of renewable energy. May be an engine with a smaller capacity could as well serve the purpose. This can also be explained by Figure 2 where there is a big intermittent fuel consumption differences between the expected and the actual. The HOMER graph indicates higher fuel consumption in January, which is expected because of low wind speeds.

ENERGY CONSUMPTION OF BTS

The installed BTS at the Sekanani site is the modern Huawei's fourth generation with one cabinet and 2000W power consumption. This translates to 2 kW X 24 X 365 = 17.52 MWH annually. It is among the latest BTS's with very economical energy consumption properties.

TOTAL ANNUAL ENERGY CONSUMED

Total annual energy demand is therefore the energy to run the BTS and its auxiliaries and the energy to have the batteries fully charged. The main power requirement annually is therefore 17.5 MWh .

ENERGY PRODUCTION

PHOTO-VOLTAIC ENERGY PRODUCTION

The power from the photovoltaic cell was calculated by HOMER, using the following equation to calculate the amount of energy produced:

$ESPV = YSPV \times PSH \times fSPV$ ....(1)

Where YSPV is the rated capacity of the SPV array (kW) and PSH is a peak solar hour which is used to express solar irradiation in a particular location when the sun is shining at its maximum value for a certain number of hours. Because the peak solar radiation is 1 kW/m^2, the number of peak sun hours is numerically equal to the daily solar radiation in kWh/m^2 and fSPV is the SPV derating factor (sometimes called the performance ratio), a scaling factor meant to account for effects of dust on the panel, wire losses, elevated temperature or anything else that would cause the output of the SPV array to deviate from the expected output under ideal conditions. In other words, the derating factor refers to the relationship between actual yield and target yield, which is called the efficiency of the SPV.

Table 2 below illustrates the energy production from wind, solar and diesel generator. The total energy produced annually from the photovoltaic panels is 20.83 MWH.

Table 2: Monthly energy produced from the different sources

	WIND ENERGY PRODUCTION	SOLAR PVC PRODUCTION	DIESEL GEN PRODUCTION	DIESEL GEN FUEL	TOTAL ELECTRICAL LOAD	AVERAGE WIND SPEED
	kWh	**kWh**	**kWh**	**Litres**	**kWh**	**Cm/s**
JANUARY	756.25	1794.76	507.01	191.66	1470.25	458
FEBRUARY	795.32	1757.54	376.97	142.54	1310.96	480
MARCH	860.22	1929.22	488.48	187.5	1524.69	476
APRIL	857.11	1720.46	490.36	184.98	1455.68	481
MAY	966.92	1709.12	449.74	170.29	1454.7	495
JUNE	1048.44	1612.35	472.56	180.01	1451.88	516
JULY	1158.16	1649.04	382.64	147.46	1476.11	528
AUGUST	1293.78	1741.39	422.27	160.9	1539.32	550
SEPTEMBER	1189.34	1813.04	434.78	168.53	1461.73	539
OCTOBER	1065.89	1798.18	419.32	161.16	1460.42	512
NOVEMBER	833.61	1593.94	465.86	175.34	1428.12	476
DECEMBER	721.44	1707.58	519.71	195.34	1488.14	448
TOTALS	***11546.48***	***20826.62***	***5429.7***	***2065.71***	***17522***	

It is evident from Table 2 that as wind speed rises the energy generation by the diesel decreases. Low wind speed in February is countered with higher energy production from the Genset and also higher wind speed in August is countered with low energy production from the Genset. Low wind speed in December is countered by higher energy production from the Genset. There is Solar energy production throughout the year with higher values experienced in March-April. It is also interesting to note that the demand of the BTS is associated with the solar irradiation, the higher the solar irradiation the higher the demand of the BTS. This might be so because of high demand of energy for cooling of the BTS. Highest wind energy production is associated with the higher demand of energy by the BTS and higher solar irradiation in August-September months of the year. August is also a holiday season and there are a lot of tourists in the region during this time and thus high demand on the communication equipment BTS.

WIND TURBINE ENERGY PRODUCTION

As evident in the above Table 2 the months of July, August and September witness high production of power from wind turbine at 1158.16, 1293.78 and 1189.34 kWh, respectively, that coincides with high wind speeds during the same period of average speeds 5.28, 5.5 and 5.39 m/s respectively for the months of July August and September. The total annual production from the turbine is 11.55 MWH which is rather below the demand of the BTS 17.52 MWH. This shows that it may not be possible to use wind turbine alone, it must be hybridized either with Solar PV, Diesel generator or both.

DIESEL ENGINE ENERGY PRODUCTION

The records at the Sekanani site revealed that the total amount of fuel consumed throughout the year was 12,620 litres. With the standards of the generator this fuel could generate about 37.2 MWH of power. This was able to bridge the gap of the energy produced from solar and wind generator only during the low seasons of the green energies. But in the final run 32.38 MWH produced from the wind and solar is adequate to supply the 17.5 MWH required of the BTS and its accessories. Only the solar panels and wind turbines are capable of producing sufficient power for the BTS demand. The generator set is only to compensate for the shortfalls due to seasons and complete absence of solar daily.

SIMULATED DIESEL ENGINE ENERGY PRODUCTION

The total energy produced from the diesel generator set for the year was 5.38 MWH. The month of December contributed the highest from the diesel generator set at 519 kWh, since there are very low wind speeds during this period therefore diesel generator therefore would work more. Figure 2: Monthly Energy produced and diesel consumedillustrates monthly power produced and the diesel fuel consumed by the diesel generator set. Very high solar irradiance is experienced during February and therefore this compensates for the low fuel, though wind speeds are also very low.

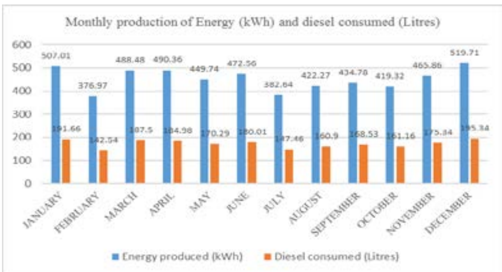

Figure 2: Monthly Energy produced and diesel consumed

TOTAL HYBRID ENERGY PRODUCTION

THE RETURN ON INVESTMENT

A comparison between the capital cost of a single generator, a wind turbine and solar panels against the operating cost of running two generators will determine the return on investment in the Sekanani BTS since it operates on wind, solar and one diesel generator. Off grid BTS are majorly powered by diesel generator this therefore means that the changing fuel prices is a major determinant in the return on investment.

Although diesel generators still remain the single most important 'backup' power source for sites where grid power is unreliable, in the case of a poor-grid deployment, the use of renewable power sources to back up the grid will be less important than for off-grid locations, because the cheapest and simplest solution may be to simply use battery backup power.

The choice of a suitable single or hybrid system was made from simulation and optimization results from HOMER using costing and sizing as the optimization variables and compared to a photovoltaic-wind-diesel-battery system. These results have been presented in Table 3. It can be seen from the results that a system without a renewable energy component is the most expensive, while a PV/Wind/Battery hybrid can meet the demand cost effectively. For the high demand level of 254 kWh/day, a diesel generator-only system is more reasonable in terms of cost than a renewable energy-only system. However, the life cycle costing of a diesel generator-only system may be improved by adding at least one renewable source with a battery.

For diesel generator alone therefore:

Total simulated energy produced annually = 34.81MWH

Net Present Cost (NPC) of production = $22,766,034

Cost per kWh produced = $22,766,034/ 34.81 x30 MWH = $21.8/MWH

Table 3: Simulated NPC values of Hybridized Solar PV and Wind only. Cost summary Cash flow compares Economics Electrical Renewable Penetration Generic 1kWh Li-Ion Generic flat plate PV system Converter Emissions

COMPONENT	CAPITAL($)	REPLACEMENT($)	O&M($)	FUEL($)	SALVAGE($)	TOTAL($)
Generic 1kWh Li-Ion	1,455,000.00	617,318.42	313,492.25	0.00	116,185.56	2,269,625.12
Generic flat plate PV	5,330,823.53	0.00	229,714.39	0.00	0.00	5,560,537.92
System Converter	127,575.41	54,126.91	0.00	0.00	19,187.23	171,515.09
System	6,913,398.94	671,445.33	543,206.65	0.00	126,372.79	8,001,678.13

System Architecture : Generic flat plate PV (1776941177kW) HOMER Cycle Charging
Generic 1kWh Li-Ion (2425 strings)
System Converter (425 kW)
Total NPC: $8,001,678.00

Levelized COE: $0.7001
Operating Cost $84,183.16

Wind turbine and solar PV are capable of generating 11.55MWh and 20.83 MWh annually respectively and therefore they have a combined annual generation of 32.38 MWh.

With an NPC of $8,001,678.00 with 30 years life span

Cost per MWH Produced = $8,001,678.00/ 32.38 x 30 = $8.24/MWH

Table 4: Simulated NPC of the Hybridized Solar PV , diesel Generator and Wind turbine

COMPONENT	CAPITAL ($)	REPLACEMENT ($)	O&M ($)	FUEL ($)	SALVAGE ($)	TOTAL ($)
10kW Fixed Capacity Genset	5,000.00	-	27,147.00	2,585.35	(1,058.05)	6,798.77
Generic 1kWh Li-Ion	1,455,000.00	617,318.42	313,492.26	-	(116,185.56)	2,269,625.12
Generic flat plate PV	5,172,915.90	-	222,909.86	-	-	5,395,825.76
System Converter	1,028.93	45,061.67	-	-	(8,481.06)	142,789.54
System	6,739,124.83	662,380.09	536,673.59	2,585.35	(125,724.67)	7,815,039.19

System Architecture : Generic flat plate PV (1724305300 kW)
10kW Fixed Capacity Genset (10 kW) HOMER Cycle Charging
Generic 1kWh Li-Ion (2425 strings)
System Converter (354 kW)

Total NPC: $7,815,039.00
Levelized COE: $0.6837
Operating Cost $82,226.89

Wind turbine and solar PV and Diesel Generator are capable of generating 11.55MWH and 20.83 MWH and 5.43MWH annually respectively and therefore they have a combined annual generation of 37.81 MWH.

With an NPC of $7,815,039.19 with 30 years life span

Cost per MWH Produced = $7,815,039.19/ 37.81 x 30 = $6.89/MWH

COMPARISON BETWEEN DIESEL ENGINE AND A HYBRID SYSTEM OF PV/WIND/DIESEL

It is worth noting that even though the initial installation cost of the hybrid system is higher than the installation of a diesel engine in the long run, the cost of operating a hybrid system is lower than the cost of running a diesel system. The initial cost of installing a diesel engine is lower than a hybrid system. The Net Present Cost per MWH of hybrid system of PV, wind and diesel is three times lower than a diesel engine system. The NPC per MWH of the hybrid is $6.89 while that of the genset is $21.80 which gives a ratio of 1:3 in respective costs. The NPC per MWH for the hybrid without the Genset is also slightly costlier than the triplet system.

PV alone is also more costly than any of the hybrid combinations. This can be attributed to the huge initial cost that is incurred to have as many PV cells as possible and the initial cost of the storage system is also very high. The high cost of the Genset-alone solution can also be attributed to the number, which has to be more than one, and therefore automatically high maintenance cost, the high cost of fuel and even the size of the location.

Table 5: (HOMER) Annual Hybrid Energy (Wind & Genset) only, (Solar PV & Genset) only and Non-Hybrid Genset only

	HYBRID ENERGY		
	WIND & GENSET-battery	Solar & GENSET-battery	GENSET-battery only
MONTH	PRODUCTION	PRODUCTION	PRODUCTION
	KWh	KWh	KWh
JANUARY	3210.59	3406.79	2920.15
FEBRUARY	2854.04	3439.86	2869.15
MARCH	3114.59	3604.35	2924.18
APRIL	3041.35	3404.01	2869.15
MAY	3165.85	3409.33	2924.18
JUNE	3289.09	3319.63	2869.15
JULY	3505.39	3356.63	2924.18
AUGUST	3606.58	3438.61	2924.18
SEPTEMBER	3617.64	3476.31	2869.15
OCTOBER	3428.98	3489.88	2924.29
NOVEMBER	3104.28	3287.28	2869.15
DECEMBER	2931.83	3395.46	2924.18
TOTALS	38870.21	41028.14	34811.09

From the records available on-site, it was established that the cost of fuel is the single factor contributing most to the recurrent expenditure. Discussions with the staff established that other items of recurrent expenditure include cost of leasing the premises and the hiring of security personnel at the site.

V. CONCLUSION

Diesel powered remote BTS is most expensive, given the cost of fuel and the routine maintenance. It was further demonstrated that there was over capacity in energy production at the site. The diesel engine at Sekanani should be able to produce up to 37 MWH of energy annually. This was despite the annual demand load of only 17.5 MWh and not to mention annual production of 20.83 & 11.55 MWh from solar and wind sources respectively. The simulation results reveal that only 5.38 MWh annually is needed for stand by purposes which can be realized from 2000 liters of diesel fuel.

It is further realized that the power produced from the photovoltaic cell and wind generator can run the BTS, however due to changing weather conditions it is necessary to have a backup diesel generator that would fill up the gap at any time there is a drop.

On economic terms, the Net Present Costs (NPC) of various combinations from HOMER simulations were found to be as follows:

- Genset and ancillaries NPC/kWh is $21.8/kWh
- Solar PV and Wind Turbine Hybrid and ancillaries NPC/kWh is $8.24/kWh
- Solar PV and Wind Turbine and Genset Hybrid and ancillaries' NPC/kWh is $6.89/kWh

Therefore, the hybrid architecture with the least net present cost is the triplet one that combines all the three sources of energy.

The simulation results showed that a system with no renewable system is the most expensive, while a PV/Wind/Battery can meet the demand cost effectively. However, it is ideal to hybridize as the supply of solar is not uniform through the day and during rainy seasons.

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