Performance analysis of particle swarm optimization approach for optimizing electricity cost from a hybrid solar, wind and hydropower plant

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Performance Analysis of Particle Swarm Optimization Approach for Optimizing Electricity Cost from a Hybrid Solar, Wind and Hydropower Plant

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Abstract-This paper deals with the cost optimization of a hybrid solar, wind and hydropower plant using a Particle Swarm Optimization (PSO) approach. PSO is a technique that belongs to Swarm intelligence, an artificial intelligence (AI) technique, known as a Meta-heuristic optimization solver, mostly used in Biology. With the consideration of solar, wind and hydro hybrid system which has become extremely relevant for developing countries, and also the existence of a wide list of constraints, the adoption of PSO technique cannot be avoided. On the other hand, a linear optimization approach was used with Matlab software to solve the same problem. Both techniques were applied to secondary data collected from RetScreen Plus software for the location Accra and results were extracted in terms of distribution of supply by individual sources and cost of hybrid system electricity. Results show in general, an improvement of hybrid system cost of electricity. A histogram was used to show the distribution of supply for the particular load and the equivalent cost of hybrid system that corresponds to it. A khi-sqaure test was run to compare the two series of data obtained from the two approaches adopted. The Khi-square test show high similarity confirming the reliability of the PSO approach which on the other hand presents the advantage of scalability over a wider range of sources with multiple constraints.

KeywordsEconomic Dispatch, PSO, Cost Optimization, Solar Energy, Wind Energy, Hydro Energy, Hybrid Energy Systems.

1. Introduction

Hybrid energy systems (HES) have increasingly gained widespread adoption in remote locations across the whole world. Usually made of a combination of a number of renewable energy sources, HES helped to provide increased system efficiency as well as convenience in energy supply. Commonly encountered hybrid system include wind-solar hybrid energy supply, wind-solar-diesel generator hybrid energy supply, hydro-wind hybrid energy supply. However, the high cost associated to these renewable energy sources poses a great challenge. Solar energy as well as wind energy are known to be very expensive even though the sun irradiation and wind speed may be available in quantity in most remote areas. As a solution, it has become relevant to optimize the cost of hybrid electricity with an ultimate objective to always minimize it. The same problem has been further described as economic load dispatch problem which is defined as short term determination of the optimal output of a number of electricity generation facilities to meet a system load, at the lowest possible cost, subject to transmission and operational constraints.

Genetic algorithm was used to solve a wind, solar hybrid energy system optimization problem by [1]. Furthermore the same optimization problem relating to solar and wind with additional storage battery has been solved with optimization based software known as OptQuest, [2]. Whist the optimization done with OptQuest was a simulation based scenario, [3, 4] developed an artificial intelligence programmed into microcontroller to physically handle the same optimization problem, precisely to improve upon the energy tracking system. Many other optimizations including [5] and [6], have adopted a Particle Swarm Optimization approach. Based on [5-8], particle swarm optimization is defined as a population based stochastic optimization technique developed by Kennedy and Eberhart (1995), inspired by birds or fish's social behaviour of grouping. The roots of PSO derive from zoology considering the modelling of the movement of individuals including birds, or fishes within a group. According to [9] PSO is a similar technique to other heuristic optimization techniques that search the best solution in parallel. In fact it is known that PSO shares many similarities with optimization techniques such as Genetic Algorithm (GA) and it is mainly used for Artificial Intelligence programming. Currently, there are many available software developed to handle PSO programming and simulation. Most remarkable of them include the PSOt toolbox of Matlab developed by [10], the educational simulator developed by [9], the software tool developed by [11].

Additionally, [5] adopted a PSOand Simulated Annealing (SA) approach to determine minimum cost of electricity for different power demands. [12, 13] also solved the economic dispatch (ED) problem with PSO approach. [14] proposed an improved approach for solving the ED problem that involved generator constraints. The technique adopted was an improved version of the traditional PSO known as particle swarm optimization with mutation operators (PSOM). [15] performed similar optimization by including algorithms to handle non-linearity aspects related to the generation units. [16] presented a particle swarm optimization to solve combinatorial constrained optimization problems like non-convex and discontinuous economic dispatch problem of large thermal power plants.

Despite all these previous prior studies on economic load dispatch problem, typical solar, wind and hydro hybrid energy have not been intensively handled. Moreover the constraints of ED problems solved before, do not consider the fact that some of the generation stations may already exist and others are just to be added-up to construct the hybrid system. Meanwhile, this situation is very common in developing countries that rely mostly on hydroelectricity only. The solar and wind energy become alternative powers that may be added to the existing hydroelectricity.

In this regard, this paper presents a PSO approach to minimizing the cost of electricity from a hybrid solar, wind and hydro power by considering the constraints in a manner that responds to the situation described above for developing countries.

2. Methods and Materials

2.1. PSO Background

The set of solutions provided by the PSO approach, known as particles, move through a search space step by step by following the current optimal particles. More specifically, in a physical n-dimensional search space, the position and velocity of individual i are represented as the vectors.

$$Y_i = (Y_{i1}, \dots\dots, Y_{in}) \quad (1)$$

And

$$V_i = (v_{i1}, \dots\dots, v_{in}) \quad (2)$$

In the PSO algorithm. let

$$Pbest_i = \left(Y_{i1}^{Pbest}, \dots\dots, Y_{in}^{Pbest}\right) \quad (3)$$

And

$$Gbest_i = \left(Y_{1}^{Gbest}, \dots\dots, Y_{n}^{Gbest}\right) \quad (4)$$

be the best position of the individual i and its neighbours can be calculated using the current velocity and the distance from $Pbest_i$ to Gbest as follows:

$$V_i^{k+1} = \omega V_i^k + c_1 rand_1 \times \left(Pbest_i^k - Y_i^k\right) + c_2 rand_2 \times \left(Gbest^k - Y_i^k\right) \quad (5)$$

$$Y_i^{k+1} = Y_i^k + V_i^{k+1} \quad (6)$$

Where:

- V_i^k: Individual i's velocity at iteration k,
- ω: parameter relating to weight
- c_1, c_2: acceleration coefficient
- $rand_1, rand_2$: Random numbers from 0 to 1
- Y_i^k: Location of individual i at iteration k,
- $Pbest_i^k$: best position of individual i until iteration k
- $Gbest^k$: best position of the group until iteration k

The constants c_1 and c_2 signify the weighing of the stochastic acceleration term that attracts each particle near the Pbest and Gbest locations. Appropriate selection of inertia weight provides a balance between global and local explorations, thus requiring less iteration on average to find sufficiently optimal solution. In general, and according to [17], [18] and [19], the inertia weight ω has a linearly decreasing dynamic parameter moving downward from ω_{max} to ω_{min} as follow:

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{Iter_{max}} \times Iter \quad (7)$$

where, $Iter_{max}$ is maximum iteration number and Iter is the current iteration number.

2.2. Problem Formulation

- Analytical model of power generation for individual sources

Existing analytical models of power generation by solar, wind and hydropower plants developed by previous studies, [20, 21, 22], are presented below

The power generated by the solar system can be expressed as follow

$$P(t) = n_r[1 - \beta(T_c - T_{cref})]A_S G(t) \quad (8)$$

Similarly, the power generated by the hydropower plant can be expressed as follow:

$$P_h = \eta_t \rho g H Q(t) \quad (9)$$

The wind power is also generated based on the equation (10) below

$$P_m(t) = \frac{1}{2}\rho A_w C_p V_w^3(t) \quad (10)$$

Where

- T_{cref}: Cell reference temperature
- T_C: Cell operating temperature
- A_S: Ideal factor dependent of the PV characteristic, A=1.3 for poly-crystalline solar cell
- B is the temperature coefficient
- n_r is the PV generation efficiency
- G(t) is the solar irradiation
- C_p is the coefficient of performance also called power coefficient
- A_w 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)

➢ **Levelized Cost of Energy (LCE).**

LCE is defined as a cost of vending energy that covers many aspects including the lifetime of the generation unit, the depreciation, maintenance and interest factors. According to [23], LCE can be expressed as shown in equation (11).

$$LCE = \frac{(CRF \times ICC) + AOE}{AEP_{net}} \quad (11)$$

Where:

- LCE: Levelized cost of electricity
- CRF: Capital Recovery Factor
- ICC: Installed Capacity Cost
- AEP_{net}: Net annual energy production
- AOE: Annual Operating Expenses, This can further be assumed to have a quadratic form.

The objective of this problem is to find the optimal combination of power generations that minimizes the levelized cost of energy while satisfying both equality and inequality constraints. In general, the problem can be formulated mathematically as a constrained optimization problem with an objective function of the form

$$\text{Minimize } LCE_T = \sum_{i=1}^{n} LCE_i(P_i) \quad (12)$$

Where LCE_T is the total levelized cost of electricity, n is the number of generating unit and $C_i(P_i)$ is the operation cost of generating unit i. A quadratic expression is mostly used to represent the operation cost as illustrated by [8], [9] and [15].

$$LCE_i(P_i) = \frac{(CRF_i \times ICC_i) + (a_i + b_i P_i + c_i P_i^2)}{AEP_{neti}} \quad (13)$$

Where a_i, b_i and c_i represent the cost coefficients of the generating units. P_i is the real power output of the i^{th} unit.

The minimization problem is subjected to the following constraints

1. The generated power must cater for the load power required and for the losses incurred during transmission of the signal. Therefore we obtain equation (14)

$$\sum_{i=1}^{n} P_i = P_d + P_l \quad (14)$$

Where:

- P_i: Generated power per unit i
- P_d: the demanded power or load power request
- P_l: Power of losses: P_l is estimated by Kron relationship shown by [24] that is based on B matrix known as transmission loss coefficient matrix. The B matrix is a square matrix with dimension n x n with n the number of generation units. Equation (15) shows how to calculate P_l using the B matrix

$$P_l = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j \quad (15)$$

Where P_i, P_j are the generated power by i^{th} and j^{th} generating units respectively; B_{ij} is an element of the B-matrix between i^{th} and j^{th} generating units.

2. The generated power by each unit must be less or equal to the capacity of this unit. Moreover there is a minimum power required for the operation of each unit ranging from the solar to the wind. Therefore equation (16) below holds:

$$P_{i,min} \le P_i \le P_{i,max} \quad (16)$$

Where:

- P_i: Generated power per unit i
- $P_{i,min}$: The minimum acceptable power that must be generated from unit i
- $P_{i,max}$: the maximum capacity beyond which unit i cannot generate

3. Variables should also stay between bounds as follow

$$\begin{cases} G_{min} \le G \le G_{max} \\ V_{wmin} \le V_w \le V_{wmax} \\ Q_{min} \le Q \le Q_{max} \end{cases} \quad (17)$$

2.3. Proposed Solution Using PSO

This paragraph presents the basic algorithm that solved the above described problem using the PSO approach. Fig. 2 shows the corresponding flowchart

- Step 1: Select the various parameters of PSO
- Step 2: Initialize a population of particles with random positions and velocities in the problem space
- Step 3: Evaluate the fitness of each particle using the objective function
- Step 4: Assign the particle's initial position to P-best position and initial fitness to P-best fitness

- Step 5: Determine the best among the P-best as G-best and save the fitness value of G-best.
- Step 6: Modify the position and velocity of the particle based on equations (5) and (6), respectively
- Step 7: For each individual particle, re-evaluate the fitness, for all decisions variable confined within the search ranges
- Step 8: compare the particles fitness value with its Pbest. If the current value is better than the Pbest value, then set this value as the Pbest for agent i and the P-best location equal to the current location in the d-dimensional search space.
- Step 9: Compare the best current fitness evaluation with the population G-best. If the current value is better than the population G-best, then reset the G-best to the current best position and the fitness value to current fitness value.
- Step 10: Repeat steps 6-9 until one of the following stopping criterion is met: sufficiently good G-best fitness or a maximum number of iterations is attained

2.4. Proposed Solution with Linear Optimization Approach

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 similar problem by Matlab, [10], 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
- bis 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 the optimization problem is constructed around the linprog function of Matlab and can be described by both the following algorithm and the flowchart in Fig. 1. and Fig. 2. respectively.

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.

2.5. Implementation with Matlab

A PSOt toolbox developed by [10] has been used for the simulation. A file however was introduced to carry the equations defined for the objective function and also the system’s constraints.

2.6. Data Collection

Data were collected on wind speed, solar radiation, temperature, location parameters including longitude, latitude and elevation using the RETScreenPlus Software that covers the period of 1997 to 2013. According to [25] the RETScreen Plus is a Windows-based energy management software tool that allows project owners to easily verify the on-going energy performance of their facilities. It is developed by the ministry of energy in Canada in collaboration with NASA. Fig. A1 in appendix A shows the data collected for Accra.

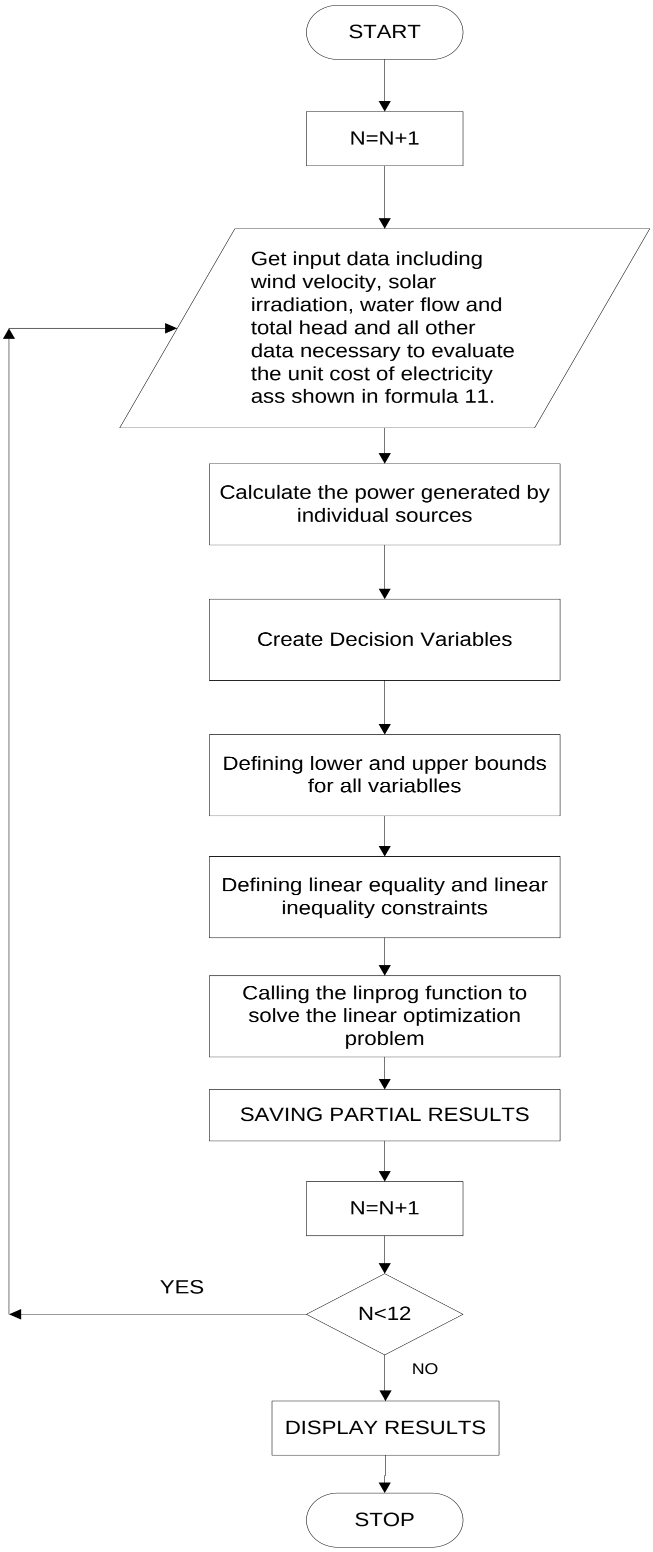


Fig. 1. Flowchart Depicting the Proposed Solution

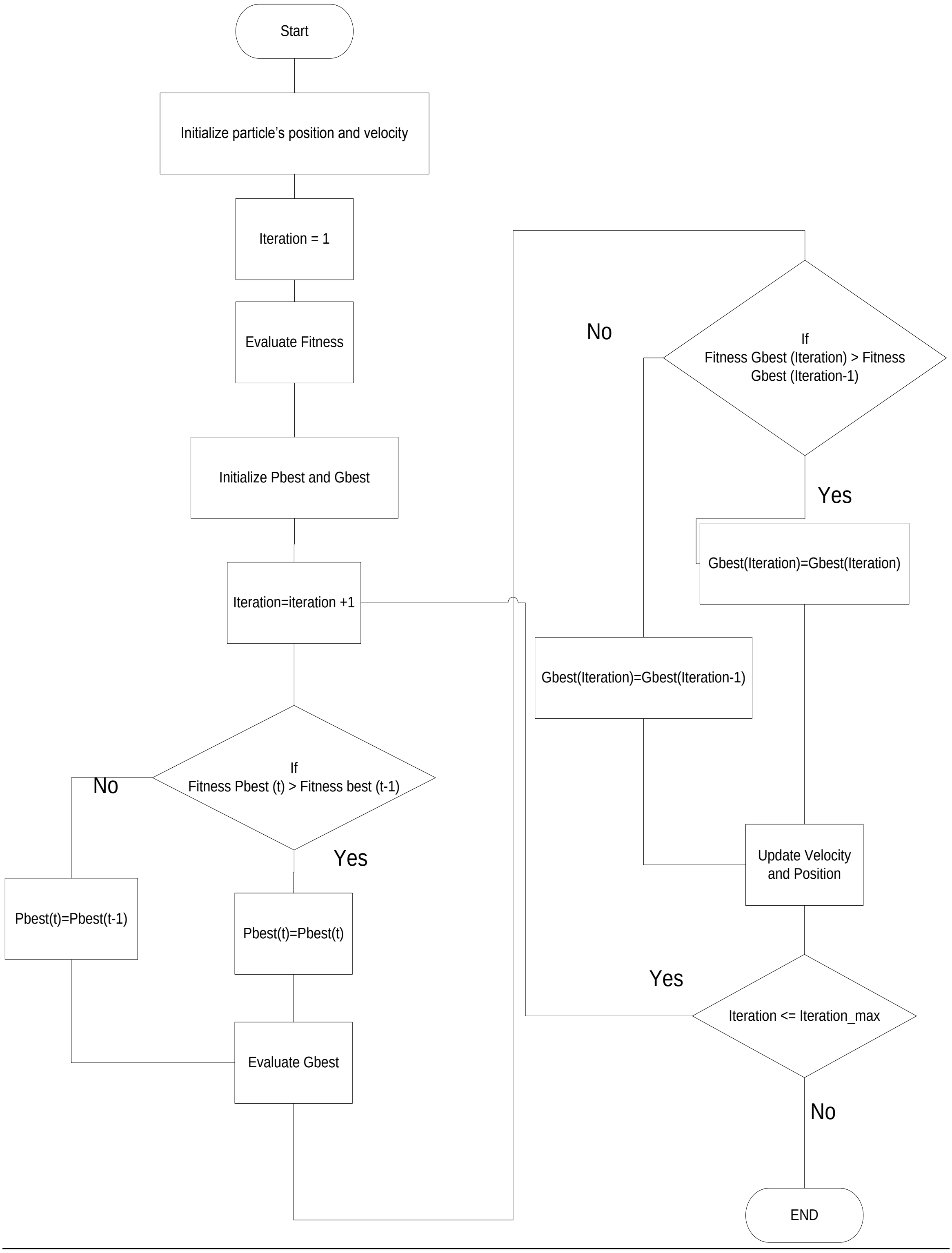


Fig. 2. Flowchart Showing the Cost Optimization Solution using PSO Algorithm

3. Results

3.1. Results Obtained from PSO Simulation

Figures 3 and 4 show sample PSO results taken for Accra for the month of January and February 2013.The sub-graphs on particle dynamic show how the particles are moving and converging towards the best optimal point which is represented in red. Also the Gbest which is evaluated after each iteration is plotted. A display in the Matlab workspace shows the numerical values obtained at the optimum point.

The simulation is continuously run for all the twelve (12) months and the numerical results obtained were saved to later plot the histogram of supply distribution as well as cost of hybrid energy system using PSO (Fig. 5 and Fig. 6).

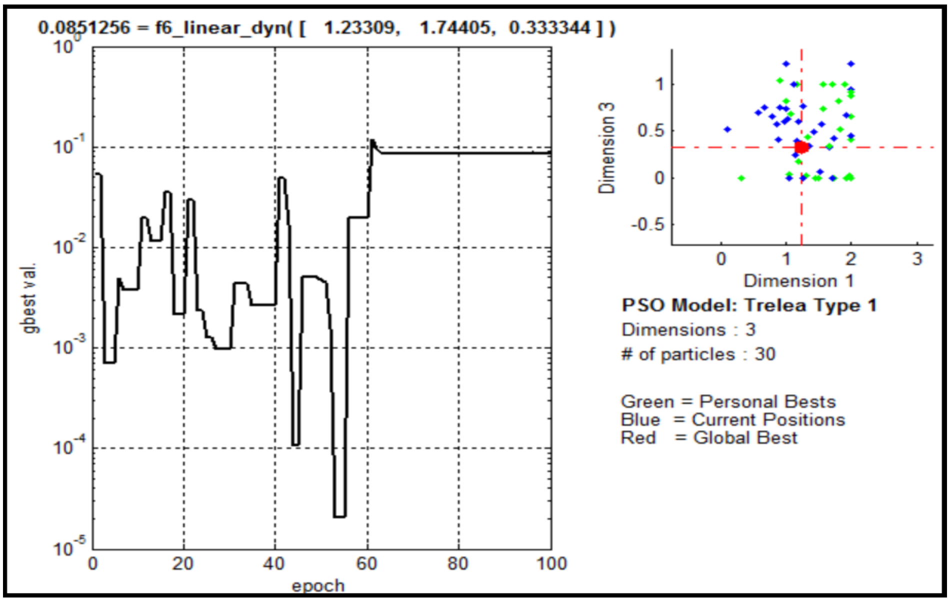


Fig. 3. PSO Sample Result for the Month of January (Case of Accra)

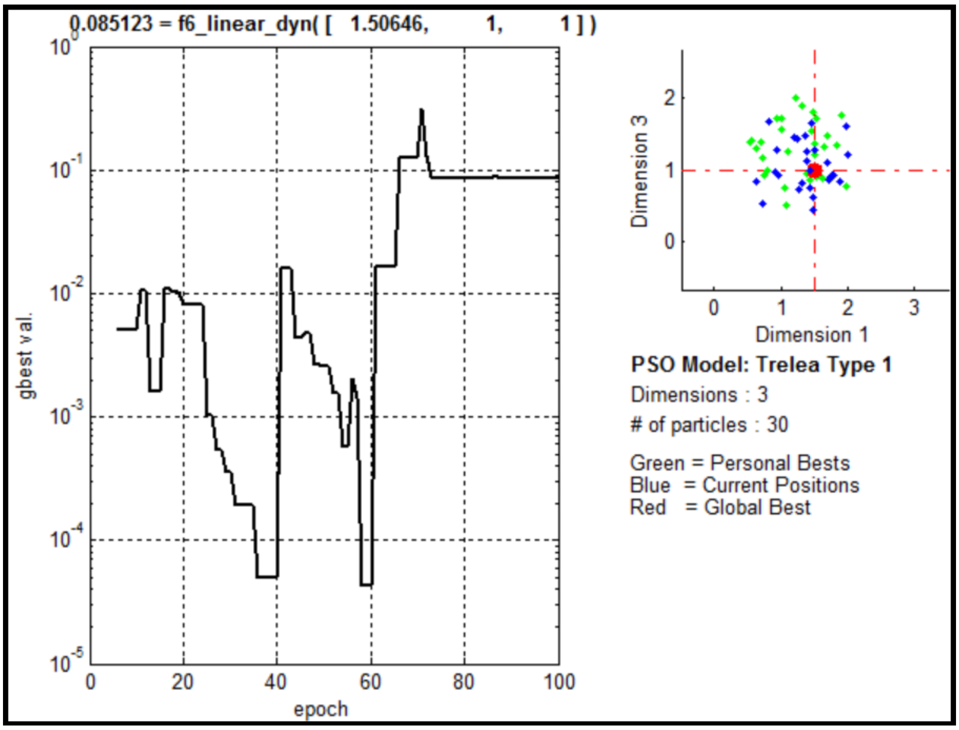


Fig. 4. PSO Sample Result for the Month of February (Case of Accra)

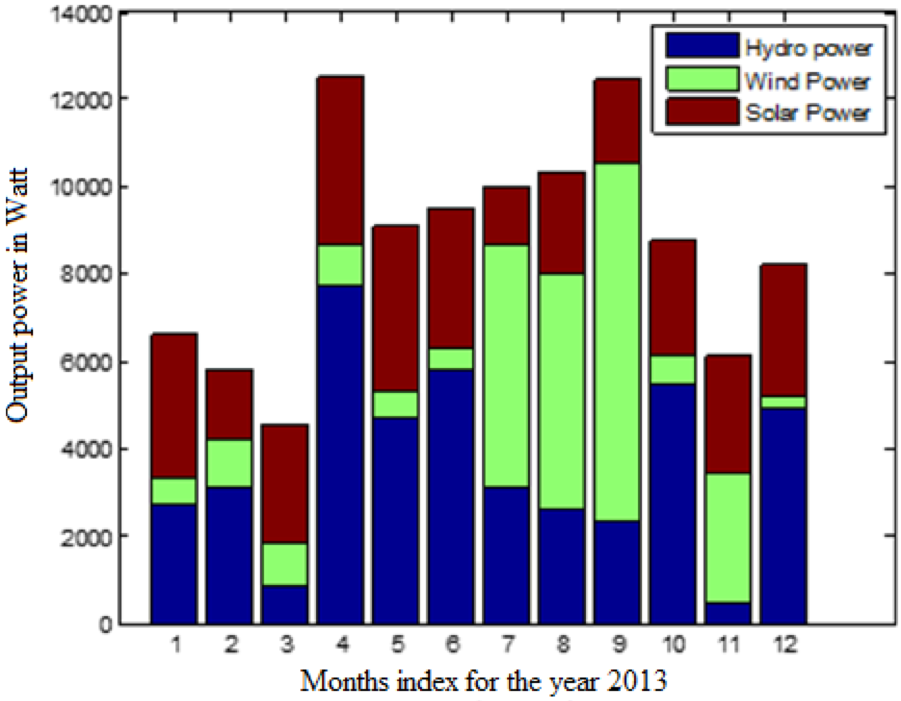


Fig. 5. Contribution of Individual Plants to the Total Energy Supplied using the PSO Approach (Case of Accra)

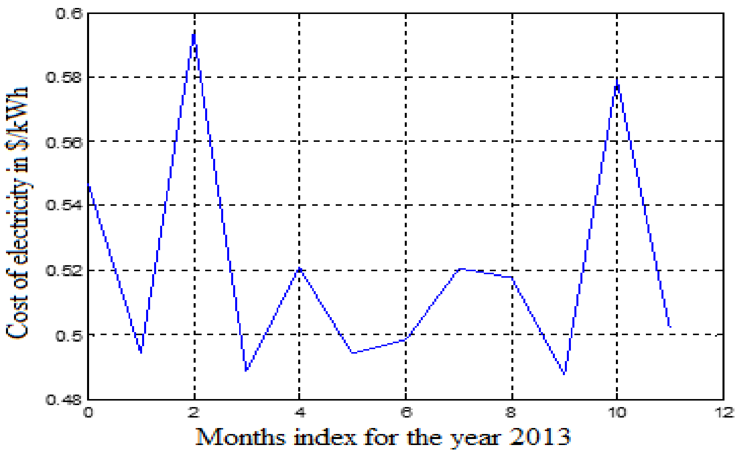


Fig. 6. Cost of Hybrid Electricity using PSO Approach (Case of Accra)

3.2. Results Obtained from the Linear System Optimization

The data obtained with the solution provided through the linear system programming is made of the distribution of supply from individual sources and the equivalent cost of electricity. The system was applied to the same data collected in Ghana.

Fig. 5. and Fig. 6. as well as Fig. 7. and Fig. 8., actually show the dynamic operation of the optimization methods in selecting the adequate sources and level of their contribution that brings the optimum cost. It is observed in both cases that the hydropower plant has been selected and used throughout the year. This is justified due to the cost of generating hydro which is the least as compared to the counterparts solar and wind. In reality, the estimated unit cost of electricity by the PSO algorithm were 0.64$/kWh, 0.52$/kWh, 0.36$/kWh respectively for the solar, wind and hydro energy. Subsequently, the other two sources become additive to compensate the load in case the hydro contribution is not enough to satisfy the request. In cases where the hydro energy produced can supply the load request, it may be solely used. It is also observed that the wind energy comes in second priority as its cost is lower than the solar one. However, wind speeds are very low in the considered location therefore making the wind energy production to be very small. Besides, solar is the most expensive and mostavailable that comes in when both the hydro and wind resources are exhausted.

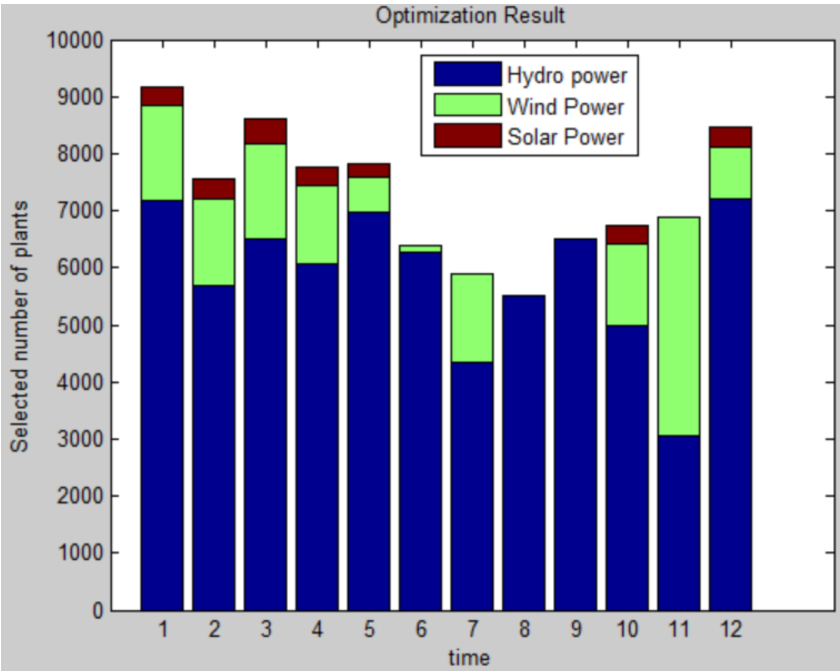


Fig. 7. Contribution of Individual Plants to the Total Energy Supplied using the Linear Programming Approach (Case of Accra**)**

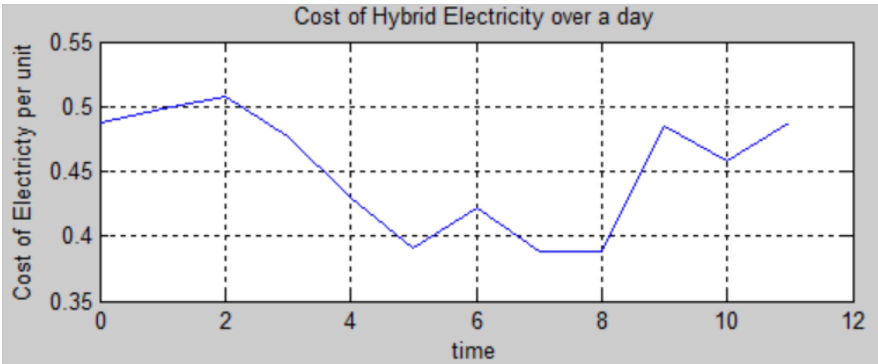


Fig. 8. Cost of Hybrid Electricity (Case of Accra)

3.3. Chi-Square Test

To ascertain the effectiveness of the PSO technique adopted, the distribution of electricity cost obtained for the PSO algorithm is compared with the one obtained with the linear programming system using a Khi-Square test.

Consequently, the following hypothesis were formulated:

- H_0: There is no significant difference between the costs of hybrid electricity estimated with the PSO and the linear programming technique.
- H_1: There is significant difference between the costs of hybrid electricity estimated with the PSO and the linear programming technique.

The calculated Chi-Square value is achieved with formula 18.

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - e_i)^2}{e_i} \quad (18)$$

Where

- O_i represents the observed values, in this case the value obtained with PSO technique
- e_i represents the expected values, in this case the values obtained with the linear programming
- n represents the total number of samples

Table 1 below shows the detailed calculation of the Chi-Square value based on the data presented in appendix A.

Table 1. Determination of Chi-Square value

e_i	0.49	0.50	0.51	…	…	…	0.39	0.51	0.52	0.51	χ^2
O_i	0.55	0.49	0.59	…	…	…	0.47	0.46	0.47	0.45	
$O_i - e_i$	0.06	-0.01	0.08	…	…	…	0.08	-0.05	-0.05	-0.06	
$(O_i - e_i)^2$	0.00	0.00	0.01	…	…	…	0.01	0.00	0.00	0.00	
$\frac{(O_i - e_i)^2}{e_i}$	0.01	0.00	0.01	…	…	…	0.02	0.00	0.00	0.01	5.47

The degree of freedom df is given by $df = n - 1 = 288 - 1 = 287$

For a risk of rejection of hypothesis H_0, of 5%, the Chi-square table shows chi square critical values. $\chi^2_{theoretical} = 327.5117$ as shown in the Chi-Square table (table 2)

In conclusion,

$$\chi^2 = 5.47 \leq \chi^2_{theoretical} = 327.5117 \quad (19)$$

Therefore hypothesis H_0 is accepted and H_1 is rejected.

This finding implies that there is no significant difference between the optimization results obtained using the self-developed algorithm and the approach by PSO at a confidence of 95%.

Table 2. Theoretical Chi-Square table

D.F.	**0.995**	**0.975**	**0.20**	**0.10**	**0.05**	**0.025**	**0.02**	**0.01**	**0.005**	**0.002**	**0.001**
245	191.739	203.539	263.409	273.762	282.511	290.248	292.577	299.417	305.767	313.580	319.138
246	192.623	204.450	264.447	274.820	283.586	291.336	293.670	300.522	306.883	314.710	320.278
247	193.507	205.362	265.485	275.878	284.660	292.425	294.762	301.626	307.999	315.840	321.417
248	194.391	206.274	266.523	276.935	285.734	293.513	295.855	302.731	309.115	316.969	322.556
249	195.276	207.186	267.661	277.993	286.808	294.601	296.947	303.835	310.231	318.098	323.694
250	196.161	208.098	268.599	279.050	287.882	295.689	298.039	304.940	311.346	319.227	324.832
300	240.663	253.912	320.397	331.789	341.395	352.425	352.425	359.906	366.844	375.369	381.425
Degrees of Freedom 287			**Critical Value**		**327.5117**						
			Probability		**0.95**						

4. Findings and Discussion

This paper proposed and solved mathematically and by programming, a cost optimization problem of hybrid solar, wind and hydropower plant that effectively minimizes the cost of electricity provided by the hybrid system with a linear optimization approach.

Amer et Al. (2013), Lal et al. (2011) and Trazouei et al.(2013) respectuvely, [23], [26] and [27] also proposed optimization of renewable hybrid energy systems that effectively reduced the cost of electricity. The proposed solution in this paper is however more dynamic as it updates the hybrid cost of electricity on monthly basis and also proposes a distribution of supplies more convenient than prior studies. Practically, the implementation of this study will bring about a relatively lower cost of electricity as the optimized solution minimizes the cost of electricity. The frequency of power outages will equally be reduced due to the non-reliance on only one source. Policy wise, the implementation of this design demands the adoption of net-metering and related policies that allow users to produce and sell electricity to the grid.

Furthermore, a particle swarm optimization approach (PSO) was further used in this paper to solve the cost optimization problem of the hybrid solar, wind and hydropower supply by programming.

A Khi-Square test shows that the linear optimization approach through simulation agrees with the PSO simulation results. Bansal et al. (2010), Ram et al. (2013), Sharma et al. (2014), Idoumghar et al. (2011) respectuvely [28-31], presented different cost optimization of renewable energy sources using the PSO approach. Their results on hybrid system cost reduction are in agreement with the findings of this study related to the use of the PSO techniques. The adoption of PSO technique that proves successful in this paper should theoretically encourage more optimization techniques of the same metaheuristic optimization family and other swarm intelligence techniques for solve HES problems.

5. Conclusion

In summary, this paper presented a cost optimization problem of hybrid solar, wind and hydropower plant and solved it using a linear optimization approach followed by a PSO approach. A khi-Square test was used to compare the two approached adopted and results show close similarity. In other terms the two techniques helped to truly reduce the cost of electricity supply and provided optimized cost of electricity that was updated on monthly basis. Moreover the Khi-square test result indicate an acceptance for the PSO technique in solving power management issues and therefore, a practical implementation of the PSO intelligence through the use of intelligent devices such as special Digital Signal Processor (DSP) or Microcontrollers is recommended for future studies.

References

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

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

[3] G. V. T. Prasad, S. Srinivasan, and V. Sriram, "Hybrid Solar And Wind Off-Grid System - Design And Control". *International Journal of Engineering Science and Technology*. Vol. 2(4). 548-552p, 2010.

[4] M. Muralikrishna, and V. Lakshminarayana, "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, 2011.

[5] V. Karthikeyan , S. Senthilkumar, and V. J. Vijayalakshmi "A New Approach To The Solution of Economic Dispatch Using Particle Swarm Optimization with Simulated Annealing". *International Journal on Computational Sciences & Applications (IJCSA)* Vol.3, No.3, pp. 37-49, June 2013.

[6] G. Zwe-Lee Gaing, "Particle Swarm Optimization to Solving the Economic Dispatch Considering the Generator Constraints". *IEEE Transactions on Power Systems*, VOL. 18, NO. 3, 1187-1195, 2003.

[7] J. F. Kennedy, R. C. Eberhart, and Y. Shi "Swarm intelligence. San Francisco: Morgan Kaufman" 2001;

[8] V. Puri, and Y. K. Chauhan, "A Solution to Economic Dispatch Problem Using Augmented lagrangian Particle Swarm Optimization", *International Journal of Emerging Technology and Advanced Engineering*. ISSN 2250-2459, Volume 2, Issue 8, pp. 511-517, 2012.

[9] W. M. Lee, and J. B. Park, "Educational Simulator for ParticleSwarm Optimization and Economic Dispatch Applications", *INTECH Publishing*. Konkuk University, Korea, 2011.

[10] B. P. Singh. (2014). Particle Swarm Optimization Toolbox. Mathworks Publishing. available on http://www.mathworks.com/

[11] L. D. S. Coelho, and C. A. Sierakowski, "A software tool for teaching of particle swarm optimization fundamentals", *ScienDirect, Elsevier, Advances in Engineering Software*, pp.877–887, 2008.

[12] L.V. Narasimha "PSO Technique for Solving the Economic Dispatch Problem Considering the Generator Constraints", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 3, Issue 7, DOI: 10.15662/ijareeie.2014.0307009, pp. 10439-10454, 2014.

[13] S. Tiwari, A. Kumar, G. S. Chaurasia, and G. S. Sirohi, "Economic Load Dispatch Using Particle Swarm Optimization", *International Journal of Application or Innovation in Engineering and Management*. ISSN 2319 – 4847. Vol. 2, Iss. 4, 2013.

[14] S. Khamsawang and S. Jiriwibhakorn, "Solving the Economic Dispatch Problem using Novel Particle Swarm Optimization", *World Academy of Science, Engineering and Technology-International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, Vol:3, No:3, pp. 529-534, 2009.

[15] R. Rahmani, M. F. Othman, R. Yusof, and M. Khalid, "Solving Economic Dispatch Problem Using Particle Swarm Optimization By An Evolutionary Technique For Initializing Particles", *Journal of Theoretical and Applied Information Technology*, Vol. 46, No.2, ISSN: 1992-8645, pp. 526-536, 2012.

[16] V. K. Jadoun, N. Gupta, K. R. Niazi, and A. Swarnkar, "Nonconvex Economic Dispatch Using Particle Swarm Optimization with Time Varying Operators", *Hindawi Publishing Corporation Advances in Electrical Engineering*, Volume 2014, ID 301615, 13 pages, http://dx.doi.org/10.1155/2014/301615, pp. 1-13, 2012.

[17] K. Y. Lee, and M. A. El-Sharkawi, "Modern Heuristic Optimization Techniques with Applications to Power Systems", *IEEE Power Engineering Society (02TP160), 2002.*

[18] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi, "A particle swarm optimization for reactive power and voltage control considering voltage security assessment", *IEEE Trans. Power System*, Vol. 15, pp. 1232-1239, 2002.

[19] J. B. Park, K. S. Lee, J. R. Shin, and K. Y. Lee, "A particle swarm optimization for economic dispatch with non-smooth cost functions" *IEEE Trans. Power Syst.*, Vol. 20, N°. 1, pp. 34-42, 2005.

[20] A. Acakpovi, E. B. Hagan, and F. X. Fifatin, "A Review of Hydropower Plant Models" *International Journal of Computer Application (IJCA),* vol.108, N°.18, pp. 33-38, Dec. 2014.

[21] A. Acakpovi, E. B. Hagan, and F. X. Fifatin, "A Wind Turbine System Model Using a Doubly-Fed Induction Generator (DFIG)" *International Journal of Computer Application (IJCA),* vol.90, N°.15, pp. 6-11, March.2014.

[22] A. Acakpovi, E. B. Hagan, and F. X. Fifatin, "Novel Photovoltaic Cell Model Using Matlab Simulink" *International Journal of Computer Application (IJCA),* vol.83, N°.16, pp. 27-32, Dec.2013.

[23] M. Amer, A. Namaane, N. K. M'Sirdi. "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, 2013.

[24] D. S. Kirschen, and G. Strbac, “Fundamentals of Power System Economic”, *WILEY*, ISBN: 978-0-470-84572-1, 296pp, 2014.

[25] R. D. Ganoe, P. W. Stackhouse, and R. J. DeYoung. RETScreenPlus Software Tutotrial. *NASA Technical Report Servers*,2014

[26] D. K. Lal, B. B. Dash, and A. K. Akella, “Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area,” *International Journal on Electrical Engineering and Info rmatics*. Vol. 3, No. 3, 2011.

[27] S. L. Trazouei, F. L.Tarazouei, and M. Ghiamy, “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, No. 2, 2013.

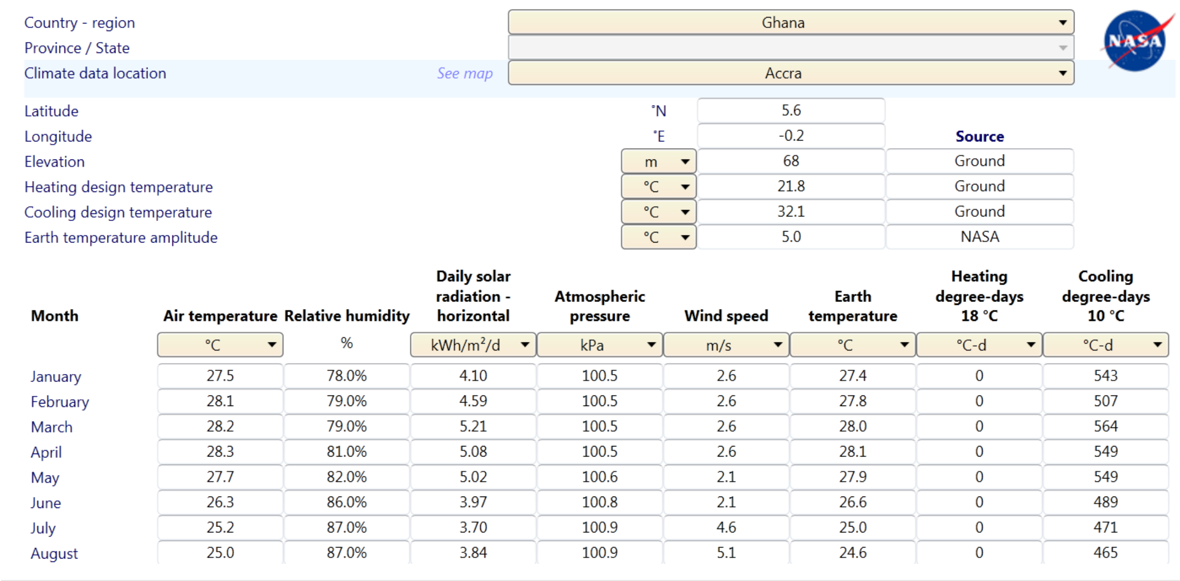
[28] A. K. Bansal, R. A. Gupta, R. Kuma, “Optimization of hybrid PV/Wind Energy System using Meta Particle Swarm Optimization (MPSO),” *IEEE, India International Conference on Power Electronics (IICPE)*, pp 1-7.

[29] G. N. Ram, J. D. Shree, A. Kiruthiga, “Cost Optimization of Stand Alone Hybrid Power Generation System Using PSO”, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 2, No. 8, 2013.

[30] D. Sharma, P. Gaur, and A. P. Mittal, “Comparative Analysis of Hybrid GAPSO Optimization Technique With GA and PSO Methods for Cost Optimization of an Off-Grid Hybrid Energy System,” *Taylor and Francis Group, Energy Technology & Policy*, ISSN: 2331-7000, pp. 106–114, 2014.

[31] L. Idoumghar, M. Melkemi, R. Schott, and M. I. Aouad, “Hybrid PSO-SA Type Algorithms for Multimodal Function Optimization and Reducing Energy Consumption in Embedded Systems,” *Applied Computational Intelligence and Soft Computing*, DOI:10.1155/2011/138078, 12p, 2011.

Appendix A



Country - region		Ghana	
Province / State			
Climate data location	See map	Accra	
Latitude	°N	5.6	
Longitude	°E	-0.2	Source
Elevation	m	68	Ground
Heating design temperature	°C	21.8	Ground
Cooling design temperature	°C	32.1	Ground
Earth temperature amplitude	°C	5.0	NASA

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	27.5	78.0%	4.10	100.5	2.6	27.4	0	543
February	28.1	79.0%	4.59	100.5	2.6	27.8	0	507
March	28.2	79.0%	5.21	100.5	2.6	28.0	0	564
April	28.3	81.0%	5.08	100.5	2.6	28.1	0	549
May	27.7	82.0%	5.02	100.6	2.1	27.9	0	549
June	26.3	86.0%	3.97	100.8	2.1	26.6	0	489
July	25.2	87.0%	3.70	100.9	4.6	25.0	0	471
August	25.0	87.0%	3.84	100.9	5.1	24.6	0	465

Fig.A1.RETScreen Plus Data Provided for the Location Accra-Ghana

(Source: RETScreenPlus Software, 2013)