Cost Optimization of an Electrical Energy Supply from a Hybrid Solar, Wind and Hydropower Plant

Amevi Acakpovi
Accra Polytechnic
P.O BOX: GP561

Essel Ben Hagan
Accra Institute of Technology
P.O. BOX: AN-19782

Francois Xavier Fifatin
Université d'Abomey-Calavi
01 BP 2009

ABSTRACT
The great availability of renewable energy resources such as wind and solar has triggered a revolution of green energy in the 21st century that led to the development of hybrid energy supplies. Many research works have dealt with optimizing hybrid energy supplies but majority of them failed to optimize the cost of supply from the perspective of the consumer. This consists of a drawback to many optimization approaches which this paper aims at solving. The objective of the paper is therefore to optimize the cost of energy from consumer perspective by adopting the best combination of initial renewable energy plants that supply a required load for a given time. An analytical model of solar plant, wind plant and hydropower plant were first proposed and later combined with cost criteria to create an objective function. The optimization problem was put in a linear form with inequality constraints and was solved by computational methods involving the special function linprog of Matlab. Data were collected on three specific locations in Ghana including Navrongo, Kumasi and Accra and fed into the program. Results show that the hybrid system dynamism is very consistent and reliable in the sense that it gives priority to the hydro followed by the wind and finally by the solar, owing to the fact that the hydro cost is lower than the wind cost and the wind energy cost is also lower than the solar one. An average cost of hybrid electricity was further determined for the three sites tested, and the values were 0.465$/kWh, 0.458$/kWh and 0.451$/kWh respectively for Navrongo, Kumasi and Accra. It was also shown that the unit cost of electricity for solar, wind and hydro power plants were estimated to 0.685$/kWh, 0.515$/kWh, 0.388$/kWh respectively. This show in all cases that, the hybrid system yielded a good cost estimate that minimizes the consumer's bill.

General Terms
Renewable Energy, Hybrid Energy Supply, Optimization

Keywords
Solar Energy, Wind Energy, Hydro Energy, Cost optimization, Matlab Simulation

1. INTRODUCTION
Hybrid energy system consists of adding up various sources of energy together in order to overcome the limitations of individual sources and design a more reliable, more robust and more effective energy system. Hybrid energy system have become the order of the day. Many consumers wish to go for combined energy supply instead of relying on the traditional hydropower only. According to Prasad & al. (2010), [1], photovoltaic energy has received considerable attention of recent as one of the most promising alternative energy supply. Additionally, others see wind power as one of the renewable energies with a greater future projection. This is due to the existence of non-exploited wind resources and to the fact that it is a clean and environmentally friendly energy source with a reduced cost of installation and maintenance. Considering the great availability of wind and solar resources in the whole world it will be very convenient to exploit these alternative power supplies in order to alleviate both the problem of high electricity cost and the unavailability of supply in remote areas. In view of this, many hybrid systems have been developed including solar and wind, solar and hydroelectricity and many others. However, the capital cost of implementing a wind farm or a solar plant is huge to the extent that many are tempted not to venture into it. On the other hand the operation and maintenance cost required for the same renewable sources are very low. In this line, some previous studies attempted to prove that cost of solar and wind expanded over their life span can be estimated to be less costly than the conventional hydropower only. To further this type of analysis, it becomes necessary to investigate the cost of electricity supplied by a hybrid system instead of individual sources. This paper is based on this concept and it is especially looking at how to minimize the cost from a consumer perspective in order to make hybrid systems more attractive.

2. LITERATURE REVIEW
Extensive works have been done to put together different sources of energy in order to design hybrid systems. One of the most commonly encountered is the solar-wind hybrid energy which was handled by Wei (2008), [2]. The work clearly highlights the variable aspects of the two sources and later show that, the effects of their individual variations could be limited by combining them. An optimal sizing method was designed to find the global optimum configuration of stand-alone hybrid power generation systems. By using Genetic Algorithm (GA), the optimal sizing method was developed to calculate the system optimum configuration which offers to guarantee the lowest investment with full use of the PV array, wind turbine and battery bank. The objective functions developed to perform the optimization task of the hybrid solar-wind system were based on the Loss of Power Supply Probability (LPSP) and the Annualized Cost of System (ACS).

In addition, works by Ekren (2009), [3] also investigated the optimization of a PV/Wind integrated hybrid Energy System with battery storage, under various loads and unit cost of auxiliary energy sources. The optimization was completed by a simulation based optimization procedure. In his study, the main performance measure was the hybrid-energy-system cost, and the design parameters were PV size, wind turbine rotor swept area and the battery capacity. The simulation model of the system was realized in ARENA 12.0, a commercial simulation software, and was optimized using the OptQuest tool. The optimum results were confirmed using Loss of Load Probability (LLP) and autonomy analysis.

Moreover, Gabler (1998), [4], worked in a small laboratory built at Olden Burg University. This laboratory was supplied by solar radiation, wind energy and a small extent of conventional fuel. Simulations of the system were done using experimentally validated models for converters and storage devices. It was then possible to combine the various sources at the experimental level and therefore the resulting hybrid system yielded the advantages of the individual sources and became a stronger system.

Furthermore, Gupta (2007), [5] presents the development of a computational model for optimal sizing of Solar-Wind Hybrid Energy System (SWHES). The performance of solar and wind system was evaluated through more accurate and practical mathematical models, involving hourly measured meteorological input data and load data. The reliability measures in terms of loss of power supply probability (LPSP) and the total life cycle cost have been used as the indices for evaluation of different configurations.

Many other research works investigated means of combining several renewable energy sources in order to use them as solution for energy supply in remote areas. Kumar Lal & al. (2011), [6] proposed a hybrid power generation system suitable for remote area application which is based on the following concept: "hybridizing renewable energy sources is that the base load is to be covered by largest and firmly available renewable source(s) and other intermittent source(s) should augment the base load to cover the peak load of an isolated mini-electric grid system". The work presented by [6] was mainly based on modeling, simulation and optimization of renewable energy system in rural area in Sundargarh district of Orissa state, India. The HOMER software was used to study and design the proposed hybrid alternative energy power system model.

Also Motin (2012), [7], developed a similar hybrid energy system for Saint Martin's Island. Another way of optimizing the hybrid energy production involving solar is to apply sun tracking techniques and wind speed regulation to maximize the solar and wind energy production respectively. Prasad GVT (2010), [1] and Muralikrishna (2011), [8] worked on this aspect of optimization by even using microcontrollers to improve the tracking systems.

Furthermore, Amer (2013), [9], proposed an optimization of renewable hybrid energy system for cost reduction using Particle Swarm Optimization (PSO) approach. An estimation of Levelized Cost of Electricy was first developed and the model was further fed into the Matlab software using the PSO approach with an in-built algorithm on cost reduction technique. PSO technique was equally used by Ram et al. (2013), [10] when they investigated the optimization of solar and wind with backup generator and battery. Ram's work proposed existing models for individual sources including wind, solar, generator, battery and poses an optimization problem with inequality constraints that were solved with the PSO approach. The result were applied to data that provided prominent results. In addition, Trazouei (2013), [11] also used the imperialist competitive algorithm, particle swarm optimization and ant colony optimization to determine the optimum configuration of a hybrid wind, solar and diesel energy supply. Simulation approaches were adopted and these show at the end that the imperialist competitive algorithm was faster and more accurate.

On the other hand, some other optimizations like [6] and Ajao (2011), [12], were done with software already made for the purpose of energy system optimization such as HOMER. [12] did a cost benefit analysis by comparing the cost of solar-wind hybrid system to the cost of central grid supply over sometimes and realize that the best solution was simply the reliance on the central grid. HOMER optimization software has the capability to determine over a life span of the supply system, the levelized cost of electricity and to show how constantly the proposed supply can meet the demand of electricity by considering all necessary conditions such as climate, wind speed, solar irradiation over a year, capital cost of investment and others. It can therefore serve for quick optimization analysis like the problem solved by Ajao (2011), [12]. Moreover, HOMER software can be used to design an isolated hybrid system with different options to achieve a minimum cost of energy supply. In this regard, the work of Kumar Lal et al. (2011), [6] is an illustration. They have considered an isolated hybrid energy supply including wind/solar/mini-hydro and diesel generator. After applying initial data to the HOMER software, based on their considered locations, they got prominent results on the optimum configuration of the hybrid system.

Other related works including Rawat (2013), [13], Dalwadi (2012), [14] and Muralikrishna (2007), [8], also dealt with optimizing hybrid wind and solar systems but their approach were based on self-developed algorithm that was modelled and computed analytically. However, some of these algorithms lack or robustness and reliability. Also, Razak (2007), [15] developed an optimization approach based on minimizing excess capacity of hybrid system by developing a more critical approach to the load analysis.

A summary of the different works reviewed on optimization of hybrid system, shows that most of these optimizations are not dynamic in the sense that the optimized cost is fixed after preliminary conditions have been well defined. However the high variability of natural resources such as wind, solar and water availability should be catered for by an optimization system that also changes its output dynamically to keep the electricity cost always minimal. On the other hand, most optimization problems were solved with software but the real analytical approach adopted by these software remain a mystery. Therefore, there is a need to re-solve the optimization algorithm with well-defined analytical tools and make it more dynamic.

This paper first assumes the existence of certain number of solar, wind and mini-hydro power plants and further looks into how these sources could be combined to the best benefit of the consumer. An analytical model of each source is proposed, followed by an objective function that estimates the cost of electricity required by a load for a given time. The problem will then be solved with combined analytical and computational methods and will be tested on data collected on three different locations.

3. METHODOLOGY

3.1 Assumptions

Based on a certain number of reasonable considerations, the following assumptions were made:

- Each module is considered independent at the construction level and therefore their various cost of electricity will be estimated separately.
- There exist numbers N_s, N_w and N_h representing respectively the total number of solar plants, wind power plants and mini-hydro power plants of equal capacity respectively in existence.

- G(t), Vw(t) and Q(t) are all constant during the integration period T. The integration period designate the duration after which the whole algorithm will be re-assessed for new cost to be implemented.

3.2 Modelling of Individual Sources of Energy Generation

The paragraph below presents a brief model of power generated by the following individual sources: solar, wind, and mini-hydro generators.

- **Mathematical model of solar power generation**

The power generated by a photovoltaic system depends on two fundamental parameters namely the solar irradiation and the ambient temperature as shown by equation 1, Amevi et al. (2013), [16], Villalva (2010), [17], Ramos-Paja (2010), [18] and Tsai (2008), [19].

$$P(t) = nAG(t)$$

Where n is the PV generation efficiency, A (m^2) is the PV generator area and G(t) is the solar irradiation in tilted module plane (W/m2). The efficiency n further relates to the ambient temperature as follow

$$n = n_r[1 - \beta(T_c - T_{cref})]$$

n_r is the reference module efficiency and T_{cref} is reference cell temperature in degree Celsius.

- **Mathematical model of wind power generation**

The output power of a wind turbine generator system is usually given by equation 1, Khajuria (2012), [20], Abbas (2010), [21] and Amevi (2014), [22]:

$$P_m(t) = \frac{1}{2}\rho A C_p(\lambda, \beta) V_w^3(t)$$

Where:

- C_p is the coefficient of performance also called power coefficient
- A is the swept area by the turbine' blades (m^2)
- ρ is the air density (kg/m^3)
- V_w is the wind speed (m/s)

The tip speed ratio λ is defined as the ratio of the angular rotor speed of the wind turbine to the linear wind speed at the tip of the blades [20] and can be expressed as follow:

$$\lambda = \frac{\omega_r R}{V_w}$$

Where ω_r is the mechanical angular velocity of the turbine rotor in rad/s and V_w is the wind speed in m/s [20]. The rotational speed n (r/min) and angular velocity ω_r are related by equation 4:

$$\omega_r = \frac{2\pi n}{60}$$

Based on Khajuria (2012), [20] for a VSWT, the coefficient Cp is calculated as shown below.

$$C_p(\lambda, \beta) = 0.73\left[\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right]e^{-\frac{18.4}{\lambda_i}}$$

With λ_i as given by equation 2.

$$\lambda_i = \frac{1}{\frac{1}{\lambda + 0.02\beta} - \frac{0.03}{\beta^3 + 1}}$$

- **Mathematical model of Mini-hydro generators**

The general formula for the determination of hydraulic power is shown by Fuchs et al. (2010), [23] and Hermandez et al. (2012), [24] as follow:

$$P_h = \rho g H Q(t)$$

Where: P_h is the hydraulic power produced at the turbine shaft (Watts), ρ is the density of water (1000 kg/m3), g is the acceleration due to gravity (9.81 m/s2), Q is the water flow rate passing through the turbine (m^3/s), H is the effective pressure head of water across the turbine (m).

The hydraulic power is later transformed into mechanical power by the turbine. Many attempt have been made in the past to come out with an analytical model of hydraulic turbine. This has always been a difficult task due to the nature of hydroelectric power generating system that exhibits a high-order and nonlinear behaviour as explained by Naghizade (2012), [25]. Based on [25], the mechanical power available at the output of the turbine is determined as follow:

$$P_m = \eta_t \cdot P_h$$

Where η_t is the efficiency of the turbine.

It is very complex to determine the hydraulic turbine efficiency and for this matter robust mathematical models are used to numerically compute it. Some of these models were reviewed by Marquez & al. (2010), [26] and Singh & al. (2010), [27]. According to one of these methods developed in [27], the efficiency is determined as follow:

$$\eta_t(\lambda, Q) = \left[\frac{1}{2}\left(\frac{90}{\lambda_i} + Q + 0.78\right) \cdot \exp\left(\frac{-50}{\lambda_i}\right)\right](3.33Q)$$

Where

$$\lambda_i = \left[\frac{1}{(\lambda + 0.089)} - 0.0035\right]^{-1} \text{ and } \lambda = \frac{RA\omega}{Q}$$

Q is the flow rate of water, ω is the angular speed of turbine rotor, R is the radius of the hydraulic turbine blades (m) and A is the area swept by the rotor blades (m^2).

3.3 Problem Formulation

The power system considered contains N_S solar plants, N_W wind power plants and N_H micro-hydro-generating stations located on the same stream. The total annualized life cycle cost of the system incorporating components of both capital and operating cost is given by

$$C_{an} = C_{ans} + C_{anw} + C_{anh}$$

With

$$\begin{cases} C_{ans} = C_{cs} \cdot CRF_s + C_{os} \\ C_{anw} = C_{cw} \cdot CRF_w + C_{ow} \\ C_{anh} = C_{ch} \cdot CRF_h + C_{oh} \end{cases}$$

Where

- C_{ans}, C_{anw} and C_{anh} represent respectively the annualized life cycle cost of energy for the solar, wind and hydropower generation.
- C_{cs}, C_{cw} and C_{ch} represent respectively the capital cost of investment for the solar, wind and hydropower generation.
- C_{os}, C_{ow} and C_{oh} represent respectively the operation and maintenance costs for the solar, wind and hydropower generation.

- CRF_s, CRF_w and CRF_h represent respectively the capital recovery factor for the solar, wind and hydropower generation.

The unit costs of electricity C_{us}, C_{uw}, C_{uh}, generated respectively by the solar, wind and hydropower plants, can be expressed as follow:

$$\begin{cases} C_{us} = \frac{C_{ans}}{E_s} \\ C_{uw} = \frac{C_{anw}}{E_w} \\ C_{uh} = \frac{C_{anh}}{E_h} \end{cases}$$

With E_s, E_w and E_h, the net energy generated by the solar, wind and hydropower plants respectively over a year.

The cost of electricity generated by the hybrid energy system over a period of time T can be expressed as follow

$$CE = C_{us} \cdot \int_0^T a_s \cdot P_S(t) \cdot dt + C_{uw} \cdot \int_0^T a_w \cdot P_W(t) \cdot dt + C_{uh} \cdot \int_0^T a_h \cdot P_H(t) \cdot dt$$

$$CE = a_s C_{us} \int_0^T \eta AG(t) \cdot dt + a_w C_{uw} \int_0^T \frac{1}{2} \rho A C_p V_w^3(t) \cdot dt + a_h C_{uh} \int_0^T \rho g H Q(t) \cdot dt$$

With the assumption that G(t), $V_w(t)$ and Q(t) are all constant over the period T, the function becomes

$$CE = a_s C_{us} \eta AGT + a_w C_{uw} \frac{1}{2} \rho A C_p V_w^3 T + a_h C_{uh} \rho g H Q T$$

Finally, the optimization problem is posed as follow:

Minimize the CE subjected to the following constraints:

1. The power generated by the hybrid system should meet the demand at any given time as expressed below:
   $$a_s \cdot P_S(t) + a_w \cdot P_W(t) + a_h \cdot P_H(t) \geq P_d(t)$$
2. The total power generated should be within range of minimum and maximum power that can be generated
   $$P_{min} \leq a_s \cdot P_S(t) + a_w \cdot P_W(t) + a_h \cdot P_H(t) \leq P_{max}$$
3. Variables should also stay between bounds as follow
   $$\begin{cases} 0 \leq a_s \leq N_s \\ 0 \leq a_w \leq N_w \\ 0 \leq a_h \leq N_h \\ 0 \leq a_s, a_w, a_h \\ G_{min} \leq G \leq G_{max} \\ V_{wmin} \leq V_w \leq V_{wmax} \\ Q_{min} \leq Q \leq Q_{max} \end{cases}$$

With the assumption that the irradiation G, the wind velocity V_w and the water flow Q are all constant during the period T, the problem can be considered as a linear optimization function subjected to linear inequalities constraints.

3.4 Proposed Solution

The Linear optimization problems are mostly solved by graphical means where all the constraints are plotted separately and the optimal point is determined by means of rigorous observations. With the advent of advanced software such Matlab, in-built functions have been created to handle linear optimization problem. The most recommended function to solve this problem by Matlab, [28], is the linprog which is called as follow:

[x fval] = linprog(f,A,b,Aeq,beq,lb,ub)

Where the optimized value is kept in the variable fval and the other variable are defined as follow:

- f is the objective function
- A is a k-by-n matrix, where k is the number of inequalities and n is the number of variables
- b is a vector of length k.
- Aeq is the matrix summarizing all equality constraints
- beq is a vector of length m.
- ub is the matrix of upper bounds applied to the variables
- lb is the matrix of lower bounds applied to the variables

The solution to our optimization problem is constructed around the linprog function of Matlab and can be described by both the following algorithm and the flowchart in figure 1.

1. Initialize an index variable to N that will serve for iteration.
2. Get the input load data, wind velocity, solar irradiation and hydro data (water flow and total head) as well as necessary data to evaluate the unit cost of electricity per individual sources
3. Calculate the power generated by individual sources of renewable energy generator using the models described above
4. Create decision variables for indexing
5. Defining lower and upper bounds for all variables
6. Defining linear equality and linear inequality constraints
7. Defining the objective function
8. Solving the linear optimization problem with the function linprog of Matlab
9. Save result
10. Increase the index N by 1
11. If index N is less than or equal to 12 (for the twelve months in a year), repeat processes from 2 to 10
12. Display result
13. Stop.

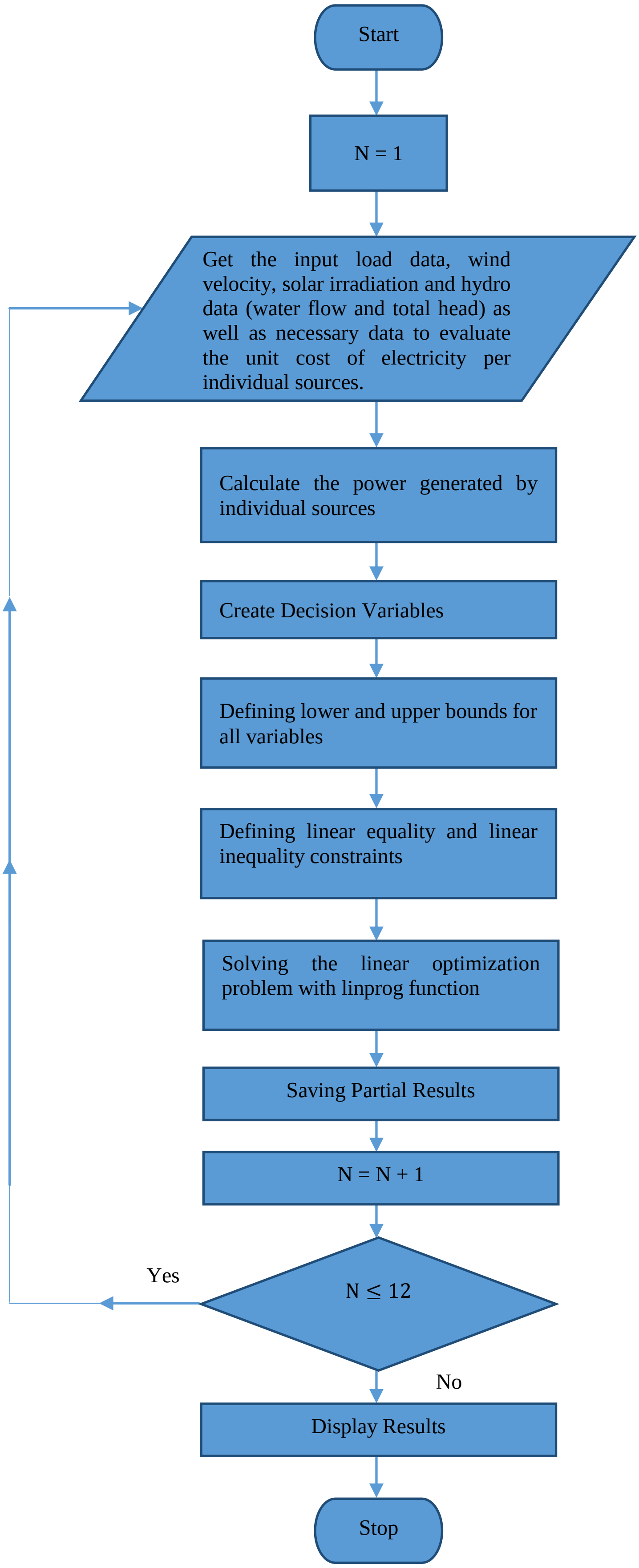

Fig 1. Flowchart of the Proposed Solution

3.5 Case Study

Secondary data were collected on three different locations. The summary of the data collected is presented as follow in tables 1, 2, 3 and 4.

Table 1. Data on the selected sites

Sites	Latitude (degree)	Longitude (degree)	Elevation
Navrongo	10.9 N	-1.1 E	203 m
Kumasi	6.7 N	-1.6 E	287
Accra	5.6 N	-0.2 E	68

Table 2. Monthly Data recorded on Navrongo Site

Month	Irradiation ($kWh/m^2/d$)	Wind Velocity (m/s)	Load Requirement per month (kWh)
Jan	6.61	2	7000
Feb	6.53	2	6000
March	6.40	2.6	6550
April	6.38	2.5	6500
May	6.46	2.7	7250
June	6.09	2.5	6400
July	5.66	2.5	5900
Aug	4.94	2.4	5500
Sept	5.47	1.9	6500
Oct	6.19	1.9	5600
Nov	6.15	2.1	6890
Dec	5.98	2.2	6240

Table 3. Monthly Data recorded on Kumasi Site

Month	Irradiation ($kWh/m^2/d$)	Wind Velocity (m/s)	Load Requirement per month (kWh)
Jan	4.18	1.5	7000
Feb	4.68	2.1	6000
March	5.04	2.1	6550
April	5.09	2.1	6500
May	4.97	2.1	7250
June	4.38	2.1	6400
July	3.67	2.6	5900
Aug	3.35	2.1	5500
Sept	3.80	2.1	6500
Oct	4.44	2.1	5600
Nov	4.66	1.5	6890
Dec	3.87	1.5	6240

Table 4. Monthly Data recorded on Accra Site

Month	Irradiation ($kWh/m^2/d$)	Wind Velocity (m/s)	Load Requirement per month (kWh)
Jan	4.10	2.6	7000
Feb	4.59	2.6	6000
March	5.21	2.6	6550
April	5.08	2.6	6500
May	5.02	2.1	7250
June	3.97	2.1	6400
July	3.70	4.6	5900
Aug	3.84	5.1	5500
Sept	4.59	5.1	6500
Oct	5.19	2.6	5600
Nov	4.79	4.6	6890
Dec	3.86	2.1	6240

Furthermore, it is assumed that the water flow vary randomly around 100l/s with an average head of 10m.

4. RESULT

The data were fed into the developed code and simulation results were obtained as follow: two types of graph are plotted per each site. They comprise of

a. A first bar chart showing the dynamic contribution of individual sources in meeting the load. This chart is necessary to prove the dynamism of the developed algorithm as a solution to the proposed optimization problem. Different input conditions must yield different optimization result and this must transpire in the first chart.
b. The second graph represents the unit cost of electricity over time

The results obtained are illustrated in figures 2, 3, 4, 5, 6, 7 respectively for the three sites under study, namely Navrongo, Kumasi and Accra, all selected in Ghana.

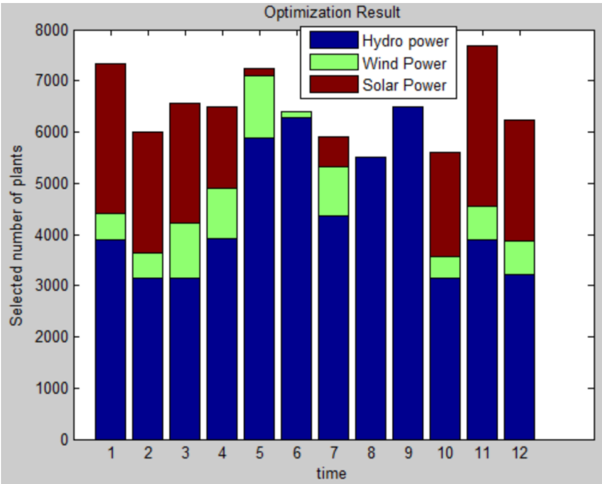

Fig 2. Power produced by individual sources to supply the requested load for the case of Navrongo

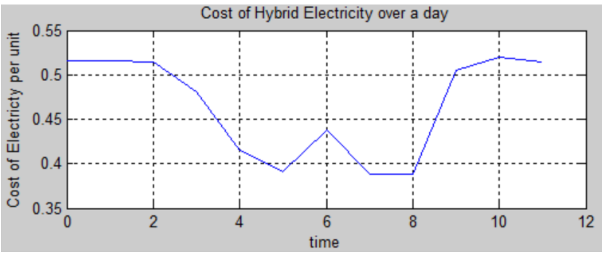

Fig 3. Cost of Hybrid Electricity (Case of Navrongo)

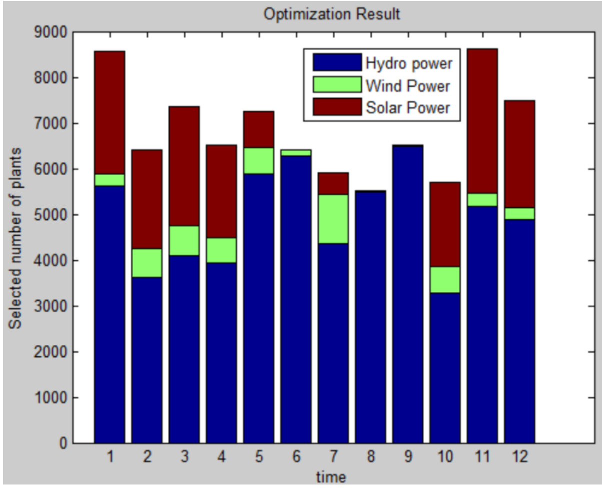

Fig 4: Power produced by individual sources to supply the requested load for the case of Kumasi

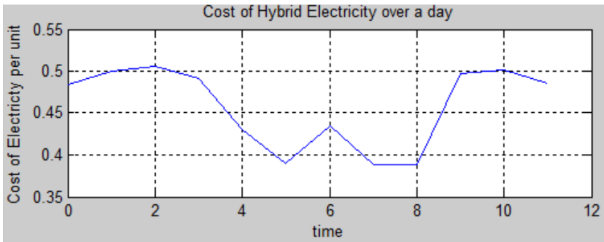

Fig 5. Cost of Hybrid Electricity (Case of Kumasi)

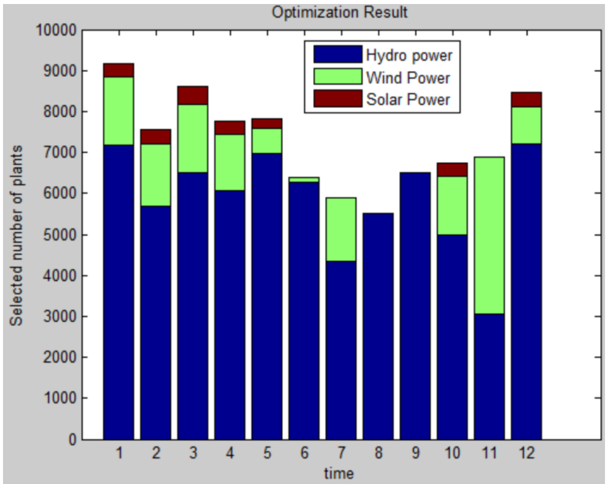

Fig 6: Power produced by individual sources to supply the requested load for the case of Accra

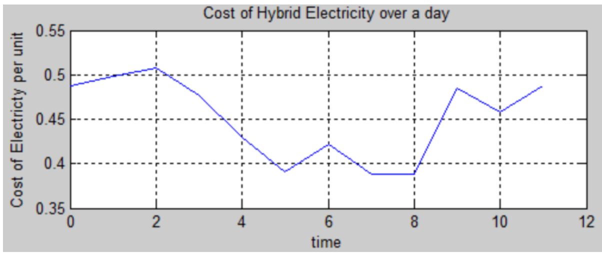

Fig 7. Cost of Hybrid Electricity (Case of Accra)

5. DISCUSSION

For each of the graph showing the contribution of individual sources to the total energy supplied to the load, a general trend can be observed: priority is given to the three sources in the following order: hydro, wind and solar. In other terms, the wind energy comes in when the water resource is exhausted and subsequently, the solar power is used only when the wind resources is also exhausted. This trend is justified because a look at the individual cost of electricity production per source shows the highest cost for solar, followed by the wind and finally by the hydro. It is therefore predictable that the hydro will be a preferred choice for minimizing cost of electricity and this has been the solution developed by the proposed solution. This further increases the credibility of the approach adopted in solving the problem.

On the other hand, the graphs on cost of electricity also show the same trend. The cost appears high at the origin but diminishes after sometimes and remain low until the end when it rises again. This pattern is directly correlated to the previous graph on the contribution of individual sources. When the energy is solely supplied by the hydro plant the cost is low but as far as the solar and wind are used, the cost of electricity automatically goes higher. Average cost of 0.465$/kWh, 0.458$/kWh and 0.451$/kWh have been respectively recorded for Navrongo, Kumasi and Accra over a period of a year. The cost details show that the design is more favorable at Accra than the other regions.

Besides, the unit costs of electricity estimated for individual sources including solar, wind and hydro power plant were 0.685$/kWh, 0.515$/kWh, 0.388$/kWh respectively. It can be observed for all the three sites that the hybrid cost is always above the unit cost of hydro and below the unit cost of wind and solar. This solution is very convenient and confirm the statement of Kumar Lal & al. (2011), [6] that: A hybrid power generation system suitable for remote area application is based on the following concept: hybridizing renewable energy sources is that the base load is to be covered by largest and firmly available renewable source (hydro in our case) and other intermittent sources (wind and solar in our case) should augment the base load to cover the peak load of an isolated mini-electric grid system.

The proposed algorithm in our paper, is very similar to that of Gupta (2007), [5] who presented the development of a computational model for optimal sizing of solar-wind hybrid energy system (SWHES) that was evaluated on the basis of meteorological data and load data. However there are other existing approaches developed by Amer (2003), [9] using PSO for instance; Additionally, Trazouei (2013), [11] worked on the imperialist competitive algorithm; Kumar Lal (2011), [6] and Ajao (2011), [12] who also used the Homer software to achieve the same optimization. It will be very appropriate to carry out a comparative analysis of all these methods against our proposed solution in further research.

6. CONCLUSION

In total, this paper dealt with the development of an algorithm as a solution to a cost optimization problem of hybrid solar, wind and hydro energy. The proposed algorithm was based on the linprog function of Matlab as it was a solution to a linear problem with inequality constraints. The solution was further programmed under Matlab environment and tested over data collected on three sites in Ghana including Navrongo, Kumasi and Accra. Results show an efficient and dynamic optimization solution. Individual cost of electricity per supply were estimated at 0.685$/kWh, 0.515$/kWh, 0.388$/kWh respectively for solar, wind and hydro plants. For each site, the graph of total energy generated showing the contribution of individual sources were shown, followed by the graph of electricity cost. It can be observed that the proposed solution performed satisfactorily in the selection of sources that meet a particular load. With cost as a criteria, hydro-electricity was first selected and if the demand is still above the supply, wind energy was used in second position and finally followed by solar energy. Consequently the final cost of electricity is also low as far as the contribution of wind and solar energy is low and the dependency is mostly on the hydro. An average cost of electricity was also calculated for each of the sources and the values obtained were 0.465$/kWh, 0.458$/kWh and 0.451$/kWh respectively for the three sites, Navrongo, Kumasi and Accra.

The approach adopted in this paper is supported by many previous works and its results were very effective. However, it will be appropriate to compare this approach to other techniques such as PSO, GA, HOMER optimization. It is therefore recommended that a comparative analysis of these methods against the proposed solution in this paper, should be carried out for further works.

7. REFERENCES

[1] Prasad, G.V.T., Srinivasan, S., Sriram, V. 2010. Hybrid Solar and Wind Off-Grid System - Design And Control. International Journal of Engineering Science and Technology. Vol. 2. pp. 548-552.

[2] Wei, Z. 2008. Simulation and optimum design of hybrid solar-wind and solar-wind-diesel power generation systems. Hong Kong Polytechnic University.

[3] Ekren, B.Y., Ekren, O. 2009. Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions. Econpapers. Applied Energy. Vol. 86, issue 9, 1387-1394p.

[4] Gabler, H., Luther, J. 1998. Wind-solar hybrid electrical supply systems. Results from a simulation model and optimization with respect to energy pay-back time. Elsevier, Solar and Wind Technology. Vol.5, Iss.3, pp 239–247.

[5] Gupta, S.C., Kumar, Y., Gayatri, A. 2007. Optimal sizing of solar-wind hybrid system. Information and Communication Technology in Electrical Sciences (ICTES 2007). ICTES. IET-UK International Conference.

[6] Kumar Lal, D., Dash, B.B., Akella, A. K. 2011. Opimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in Homer for the Study Area.

[7] Motin, M.A., Zaman, M.F. and Sheikh, M.R.I. 2012. Energy Efficient Modelling of Solar Wind Hybrid Power System for a Tourist Island. International Journal Of Advanced Renewable Energy Research. Vol.1. Iss.1. pp. 1-7.

[8] Muralikrishna, M., Lakshminarayana, V. 2011. A 10 Kw Combined Hybrid (Wind and Solar Photovoltaic) Energy Systems for Isolated Generating System. ARPN Journal of Engineering and Applied Sciences. Vol. 6. No. 6. ISSN 1819-6608p.

[9] Amer, M., Namaane, A., M'Sirdi, N.K. 2013. Optimization of Hybrid Renewable Energy Systems (HRES) Using PSO for Cost Reduction, The

Mediterranean Green Energy Forum 2013, MGEF-13, Elsevier-Science Direct, Energy Procedia 42 (2013) 318 – 327.

[10] Ram, G.N., Shree, J.D., Kiruthiga, A. 2013. COST OPTIMIZATION OF STAND ALONE HYBRID POWER GENERATION SYSTEM USING PSO. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE), Vol. 2, Iss. 8, ISSN (Online): 2278 – 8875.

[11] Trazouei, S.L., Tarazouei, F.L., Ghiamy, M. 2013. Optimal Design of a Hybrid Solar -Wind-Diesel Power System for Rural Electrification Using Imperialist Competitive Algorithm, INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH. Vol. 03. N°. 2.

[12] Ajao, K.R., Oladosu, O.A., Popoola, O.T. 2011. Using Homer Power Optimization Software for Cost Benefit Analysis Of Hybrid-Solar Power Generation Relative To Utility Cost In Nigeria, IJRRAS, Vol. 07, Iss. 1.

[13] Rawat, R., Chandel, S.S. 2013. Simulation and Optimization of Solar Photovoltaic-Wind Stand Alone Hybrid system in Hilly Terrain of India. INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH, Vol.3, No. 3.

[14] Dalwadi, P.G., Mehta, C.R. 2012. Feasibility Study of Solar-Wind Hybrid Power System, International Journal of Emerging Technology and Advanced Engineering. Vol. 2, Iss. 3, ISSN 2250-2459.

[15] Razak, J.A., Sopian, K., Ali, Y. 2007. Optimization of Renewable Energy Hybrid System by Minimizing Excess Capacity. INTERNATIONAL JOURNAL OF ENERGY, Vol. 1, Iss. 3.

[16] Acakpovi, A., Hagan, E. B. 2013. Novel Photovoltaic Module Modeling using Matlab/Simulink, International Journal of Computer Applications (IJCA) Vol. 83, N°.16, pp 27-32.

[17] Villalva, M., G., Gazoli, J.R., and Filho. E.R. 2009. Comprehensive Approach of Modeling and Simulation of a Photovoltaic Arrays. IEEE Transaction on Power Electronics. Vol.24. No.5. pp. 1198-1208.

[18] Ramos-Paja, C.A., Perez, E., Montoya, D.G., Carrejo, C.E., Simon-Muela, A., Alonso, C. 2010. Modelling of Full Photovoltaic Systems applied to Advanced Control Strategies. Columbia: Universidad Nacional de Columbia

[19] Tsai, H.L., Tu, C.S., and Su, Y.J. 2008. Development of Generalized Phottovoltaic Model Using MATLAB/SIMULINK. Proceedings on the world congress on Engineering and Computer Science. WCECS, ISBN: 978-988-98671-0-2, 6p.

[20] Khajuria, S., and Kaur, J. 2012. Implementation of Pitch Control of Wind Turbine using Simulink (Matlab). International Journal of Advanced Research in computer Engineering and technology (IJARCET), vol.1, ISSN: 2278-1323.

[21] Abbas, F. A. R., Abdulsada, M. A. 2010. Simulation of Wind-Turbine Speed Control by MATLAB. International Journal of Computer and Electrical Engineering. Vol. 2, No. 5, 1793-8163p.

[22] Acakpovi, A., Hagan, E. B. 2014. A Wind Turbine System Model Using a Doubly-Fed Induction Generator (DFIG). International Journal of Computer Applications (IJCA). Vol. 90, N°.15, pp 6-11.

[23] Fuchs, E.F., Masoum, M.A.S. 2011. Power Conversion of Renewable Energy Systems. Springer. ISBN 978-1-4419-7978-0.

[24] Hernandez, G.A.M., Mansoor, S.P., Jones, D.L. 2012. Modelling and Controlling Hydropower plants. Springer. DOI 10.1007/978-1-4471-2291-312.

[25] Naghizadeh, R.A., Jazebi, S., Vahidi, B. 2012. Modelling Hydro Power Plants and Tuning Hydro Governors as an Educational Guideline. International Review on Modelling and Simulations (I.RE.MO.S), Vol. 5, N°. 4

[26] Marquez, J.L., Molina, M.G., Pacas, J. M. 2010. Dynamic modelling, simulation and control design of an advanced micro-hydro power plant or distributed generation applications. Elsevier Trans. On Hydrogen Energy Policy, pp. 1-6.

[27] Singh, M., and Chandra, A. 2010. Modeling and Control of Isolated Micro-Hydro Power Plant with Battery Storage System. National Power Electronic Conference. Roorkee. India.

[28] Mathworks. 2014. Optimization Toolbox, User's Guide, R2014b. Natick, MA 01760-209