Implementation of Micro-Grid Model for Power Generation in Rural Communities

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Abstract— The study examined the stand alone provision of power in a micro-grid using PV- Storage only, Diesel generator only and combines Diesel generation (DG), Photovoltaic Cell (Solar Panel) – Storage, to get the optimal mix, in order to determine the best cost/kWh at Alabe–oja; a village in Irelodun Local Government Area of Kwara State, Nigeria selected for this study. The load study carried out showed an estimated requirements of 159.8kWh per day and total power estimated generator capacity of 20kVA. Using Diesel generator, only a cost per kW of ₦20.12 was derived over 20 years. The combination of solar PV and storage produced ₦18.64/KWHR. Extending power to Alabe–Oja from the national grid would give a cost of ₦17/KWHR, but this discounted the cost of extending the power network at ₦163million. Using software (HOMER and PVWATTS) produced a cost of ₦200/kWh when combination of diesel generator and PV/storage is simulated. The results were considered unacceptable and possible reasons why the results were as such were adduced. It is recommended that Regional Electricity Authority of Federal and State governments in Nigeria and elsewhere should adopt the policy of using renewable sources to provide electricity to rural community, as the cost in money is justified and this would help reduce carbon emission to the atmosphere as part of the country's multilateral commitment.

Index Terms— Cost of Energy, Energy Mix, Micro-grid, Photovoltaic Cell (PV), Renewable Energy.

1 Introduction

IN Nigeria, authorized utility companies supply power to rural areas by linking them to the National grid. For the most parts, the rural communities are far from distribution network and these communities are not serviced with their required load demand because of the enormous cost associated with taking power to them. In some cases the topography of the location of these rural communities (such as hilly, water, mud, swampy) makes it daunting, impossible and/or technically invisible and financially exorbitant to connect them to the National grid [1].

It is obvious that most developing economies of the world have not been able to develop at a faster pace because, among other reasons, they have poor or low electricity supply. This is also applicable to Nigeria, which currently produces less than 5,000MW of electricity, instead of projected power requirements of about 26,000MW. Nigeria for example needs to add at least 3,000MW capacities at an estimated cost of $10 Billion, per year from Generation to Transmission and Distribution in other to meet her developmental goals and aspiration. Unfortunately, the resources for this purpose are not available and so there must be new ways of supplying electricity to rural and/or isolated communities, using off- grid for example, at lower cost [2]. There are indeed many sources of power generation that can be used to serve these rural communities, but the problem is that the cost of extending the over stressed nation grid is exorbitant and the epileptic supply cannot sustain a healthy economic growth. In order to justify use of a source of energy to power the micro-grid, there is the need to consider many costs associated with the adoption of the energy source.

There are lots of studies that have demonstrated that using diesel generators to supply power to off-grid locations has better initial cost and very high overall cost. In addition, with average amount of CO_2 emitted per kWh at 445g in fossil fuel generators per day [3], there is therefore the need to find other power sources especially renewable as options. The carbon emission is saved in renewable energy sources in addition to justification in cost profile over a sufficiently long period. This thus, should encourage decision makers in government and private sectors to invest in renewable energy.

2 Related Works

Many researchers have investigated the potentials of Standalone Photovoltaic Power Source as a reliable electric energy source for rural communities and isolated consumers [4], [5], [6], [7]. Analysis in terms of cost and effectiveness of such standalone systems proved that such systems when implemented are reliable and cost effective [8], [9]. Works have been done in the area of analysing as well as improving the performance of photovoltaic systems [10], [11], [12], [13], especially in Hybrid Renewable Energy System [14], [15], [16] where more than one renewable source is put into use as the supply. The technique/tool for the analysis and optimization common in this area of study is Hybrid Optimization Model for Electric Renewable (HOMER) software. HOMER was used conduct micro-grid system sizing for standalone, off-grid and distributed generation scenarios [4], [5]. Artificial Intelligent/ Machine Learning based optimization techniques have also being applied in the optimization and management of micro-grids consisting of photovoltaic source. Particle Swarm Optimization (PSO) was proposed in [8], [10], [12], and non-dominated sorting genetic algorithm was proposed in [10]. ANN based artificial bee colony (ABC) algorithm was used in two stages as a hybrid algorithm [16]. Numerial technique has also been explored in works [17], [18].

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3 Methodology

Alabe-Oja was selected as a location for this study because it does not have electricity at all and there is no hope of the national grid extending to the location soon.
Alabe-Oja is a flat landscape with normal weather and a small village in Oke-Ode ward. The village is located 10km to Oke-Ode, a fully serviced big village, and about 25km to Share, the capital of Ifelodun LGA. Alabe-Oja is about 128km to Ilorin, the capital city of Kwara State, Nigeria. The Alabe-Oja G.P.S. and other statistics are shown below. All these specifics would be considered in the mathematical model of the network for the transients and the steady-state modes formulation.

ALABE-OJA GPS STATISTICS
Latitude: 8.609363
80 36′ 33′N
Longitude: 5.023725
50 1′ 25′ E
Wind Speed: 0.046111Km/Hr
The above specified data was recorded at 5:48:16pm, 29th February, 2016 with picture taken at the only school in the village as shown in Fig. 1.

From Table 1, the load estimate for the community in kWh for a 24 hours circle is given as:

Projected load in 24 hours
of operation in kWh = 159.8 kWh (1)

So the Load per hour is given as:
kW/h = 159.8/24 = 6.658 ≈ 6.69 kW/h (2)

Considering the over 5 villages neighboring the village and the likelihood that demand for the village will suddenly increase once electricity is provided, hence, load estimate below was used:

Load Estimate for Alabe-oja = 6,690 x 2
= 13,380W or 13.38KW (3a)
or PLA = 13.38KW (3b)

Converting to KVA gives:
PLA = 13.38 /0.8 = 16.72 KVA (3c)

With the Load Demand is 16.72KVA allowing for 20% tolerance the rated power demand becomes:

PRLA = (PLA x 20/100) + PLA) KVA (4a)

PRLA = (16.72 x 20/100) + 16.72 = 20.064KVA (4b)

So the Rated Power Demand for Alabe-oja (PRLA) is 20.064KVA.

3.1 Estimating Future Cost

The Net Present Cost (CNP) is estimated for 20 years for this study.
The CNP for each of the subsequent years is incremented by 2% per year to provide for inflation.

Net Present Cost is given by the expression:
CNPn= CNP1×⟦1.02⟧^((n-1)) (5)
Where n is the number of years and CNP1 is the amount for first year.

Cost analysis for 20 years continuous running of Diesel Generator was carried out using Equation (5) and the results were displayed in Table 5 of the appendix.

Fig. 1 The only Primary School at the Entrance of Alabe-oja

Table 1

Projected Load Estimate for Alabe-oja

Appliances	Wattage(W)	Number of Appliances of all Consumer	Total Power Consumed	Estimated Hours of Usage	Project 24 Hour Load in kWh
Lamps	15	200	3000	12	36
Fans	100	50	5000	14	70
TV	200	5	1000	10	10
Fridge	400	4	1600	14	22.4
Stereo	20	8	160	10	1.6
DVD	50	10	500	10	5
Computer	100	2	200	6	1.2
Decoder	40	7	280	10	2.8
Charging Handsets	5	80	400	18	7.2
Others	300	1	300	12	3.6
Projected load in 24 hours of operation in kWh is					**159.8**

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3.2 Determination of Total Cost of Generating 13.6kW by Photovoltaic System

The initial cost of setting up the 13.6kW Micro-grid electricity generator is very high initially at ₦10, 782,000.00, in the first year, but other factors associated with running cost makes PV a good proposition as demonstrated below with the following: Assumptions:

- ✓ Warranty on Solar Panels is 25 years so there is no replacement cost in this study.
- ✓ Warranty on Trojan Batteries used in this study is 12 years but provision is made for 8 years replacement for uninterruptible performance.
- ✓ Warranty on the Inverter is life, but since they are made of many electronics components, a replacement cost is built in after every 10 years.

3.3 Maintenance Cost Calculation

For the analysis, 2% is provided for inflation yearly.

So, to get the yearly cost of generating by PV, CPM is given using Equation 5 above.

It translates to: $CPM_n = CPM_1 \times [1.02]^{(n-1)}$ (6)

Where n is the number of years and CPM1 is the amount for first year.

3.4 Determination of Annual Cost of Replacements

Also, 2% annual increment is applied to the present cost of Batteries and Inverter to take care of inflation and the Equation 5 is then applied.

This is necessary to help account for future increases in the value of these items, as provisions needs to be made to replace them.

For example, the Batteries can actually serve for 12 years and more producing 80 to 90% of capacity if they are operated at 30-50% DOD. However, the batteries are to be changed every 8 years in this study and we needed to determine the future prices for each of the batteries. The summary of the cost profile is presented in Table 6 in appendix.

3.4 Calculation of Cost of KWh from Photovoltaic Generator

The total cost of Electricity generated by the 13.6kW PV system CPV_{20} over 20 years is:

CPV_{20}= ₦ 44,419,012.78

Taking Equations 5, and 6 together, we can calculate cost of Energy produced by the PV generator per hour CPVH thus:

$$CPVH = CPV_{20}/((20\times365\times24)) \quad (7)$$

Which implies that Cost of energy produced per hour is given as:

$$CPVH = 44{,}419{,}012.78/((20\times365\times24)) = ₦253.53 \quad (8)$$

So cost of kWh (CPKw) produced by the 13.6 KWW PV Generator is:

$$CPKw = CPVH/13.6 = 253.53/13.6 = ₦18.64 \quad (9)$$

3.5 NREL PVWATTS Calculator

The National Renewable Energy Laboratory (NREL) Photovoltaic Watts (PVWATTS) Calculator is an application that is available on the website of National Renewable Energy Laboratory for estimation and costing of energy of grid connected PV (Photovoltaic) + Inverter + Storage (Battery Bank) energy systems throughout the world.

The software allows homeowners, small building owners, installers, researchers and manufacturers to easily develop estimates of the performance of potential PV installations. The assumptions used in calculations and analysis are stated in Table 2. Fig. 2 gives the design model of the system used in the study.

Table 2

Assumptions used in Calculations and Analysis

Requested Location:	**Alabe-Oja, Kwara, Nigeria**
Location with nearest weather file to Location selected:	ACCRA/KOTOKA INTL, GHANA
Lat (deg N):	5.6
Long (deg W):	0.17
Elev (m):	69
DC System Size (kW):	50
Module Type:	Standard
Array Type:	Fixed (open rack)
Array Tilt (deg):	20
Array Azimuth (deg):	180
System Losses:	14
Invert Efficiency:	96
DC to AC Size Ratio:	1.1
Average Cost of Electricity Purchased from Utility ($/kWh):	0.09
Initial Cost	10.41
Cost of Electricity Generated by System ($/kWh):	0.44
Naira-Dolar Exchange	₦200/$

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In this study, NREL PVWATTS is used to estimate the cost for a PV standalone 50kW Micro-grid for Alabe-oja community Kwara State for the purpose of comparing the results with results from Homer for optimization analysis and suggestions.

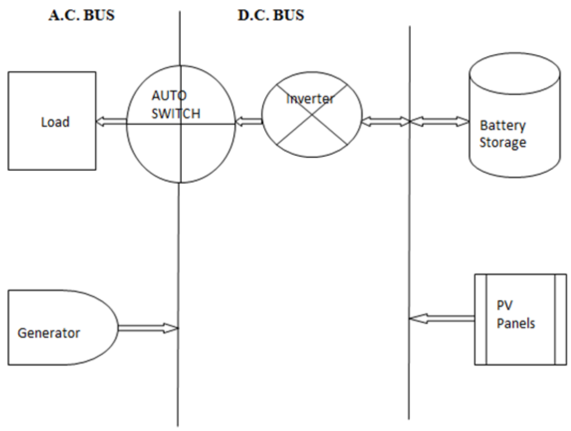

Fig. 2 Line Diagram of the Design Model used for the Study

4 Results and Discussion

In using the PVWATTS software, 50 kW Micro-grid system was used, for standalone PV and storage with an Inverter as a test case to analyse the cost profile. The following cost profile was derived as shown in Table 3.

It is clear from Table 3 that the system will produce a total of about 70, 659 kWh for the whole year at a cost of $6,359.29 (₦1,271,858.00). Otherwise kWh of Electricity with PV only using this software gives ₦18 which is close to the earlier figures calculated. This also conforms to the generally used ₦23.09 cost for kWh in MYTO (Multi Year Tariff Order) of Nigerian Energy Regulation Council (NERC).

Now using the assumptions for solar panel charge time in 24 hour circle and slotting in the figures and running the Homer software the following optimized results were derived as shown in Table 4, with the first one obviously the best choice from the point of view of cost, which is the main focus of this study.

50kW power system was used in this analysis, because of limitations set by the software. Therefore because of limitations of setting constraints for the two software, (PVWATT and HOMER), the peak distributable power from the results shown in Fig. 3 is 50kW. For the purpose of this analysis, this is insignificant difference as the Homer analysis is 65,050 kWh and PVWATT gave 70, 659 kWh as shown in Fig. 3.

Looking again at Fig.3 the first list shows that with the PV rated at 18.4kW, Diesel Generator rated at 27kW, Storage rated at 36kWH and Inverter rated at 8.4KW would be the optimized combination that gives the most cost effective power supply to the area used for this study, at a Cost of Energy (COE) of $0.45 (₦90).

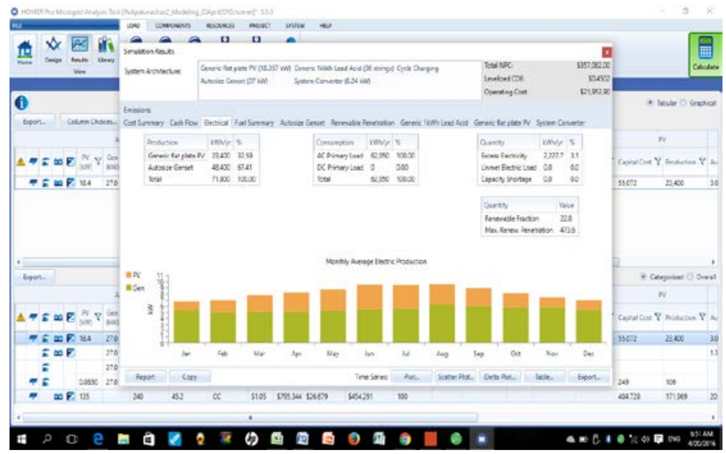

Fig. 3 Simulated Monthly Electricity Generations

The worst alternative in the figure referenced above gave a Cost of Energy of $1.05 (₦210) and even the next best alternative which is the second on the table gave $0.546 (₦109.2)

It should be noted that the best COE we got in the above calculation of ₦90 is still above the amount (₦23.09) approved by NERC (Nigeria Energy Regulation Council) to be charged by power distribution companies. In advance countries like USA where the software was developed; cost of energy generation with any combination of renewable energy is usually subsidized to the tune of 40%.

The estimated Net Present Cost (NPC) in a year (Annual) for the best combination in this study gave a value of $357,082 as against the annual NPC of $795,344 for the worst alternative.

However the NPC of the last combination on the list gives a value of $795,344 with operating cost of $26,679.

One other factor this study has highlighted is that even with serious reduction in prices of PV panels and improvement in battery technologies and prices, in recent times, the cost of setting up a 100% renewable energy generating facility such as PV based model (used in this study) is still higher than the traditional fossil fuel generations such as Diesel based generators.

To demonstrate the above assertion, when Diesel Generator is not used at all but only the PV is used at 135kW as shown in line 5 of Fig. 3, there is the need to raise the capacity of the Inverter to 45.2kW and then increase the storage deliverable of the Battery to 240kWh, this then leads to a massive jump in NPC to $795,344. The Initial Capital Cost of the optimized combination is then increased from $76,445 to $454,291.

However, when using the mathematical analysis using locally available factors and assumptions, it is obvious that at a cost of production of ₦18.64 and PVWATT software result of ₦18 per kWh PV power generator is more economical than producing

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power with Diesel Generator, which is costing ₦20.12, as a standalone, in the long run.

Table 3

PVWATTS Cost Estimates Results for 50kW Photovoltaic System

Month	AC System Output(kWh)	Solar Radiation ($kWh/m^2/day$)	Plane of Array Irradiance (W/m^2)	DC array Output (kWh)	Value ($)
1	6633.492676	5.73648882	177.8311462	6921.786133	597.01
2	6187.331543	5.88349104	164.7377472	6455.972168	556.86
3	6785.443848	5.8693676	181.9503937	7079.986816	610.69
4	5938.552734	5.23630667	157.0892029	6199.527832	534.47
5	5453.931641	4.67662001	144.9752197	5701.560059	490.85
6	4893.226074	4.2480464	127.4413986	5120.975098	440.39
7	4961.104492	4.13803768	128.2791748	5194.589355	446.5
8	5253.694336	4.3818655	135.8378296	5495.473633	472.83
9	5623.436523	4.8636632	145.9098969	5874.862793	506.11
10	6278.700684	5.31663227	164.8155975	6555.849121	565.08
11	6298.969727	5.59412146	167.8236389	6574.095215	566.91
12	6350.972168	5.47392321	169.6916199	6629.315918	571.59
Total	**70,658.85645**	**61.41856386**	**1866.382866**	**7,3803.99414**	**6,359.29**

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Table 4

Values of the Optimized Combination of Power Sources

	System Architecture				Cost Profile				System
Optimized Combinations Options	**PV (KW)**	**GEN (KW)**	**Battery (KWh)**	**Inverter (KW)**	**COE ($)**	**NPC**	**Operating Cost**	**Initial Capital Cost**	**Ren Fraction %**
1	18.4	27	36	8.24	0.45	$357,082	$21,953	$76,445	$22
2	0	27	15	12.6	0.546	$432,904	$32,337	$19,526	0
3	0	27	0	0	0.576	$457,062	$34,698	$13,500	0
4	0.083	27	0	0	0.576	$457,138	$34,685	$13,749	0
5	135	0	240	45.2	1.05	$795,344	$26,679	$454,291	$100

KEY:

Optimized Combination: In order of best cost advantage

PV (kW): Photovoltaic Cell in Kilowatt rating specified

GEN (kW): Diesel Generator rating in Kilowatt

Battery (kWh): Battery storage in Kilowatt hour rating

Inverter (kW): Inverter in Kilowatt rating specified

COE ($): Average useful kWh electrical energy produced by the system

NPC: Net Present value of Cost of the project minus the present value of all revenue it earns over its lifetime

Operating Cost: The annualized cost minus annualized capital cost

Initial Capital Cost: The total installed cost of components at the beginning of the project

REN Fraction: Percentage of Renewable energy sources supplied to the load

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5 CONCLUSION

This study demonstrated that in setting up a micro-grid power system, where cost is a factor and there is no government subsidy as it happens in developed countries of the world, it is very economical to use only PV as the renewable energy source, in comparison to only Diesel, as the Cost of Energy (COE) for PV is less than that of Diesel only.

The initial cost of setting up the Micro-grid generation dramatically falls when an appropriate capacity of Diesel Generator is brought to the mix. However, the kWh cost of energy gotten from the software is higher due to unacceptability of certain information by the software, for example, Alabe-oja was selected, with GPS settings, yet the information displayed by the software referred to Ghana.

The government and other private agencies should encourage the building of renewable micro-grid nation-wide; this would also rapidly increase the installed electricity generation capacity of the country and put less pressure on the national grid.

This study has demonstrated conclusively that at the prevailing cost profile, solar systems produces better cost of energy than diesel generator where the whole factors are taken into consideration over a sufficiently long period of time like 20 years.

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Appendices

Table 5

Cost of Running Diesel Generator for 20 Years

Years	Initial Capital Cost	Diesel Cost (Naira)	Diesel Consumption per day (Liters)	Diesel Consumption per hour (Liters)	Cost of Diesel/year	Maintenance Cost per Month	Yearly maintenance cost	Replacement Cost	Yearly Total cost of DG ownership
1	1,900,000	135	24	1	1182600	40,000	480000	1,900,000	3,562,600
2	1,938,000	137.7	24	1	1206252	40,800	489600	0	1,695,852
3	1,976,760	140.454	24	1	1230377	41,616	499392	0	1,729,769
4	2,016,295	143.26308	24	1	1254985	42,448	509379.8	2,016,295	3,780,660
5	2,056,621	146.128342	24	1	1280084	43,297	519567.4	0	1,799,652
6	2,097,754	149.050908	24	1	1305686	44,163	529958.8	0	1,835,645
7	2,139,709	152.031927	24	1	1331800	45,046	540558	2,139,709	4,012,066
8	2,182,503	155.072565	24	1	1358436	45,947	551369.1	0	1,909,805
9	2,226,153	158.174016	24	1	1385604	46,866	562396.5	0	1,948,001
10	2,270,676	161.337497	24	1	1413316	47,804	573644.4	2,270,676	4,257,637
11	2,316,089	164.564247	24	1	1441583	48,760	585117.3	0	2,026,700
12	2,362,411	167.855532	24	1	1470414	49,735	596819.7	0	2,067,234
13	2,409,659	171.212642	24	1	1499823	50,730	608756.1	2,409,659	4,518,238
14	2,457,853	174.636895	24	1	1529819	51,744	620931.2	0	2,150,750
15	2,507,010	178.129633	24	1	1560416	52,779	633349.8	0	2,193,765
16	2,557,150	181.692226	24	1	1591624	53,835	646016.8	2,557,150	4,794,791
17	2,608,293	185.32607	24	1	1623456	54,911	658937.1	0	2,282,394
18	2,660,459	189.032592	24	1	1655926	56,010	672115.9	0	2,328,041
19	2,713,668	192.813243	24	1	1689044	57,130	685558.2	2,713,668	5,088,270
20	2,767,941	196.669508	24	1	1722825	58,272	699269.4	0	2,422,094
		Total cost of operating Diesel Generator for 20 years 24Hrs per day non stop							**₦ 56,403,964**

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Table 6

Analysis of Cost of Running 13.6KV Photovoltaic Generator for 20 Years

YEARS	Capital Cost of PV + Mounting Accessories	Cost of Inverter + Safety devices	Battery Storage	Others and Installation Costs	Cost Maintenance per year	Total Cost of Generation per Year
1	5, 555,120	3,342,000	5,600,000	1,600,000	240,000	10,782,000
2	0	0	0	0	252,000	252,000
3	0	0	0	0	264,600	264,600
4	0	0	0	0	277,830	277,830
5	0	0	0	0	291,722	291,722
6	0	0	8,273,720	0	306,308	8,580,028
7	0	0	0	0	321,623	321,623
8	0	0	0	0	337,704	337,704
9	0	0	0	0	354,589	354,589
10	0	0	0	0	372,319	372,319
11	0	5,443,783.80	0	0	390,935	5,834,719
12	0	0	0	0	410,481	410,481
13	0	0	12,223,680	0	431,006	12,654,686
14	0	0	0	0	452,556	452,556
15	0	0	0	0	475,184	475,184
16	0	0	0	0	498,943	498,943
17	0	0	0	0	523,890	523,890
18	0	0	0	0	550,084	550,084
19	0	0	0	0	577,589	577,589
20	0	0	0	0	606,468	606,468
	Total cost of constructing and running Photovoltaic Generator for 20 years					**₦ 44,419,012.78**

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Table 7

Cost of Extending Grid to Alabe-oja from Oke-ode (20Km)

No	Materials	No(20Km)	Rate	No(1Km)	Total(1Km)	Total (20Km)
1	Poles	440	21,000	22	462,000	9240000
2	Cable (150 mm)	66,000	360	3,300	1,188,000	23760000
3	Cross Arm	460	3,000	23	69,000	1380000
4	Insulators	1,260	1,200	63	75,600	1512000
5	Ties Strap	900	600	45	27,000	540000
6	Bolt/Nut & Others	20	120,000	1	120,000	2400000
7	Civil materials and work	1	250,000	20	5,000,000	250000
8	Stay materials	240	5,000	12	60,000	1200000
9	Pot Insulator	540	1,200	27	32,400	648000
10	Labour	10	2,000,000	1	2,000,000	20000000
11	50KVA Transformer + Feeder pillar		1,000,000			1,000,000
12	Fence, Civil materials and work		400,000			400,000
13	H Poles and Accessories		150,000			150,000
14	Up riser and down riser cables		200,000			200,000
15	Other materials, such as fasteners		50,000			50,000
16	Permits and Labour		500,000			500,000
	Estimated Cost of Extending National grid per Km				**9,034,000**	
	Cost of Extending National grid to Alabe-Oja from 20Km Last Mile					**₦ 63,230,000.00**

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