Journal of Advances in Mathematics and Computer Science

33(2): 1-16, 2019; Article no.JAMCS.49935

ISSN: 2456-9968

(Past name: British Journal of Mathematics & Computer Science, Past ISSN: 2231-0851)

Optimization of a Grid-Connected Photovoltaic System in a Densely Populated Residential Community

Bernard Atta Adjei[1*], Elvis K. Donkoh[1], Dominic Otoo[1], Emmanuel De-Graft Johnson Owusu-Ansah[2] and Francois Mahama[3]

[1] *Department of Mathematics and Statistics, University of Energy and Natural Resources, Ghana.*
[2] *Department of Mathematics, Kwame Nkrumah University of Science and Technology, Ghana.*
[3] *Department of Mathematics and Statistics, Ho Technical University, Ghana.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAMCS/2019/v33i230175
Editor(s):
(1) Dr. Kai-Long Hsiao, Associate Professor, Taiwan Shoufu University, Taiwan.
Reviewers:
(1) Himanshu Dehra, Canada.
(2) K. Karthick, GMR Institute of Technology, India.
(3) Hachimenum Amadi, Federal University of Technology, Nigeria.
Complete Peer review History: http://www.sdiarticle3.com/review-history/49935

Received: 15 April 2019
Accepted: 26 June 2019
Published: 20 July 2019

Original Research Article

Abstract

In Ghana, the majority of reliable electricity is generated in centralized plants. This type of electricity generation structure undoubtedly contributes to the economic rise in electricity tariffs and transmission losses due to the operational cost of such plants and their vast distances from the communities respectively. In this paper, Linear Programming was used to find the optimal power dispatch of a decentralized grid-connected photovoltaic system in the form of a microgrid for a minimum cost of electricity. The fundamental LP problem was optimized in AMPL (A Modeling Language for Mathematical Programming) properly employing the CPLEX solver. In the case study, the involvement of microgrid in the energy sector convincingly demonstrated a daily cost of GHS63,426.23 in the first five years accurately representing 18% potential reduction. This cost reduction will be increased tremendously to 75% in subsequent years. This is a lower energy bill as compared to the bill of the existing electricity structure.

Corresponding author: E-mail: bernard.adjei.stu@uenr.edu.gh;

Keywords: Linear programming; cost of operation; grid-tie; AMPL; dispatch.

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16.

1 Introduction

A huge sum of money is involved in the operation of centralized plants. Due to this gigantic amount of economic resources, the tariffs on electricity tend to be higher [1]. This cost involves operational cost, maintenance cost, the purchases of tons of millions of fuel for the thermal plants and the hire of skilled labors needed to oversee the plants. Knowing from previous studies that renewable energy can subsidies the price of electricity. The objective of this paper was to use Linear Programming (LP) to find the optimal power dispatch for a decentralized grid-connected photovoltaic system in the form of a microgrid for a minimum cost of electricity. To produce several useful energy products, a complex energy system may use a variety of conventional energy sources and a combination of various equipment. The performance of such a system can be operated in alternative operating modes and therefore it is of critical importance to analyze systems consuming large amounts of natural and economic resources before implementing. This paper exhibits the importance of applying optimization in energy systems. Moreover, the study provides adequate tools for decision making in the residential building planning phase, which will resolve questions on whether to connect to only the utility grid or implement a grid-connected system. It will also respond to questions on the impact of feed-in in electricity generation. This paper will additionally provide a study of modern technological ideas to promote affordable and alternative energy. The

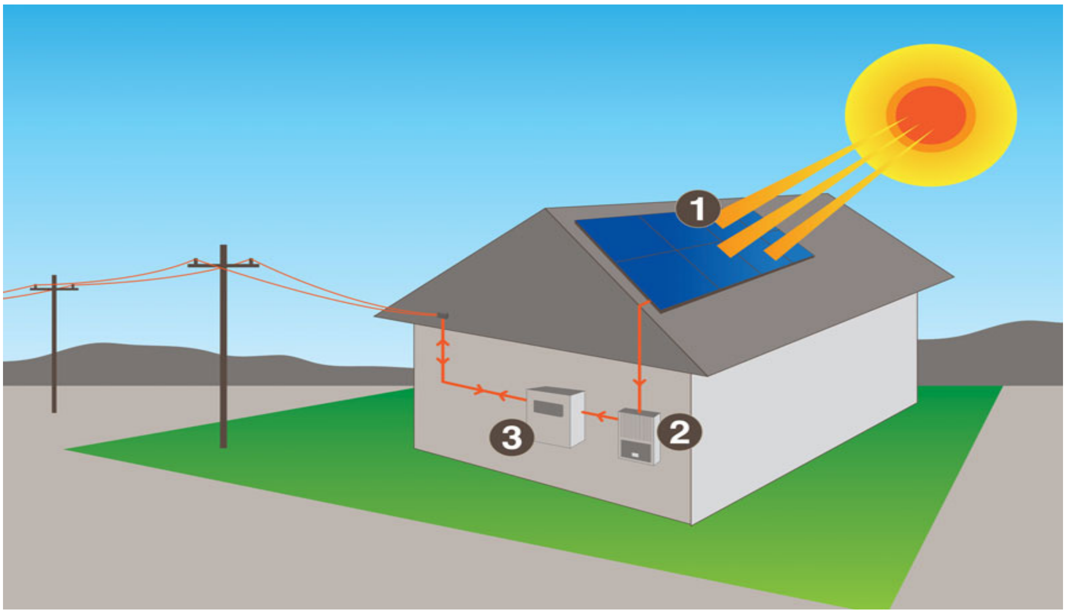

Fig. 1. A grid-tie PV system.

figure 1 shows a diagrammatic representation of a simple grid-tie photovoltaic system [2] which involves a roof-top mounted photovoltaic modules (1), a DC-AC inverter (2), and a bi-directional utility meter (3).

2 Related Literature

Currently, there are frequent discussions concerning how our generation can support environmental legislation while balancing a grid under pressure. There is, in addition, the issue of how to meet future energy demands especially electricity. In resolving these questions, there are many independent solutions being discussed and explored [3]. The evaluation of microgrids just started, and with certainty, there will be sustainability, plug-and-play, and ultra-resilient services for the microgrid which will include both photovoltaic and energy storage [4]. In an article by [3], he discussed the effect of frequent severe weather incidents that have a negative effect on the power grid in areas such as North and South America specifically. Looking at things from the utility perspective, there is a business case for a microgrid that exists for customers in the case of delivery of electricity if the traditional grid is faulty for whatever reason [5]. Until lately the unique choice was to commission the erection of another line but we believe that public utility commissions after considering other possibilities are going to start asking about the alternatives to constructing new lines. In 2018 a work on microgrids was submitted to the MDPI journal by [6]. The purpose of their work was to meet the demand response and reduce the operational cost of the microgrid. According to Yongli solar energy is renewable energy with a widespread distribution.

[7] proposed a dispatch and optimization models for a microgrid. In this work, over a 24-hour horizon, the objective was to minimize the cost of the grid operation and maximize environmental benefits. Ding considered three scenarios;

1. In the first scenario the microgrid could not supply to the main grid but the grid can supply to the microgrid, in this case, the load will be satisfied by the distributed system.

2. The optimization variables are both distributed energy systems and the main grid.

3. There is free communication of energy between the microgrid and the utility grid.

Ding further discusses the influence of power price on the grid concluding that the energy will flow from the microgrid to the utility grid when the spot price is high and vice versa.

[8] demonstrated power scheduling for energy management in the smart home. The heuristic method and evolutionary approach were implemented in this study. In conclusion, the researchers made it clear that the heuristic method limits the system performance in a real-world application. Sun further went on to state that using a hybrid of the evolutionary and heuristics including artificial intelligence are good when the model is complex or impossible to develop.

[9] propose a new approach based on the Lagrangian relaxation for short term generation scheduling problem implementing the Lagrangian relaxation. They concluded that the algorithm was fast, robust and efficient.

[10] develop a model to optimize the operation of an isolated small power system. In this work, Morais et al. implemented the mixed-integer linear programming in General Algebraic Modeling Systems (GAMS) and concluded that using mixed-integer linear programming have an extremely low execution time.

[11] presented an approach to minimize the energy costs and emissions of microgrids using the branch-and-cut method. The Photovoltaic uncertainties in this study were modeled by the Markovian process for effective coordination. But in this paper, we used the Linear Programming and the Photovoltaic output was evaluated.

3 Solar Cell Theory Development

Solar cells operation is based on semiconductors ability to convert solar energy into electricity, and power generation occurs predominantly during the day. The front and back of a p-n junction are made of electrical contacts. In order not to block the sun from the silicon semiconductors, the back side is completely covered by metal, but the front only has a grid pattern. The life span of a photovoltaic cell is usually between 20-30 years [12]. The STC for the photovoltaic cell is generally taken as $1000W/m^2$, $25°C$ and a 1.5AM [13],[14]. When the solar cell is exposed to the direct sunlight, photons with energy greater than the band-gap energy of the semiconductor create some electron-hole pairs proportional to the incident irradiation [15]. The mobile charges generated by the incident radiation produced an electrical current.

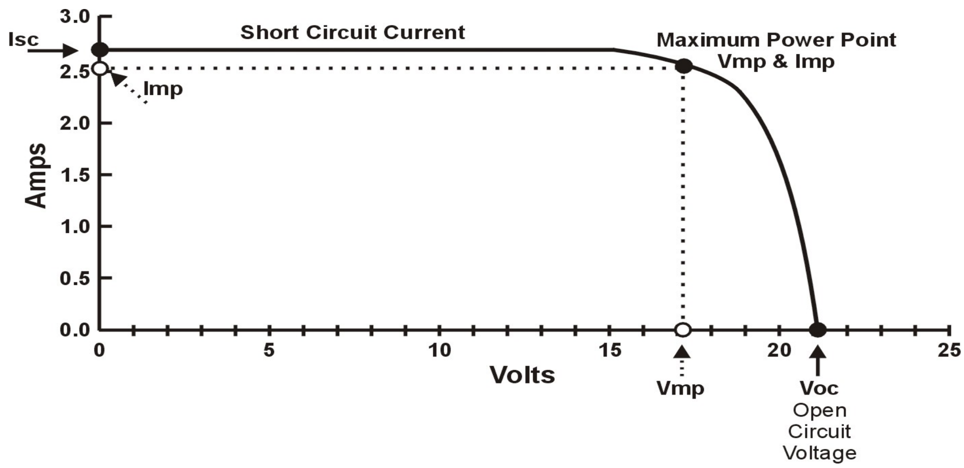

Fig. 2. A solar cell I-V Curve
Source: https://i.stack.imgur.com/btCSi.ipg

The Short Circuit Current (Isc) from figure 3 is the maximum current produced by the cell under a given standard condition of light and temperature corresponding to no output voltage. It can be declared that at this point there is no power. Again the Open Circuit Voltage (Voc) is the maximum voltage under the similar standard condition of light and temperature but zero current flow. The Current at Maximum Power (Imp), this current is rated as the current of the device under given standard condition of light and temperature. This value usually occurs at the "knee"of the I-V curve. Lastly, the Voltage at Maximum Power (Vmp) which equally occurs at the "knee"is the rated voltage of the device under standard conditions [15]. Photovoltaic power generation make use of solar panels to convert solar energy into electrical energy; t moment solar panel output $P_{photovoltaic}(t)$ can be calculated from (3.1) [6].

$$P_{photovoltaic}(t) = P_{stc}\frac{I(R_b, k_t, I_{0t})}{I_{stc}}[1 + \alpha_T(T_t - T_{stc})] \tag{3.1}$$

where I_{stc} represent the intensity of solar radiation, P_{stc} represent the rated output of the solar panel, $I(R_b, k_t, I_{0t})$ is the total solar radiation after considering the solar radiation, sun index, photovoltaic tracking type, and other factors; T represent the degree of atmosphere, and α_T is the power temperature coefficient. One of the commonly distributed generations preferred in a microgrid system is the photovoltaic systems because of its ability to exploit solar radiation in order to generate electric power and the advanced improvement of inverters [16].

4 Programming in AMPL

Practical mathematical programming involving large-scale variables involves more than just the application of an algorithm to maximize or minimize the objective function. AMPL is designed to make optimization less error-prone and easier steps [17]. In the current era of research, AMPL supports an extensive range of problems including linear programming, quadratic programming, nonlinear programming, and mixed-integer programming [18]. [19] used this software in optimization for robotic handling of compliant sheet metal parts in multi-press stamping lines, again [20] used AMPL in the reduction decomposition for dynamic optimization problems. AMPL was again used by [21] in finding an optimal solution to reduce costs and balances workload at Georgetown cross-dock. AMPL contains the MINOS and CPLEX optimizer which provide high performance and flexible mathematical programming solvers for linear programming [22].

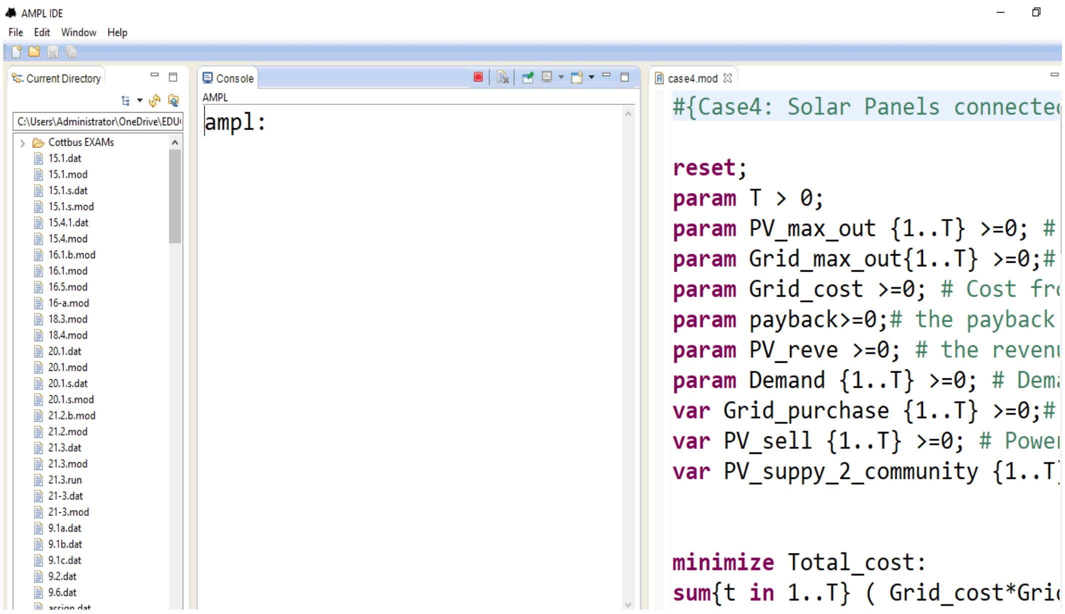

Fig. 3. AMPL interface.

5 Methods

A residential community was selected, and electricity consumption data of this community was collected to investigate how successful the implementation of a grid-connected photovoltaic system in Ghana will be using mathematical models. The optimization problem was solved as a linear programming problem in AMPL employing the CPLEX solver. Lastly, sensitivity was computed and discussed.

6 Optimization Problem Formulation

The power scheduling problem was computed over a 24-hour horizon. The electrical consumption of the community was represented in an hour interval over the 24-hour horizon since the fundamental problem or the average electricity demand was assumed to be repeated each day. The mathematical models of the system will comprise of the grid, which can provide a significant amount of power (MWh), and the photovoltaic module will be the renewable energy source. There will be constraints on each of the system components. The photovoltaic will have a different maximum power output every hour depending on the solar irradiation.

6.1 Optimization Model

Electricity consumption data for the optimization was gathered over a 24-hour horizon to determine the power required during each hour of the day. Given the temperature and the irradiation from previous data, the power generated by the photovoltaic modules every hour was estimated. Since no system is 100% efficient, a system loss of 14% [23] which represented the efficiency of the inverter and the photovoltaic modules. The purpose of the inverter is to convert the direct current (DC) produced by the photovoltaic modules to alternative current (AC). According to the training manual for Ghana's grid-connected photovoltaic system, the grid-connected inverter is used to convert the DC power from the photovoltaic module to a 240V AC at 50Hz [24].

6.1.1 Nomenclature of Variables

γ_u^t - power generated by photovoltaic $t \in T$.
γ_s^t - power fed into the grid at $t \in T$.
δ_u^t - power used from the grid at $t \in T$.

6.1.2 Nomenclature of Parameters

γ_m^t - maximum power generated by the photovoltaic module at $t \in T$.
δ_m^t - power available by the grid at $t \in T$.
Δ^t - the load demand of the community at $t \in T$
υ_p - a unit price electricity purchase from the grid.
υ_s - a unit price of electricity sold to the grid.
β - payback, maintenance and component replacement cost factor.
ρ - total daily demand.

6.2 Scenario 1: Grid

This was the first scenario considered because that is the currently Ghana's electricity power structure. In this scenario, the community was connected to only the utility grid. The objective was to minimize the cost of electricity while meeting the electricity demand of the community and this was done by minimizing the objective function eqn. 6.1 with constraints eqns. [6.2 - 6.4]

6.2.1 Objective Function

$$Minimize \quad \mathcal{F} = \sum_{t=1}^{T} \upsilon_p \delta_u^t \tag{6.1}$$

The objective is to find the optimal power schedule of the grid-connected PV system for minimum cost. The decision variable is δ_u^t.

6.2.2 Demand/ System Power Balance

$$\delta_u^t \geq \Delta^t, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.2}$$

At all time the system should purchase enough power from the grid to meet demand.

6.2.3 Maximum Available Grid Power

$$\delta_u^t \leq \delta_m^t, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.3}$$

The amount of power to be consumed by the community cannot be more than the available power supplied by the grid. Therefore at all times, the power supply by the grid will be less or equal to its available power.

6.2.4 Non-negativity Constraint

$$\delta_u^t \geq 0, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.4}$$

This fundamental constraint ensures that the decision variable does not assume a negative value.

6.3 Scenario 2: Solar Panels Connected to the Grid

In this scenario, we tend to combine the two sources of electricity (Photovoltaic and Grid) and consider the possibility of selling excess photovoltaic power to the grid for cost savings. Equation 6.5 becomes the objective function and eqns. [6.6 - 6.9] are the constraints.

6.3.1 Objective Function

$$Minimize \quad \mathcal{F} = \sum_{t=1}^{T} (\upsilon_p \delta_u^t - \upsilon_s \gamma_s^t) + \beta \tag{6.5}$$

The implementation of renewable energy comes at a cost. Energy system structures such as a microgrid are a socio-technical system that will involve numerous investors with diverse and spread primacies. So β will represent this cost. Power sold to the grid (feed-in) will be a form of cost savings.

6.3.2 System Power Balance

$$\delta_u^t + \gamma_u^t - \gamma_s^t \geq \Delta^t, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.6}$$

With the combination of PV generated power and available power from the grid, the system controls must ensure adequate power to meet the end user demand.

6.3.3 Photovoltaic Output Constraint

$$\gamma_u^t \leq \gamma_m^t, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.7}$$

The power generated by photovoltaic modules varies with varying time in a day. This constraint ensures that at any time of the day, the power from the PV consumed by the community is less or equal to the available power from the PV modules.

6.3.4 Maximum Available Grid Power

$$\delta_u^t \leq \delta_m^t, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.8}$$

6.3.5 Non-negativity Constraint

$$\gamma_u^t, \gamma_s^t, \delta_u^t \geq 0, \quad \forall t \in \{1, 2, \cdots, T\} \tag{6.9}$$

This fundamental constraint ensures that the decision variables does not assume a negative value.

6.4 Load Profile

The load profile is the graphical representation of the energy consumption of the community. According to Fig. 6.4 the hourly average electricity consumption of a community varies with

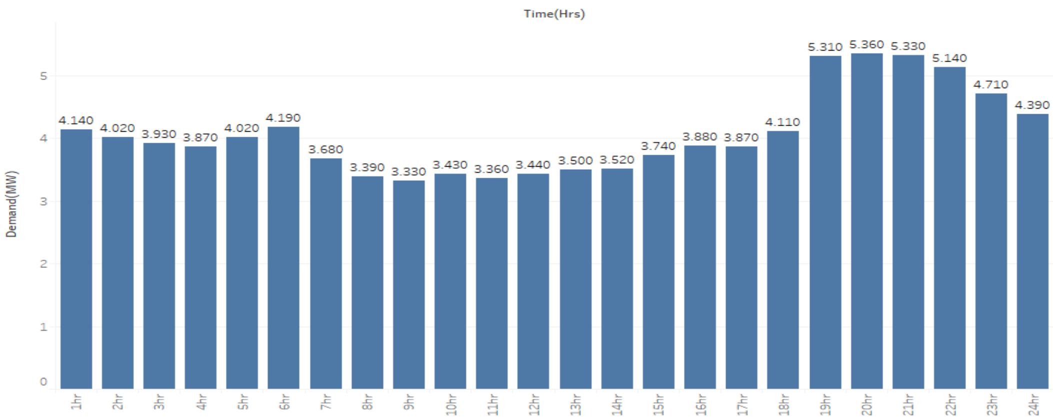

Fig. 4. Column graph representation of the load profile.

time. The morning peak could be found at 6:00 am and it can be seen that consumption is high during the evening between the hours of 7:00 pm to 10:00 pm. These periods are known as the peak hour period. The consumption of a residential community is moderate during mid-days and rise gradually throughout the evening. The highest recorded average consumption was 5.36MWh which was documented at 8:00 pm and the lowest was logged at 9:00 am with a value of 3.33MWh. The highest peak occurred in the evening due to the activities of the community. During the hours between 7:00 pm to 10:00 pm the community is engaged in various activities such as ironing, cooking, lighting, and watching television. Since the case study is from a residential community, most of the households in the community are vacant during the day resulting in a low peak at 9:00 am. The total daily consumption was estimated as 97.66MW.

6.5 Photovoltaic Sizing

It is substantial to determine the exact size of the photovoltaic output since there is a relationship between the installed photovoltaic modules and its power output [25]. In order to increase the efficiency of the optimization results, the photovoltaic sizes could not be approximated but rather computed. Since the photovoltaic is a source of electricity for the community, at standard test conditions the output from these modules would be enough to sustain the community's demand. The photovoltaic system efficiency is affected by derating factors such as; temperature, dirt, inverter efficiency and the model efficiency [23]. Here the emphasis is given to the installed capacity, not the number of modules. The amount of power required from the photovoltaic module would be able to supply the community average daily load of 97.66MW. The following equation will be used to determine the ideal size of the solar panels [26],

$$\text{photovoltaic size} = \frac{\rho}{PSH \times 0.86} \tag{6.10}$$

where PSH is the peak sun hours and 0.86 is the system efficiency [23]. The available Peak Sun Hours for the city in close proximity to our case study is Kumasi which is 4.5hrs [27],

$$\begin{aligned} \text{photovoltaic size} &= \frac{97.66}{4.5 \times 0.86} \\ &= 25.24MWp \end{aligned} \tag{6.11}$$

6.6 Photovoltaic Output

The photovoltaic power output was evaluated with hourly time stored solar radiation from satellites [28]. The .csv time-series file contained 8,760 data points, each representing the hourly photovoltaic output for the entire year. It is crucial to find an average of 24 hour data that will represent the photovoltaic output all year around since climate differs from each month. To do this R programming was used to find the average PV output over the 24 hours for the entire year.

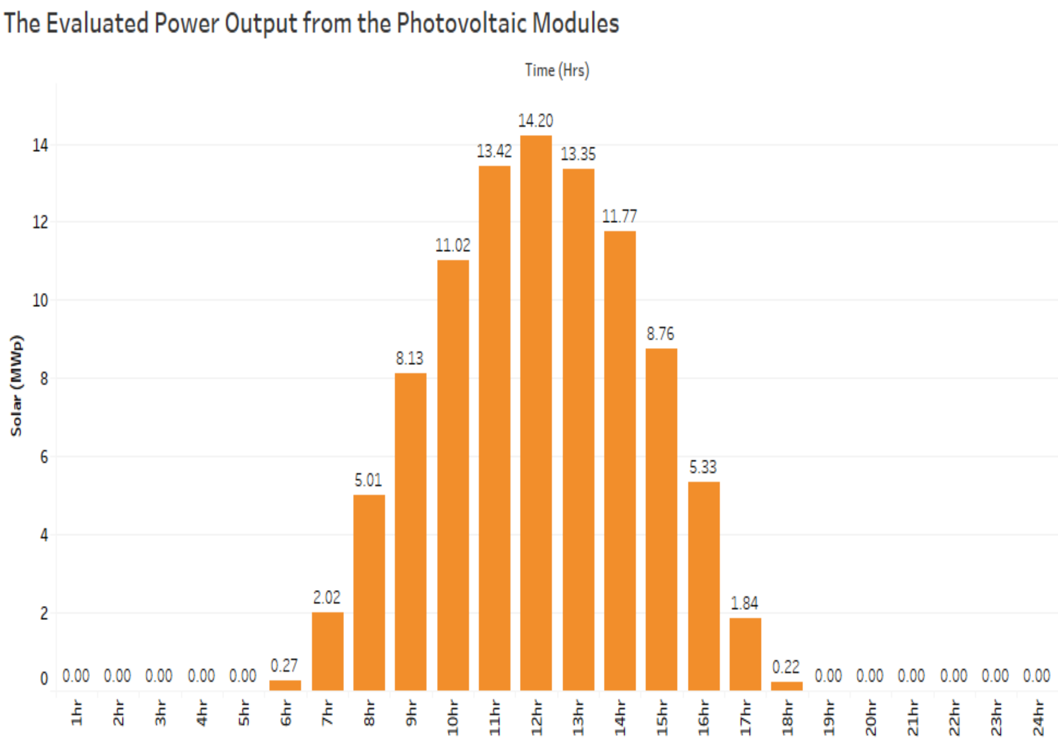

Fig. 5. The average PV output based on the size of PV

7 Results

7.1 Scenario 1: Grid

The first scenario considered connecting the community to only the utility grid. In such a connection, only the grid supply electricity to the community. The microgrid emphasis is on eqn. 6.2 where demand must be met. Since the sole source of electricity is the utility grid which was assumed can supply the entire community all day, the control system of the system uses electricity from the utility grid to fulfill the demand of the community.

Table 1: Optimization results for case 1 in scenario 1

T	Grid-δ_u (MWh)	Demand-Δ (WMh)
1	4.14	4.14
2	4.02	4.02
3	3.93	3.93
4	3.87	3.87
5	4.02	4.02
6	4.29	4.29
7	3.68	3.68
8	3.39	3.39
9	3.33	3.33
10	3.43	3.43
11	3.36	3.36
12	3.44	3.44
13	3.5	3.5
14	3.52	3.52
15	3.74	3.74
16	3.88	3.88
17	3.87	3.87
18	4.11	4.11
19	5.31	5.31
20	5.36	5.36
21	5.33	5.33
22	5.14	5.14
23	4.71	4.71
24	4.39	4.39

Optimizing equation (6.1) subject to constraints (6.2)-(6.4) in AMPL determines the values for the unknown variable (Table. 1) for the optimization problem, in this case, δ_u^t. δ_u^t can then be computed manually by summing the decision variable values over the 24-hour horizon. The decision variable coefficient, $\upsilon_p = 801$ (unit MW cost of electricity purchased). Given the total power purchased from the grid $\sum_{t=1}^{24} \delta_u^t = 97.66$, the price of electricity can be manually computed as,

$$\begin{aligned} \mathcal{F} &= \sum_{t=1}^{24} \upsilon_p \delta_u^t \\ &= 801 \times 97.66 \\ &= 78,225.66 \end{aligned} \tag{7.1}$$

It can be observed from Fig. 7.1 that exactly the needed amount of electricity was purchased from the grid company. So in this case demand is met irrespective of the cost. In this set-up, the optimization problem becomes infeasible when there is no power generation from the utility grid. The column bar below the horizontal axis of Fig. 7.1 represent the demand for electricity

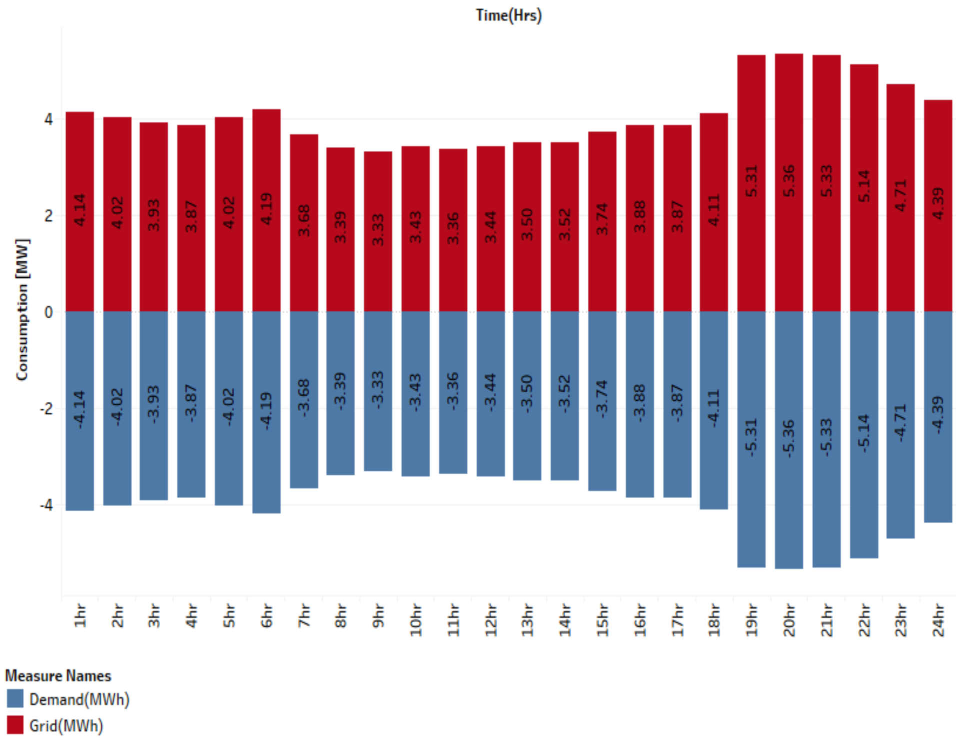

Fig 6. A graph showing the power scheduling for scenario 1

and the bars above represent the electricity purchased from the utility grid. It can be seen that enough power was purchase to satisfy the demand of the community that is honoring eqn. 6.2. A unit increase in the demand for electricity at any hour between the 24 horizons will increase the objective function value by 801, likewise, a unit decrease will reduce the cost function by GHS801. Where GHS801 is the price for 1MW of electricity purchased from the utility grid according to the Public Utilities Regulatory Commission [29].

7.2 Scenario 2: Solar Panels Connected to the Grid with Feed-in

In this scenario, the photovoltaic system is not connected to any storage plant, so any abundant power from the photovoltaic modules during midday will be sold to the utility grid. In this set-up, a solar bi-directional utility meter is used in the unit reading. When the energy consumed from the grid the meter will read in one direction and when electricity is being fed into the grid the meter reverses its direction of reading nullifying the previous readings. At the end of the month, the community will pay for the power it's consumed from the utility grid. The utility company has to equally pay the community for the power fed into the grid in the course of the month.

Table 2: Optimization results for case 1 in scenario 4

T	Photovoltaic-γ_u	Grid-δ_u	Sold-γ_s	Demand-Δ
1	0	4.14	0	4.14
2	0	4.02	0	4.02
3	0	3.93	0	3.93
4	0	3.87	0	3.87
5	0	4.02	0	4.02
6	0.27	3.92	0	4.19
7	2.02	1.66	0	3.68
8	5.01	0	1.62	3.39
9	8.13	0	4.80	3.33
10	11.02	0	7.59	3.43
11	13.42	0	10.06	3.36
12	14.20	0	10.76	3.44
13	13.35	0	9.85	3.50
14	11.77	0	8.25	3.52
15	8.76	0	5.02	3.74
16	5.338	0	1.45	3.88
17	1.84	2.03	0	3.87
18	0.22	3.89	0	4.11
19	0	5.31	0	5.31
20	0	5.36	0	5.36
21	0	5.33	0	5.33
22	0	5.14	0	5.14
23	0	4.71	0	4.71
24	0	4.39	0	4.39

Successfully optimizing equation (6.5) subject to constraints (6.6)-(6.9) in AMPL accurately determines the values of the unknown variables (Table. 2) for the optimization problem, in this case, δ_u^t, γ_s. These variables can then be computed manually by summing the decision variables values over the 24-hour horizon. The decision variables coefficient, $\upsilon_p = 801$ (unit MW cost of electricity purchase) and $\upsilon_s = 600$ (unit MW cost of electricity sold). Given the absolute power purchased from the grid $\sum_{t=1}^{24} \delta_u^t = 61.72$ and the total power sold to the utility grid, $\sum_{t=1}^{24} \gamma_s^t = 59.4$, the cost can be computed as;

$$\begin{aligned} \mathcal{F} &= \sum_{t=1}^{T}(\upsilon_p \delta_u^t - \upsilon_s \gamma_s^t) + \beta \\ &= (801 \times 61.72 - 600 \times 59.40) + 49,628.51 \\ &= 13,797.72 + 49,628.51 \\ &= 63,426.23 \end{aligned} \tag{7.2}$$

From Fig. 7.2 an increase in the demand of electricity between the hours of 1:00 am-7:00 am and 5:00 pm-12:00 am will increase the cost function by a shadow price of GHS801 and a decrease in demand within these time interval will reduce the cost function by GHS801. Since there is sufficient generation of electricity between the hour of 9:00 am - 3:00 pm, an increase in the demand at this interval will increase the price by GHS600 which is the unit feed-in tariff for selling power to the utility grid [29] and a decrease in demand will reduce the price equivalently. The difference in the prices at a different time is as the result of the available power to be sold to the grid. In the morning and evening, since there is no available power from the photovoltaic, a unit increase in demand will attract an amount of GHS801 but during the day where there is sufficient power from

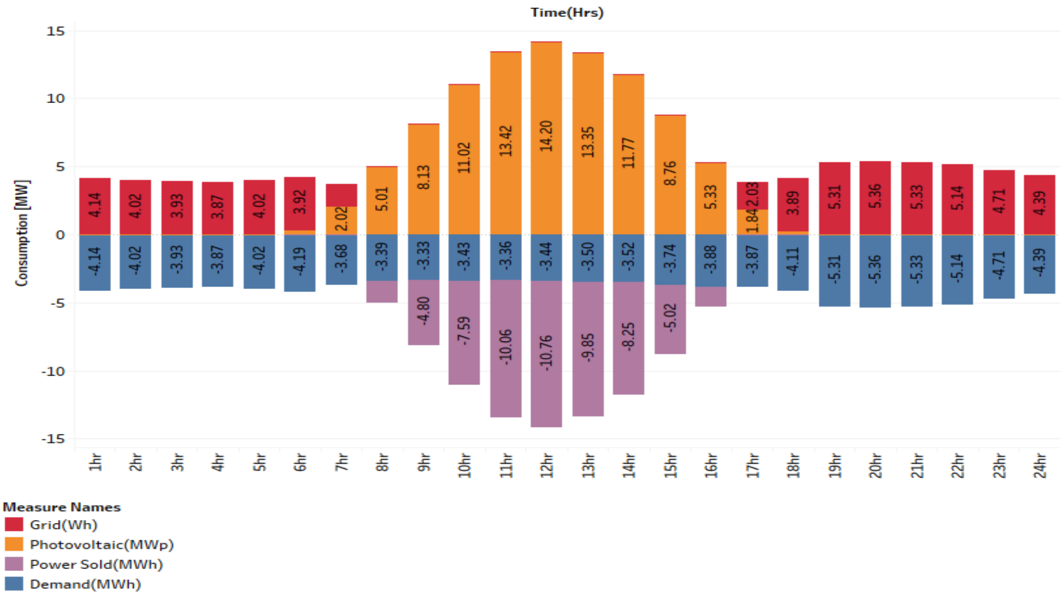

Fig. 7. A graph showing the power scheduling for scenario 2

the photovoltaic modules a unit increase in the demand will absorb an amount of GHS600 because the system substitute selling to the grid to provide energy to meet the increasing demand of the community.

Again, a unit increase in the photovoltaic maximum output between 1:00 am - 7:00 pm and 5:00 pm - 12:00 am will affect the cost function by a decrease of GHS801, with a unit decrease in the photovoltaic modules output the cost function will increase by GHS801. Since between these hours, there is no or little power generated by the photovoltaic module. This analysis is theoretical. During the day between the hours of 9:00 am-3:00 pm increasing the photovoltaic by 1MW reduce the cost function by GHS600 and a decrease of 1MW increase the cost function by GHS600.

8 Discussion

As stated earlier, the objective of this paper was to optimize a grid-connected photovoltaic system for minimum cost of electricity by optimal scheduling of photovoltaic power generation and the utility grid. Many factors will contribute to the operational cost of a microgrid. These costs depend on the type of investors or stakeholders involved in the construction of the microgrid. If the stakeholders are from a private organization then running at a loss is not an option. These investors will be willing to purchase the system components, maintain and manage the system. Costs like the capital cost, maintenance, and replacement cost will be an important part of the cost function the community has to consider. On the other hand, if government policy leads to the implementation of the microgrid, then the capital cost will be from the national funds.

The daily cost of electricity in the community was found to be GHS78,225.66 when connected to only the utility grid. In the second scenario which involved photovoltaic modules and the utility grid, the cost reduced to GHS63,426.23. Comparing scenario two to the first scenario, the percentage reduction in the first five years will be,

$$\frac{78,225.66 - 63,426.23}{78,225.66} \times 100 = 18.9\%$$

So in the first five years this set-up will reduce the cost of electricity by 18.9%. In the subsequent years, β will be reduced since the capital cost have been paid. The cost % for next, years:

$$\frac{78,225.66 - 19,500.511}{78,225.66} \times 100 = 75.07\%$$

The communities will pay 24.92% of the initial cost (scenario 1) of which 17.2% is for the purchase of power from the utility grid and 7.72% for the operation, maintenance, and replacement of the photovoltaic modules.

9 Conclusion

This paper presented an optimal operation mode of a grid-connected photovoltaic system. The core goal was to investigate the impact of renewable energy on electricity tariff. The dispatch algorithm has been framed as a linear programming problem and solved with AMPL employing the CPLEX solver. When photovoltaic technologies are employed, excess power generated can be sold to the grid for cost saving. This set-up is reliable and has a cost reduction of over 18% in the first lustrum and 75% thereafter. This will be the best and recommended electricity set-up for any residential community considering a reduction in cost of electricity.

Acknowledgement

The authors are grateful to the referees for their careful reading, constructive criticisms, comments and suggestions, which have helped us to improve this work significantly.

Competing Interests

Authors have declared that no competing interests exist.

References

[1] Mensah JT, Marbuah G. Amoah A. Energy demand in Ghana: A disaggregated analysis. 2016;53:924-935.
Available:https://doi.org/10.1016/j.rser.2015 .09.035

[2] Solar Electric Technology. A pv solar grid connected system; 2019.
Available:https://www.esolar.co.nz/grid-tied-solar-systems
(Accessed: May 4, 2019)

[3] Shavit G. Are microgrids the future for utilities? 2018.
Available:https://www.powerengineeringint.com/articles/2018/09/ are-microgrids-the-future-for-utilities.html
(Accessed: December 13, 2018)

[4] Navigant Research. What will the microgrid of the future look like?; 2018.
Available:https://www.navigantresearch.com/news-and-views/ what-will-the-microgrid-of-the-future-look-like
(Accessed: December 13, 2018)

[5] Runyon J. The future of microgrids: Business cases; 2017.
Available:https://www.renewableenergyworld.com/articles/2017/01/the-future-of - microgrids-business-cases.html.
(Accessed: December 13, 2018)

[6] Wang Y, Huang Y, Wang Y, Li F, Zhang Y, Tian C. Operation optimization in a smart microgrid in the presence of distributed generation and demand response. mdpi; 2018.
DOI:10.3390/su10030847
Available:https://www.mdpi.com/journal/sustainability

[7] Ding M, Zhang Y, Mao M, Yang W, Liu X. Operation optimization for microgrids under centralized control. IEEE International Symposium on Power Electronics for Distributed Generation Systems, 2nd; 2010.

[8] Sun H, Huang Y. Optimization of power scheduling for energy management in Smart Home . Procedia Engineering. 2012;1822-1827.

[9] Wang SJ, Shahidehpour SM, Kirschen DS, Mokhtari S, Irisarri GD. Short-term scheduling of thermal-electric generators using lagrangian relaxation . IEEE Transactions on Power Systems. 1995;10(3).

[10] Morais H, Peter K, Faria P, Vale ZA, Khodr H. Optimal scheduling of a renewable microgrid in an isolated load area using mixed-integer linear programming . Elsevier. 2009;151-156.

[11] Yan B, Luh PB, Warner G, Zhang P. Operation and Design Optimization of MicrogridsWith Renewables . IEEE Transactions on Automation Science and Engineering; 2017.
DOI: 10.1109/TASE.2016.2645761
Available:https://www.researchgate.net/publication/313873392

[12] Sherwani AF, Usmani JA. Life cycle assessment of solar photovoltaic based electricity generation systems: A review. Elsevier. 2010;540-544.

[13] Peng L, Sun Y, Meng Z. An improved model and parameters extraction for photovoltaic cells using only three state points at standard test condition . Journal of Power Sources. 2014;248:621631.
DOI:10.1016/j.jpowsour.2013.07.058

[14] Kenny RP, Dunlop ED, Ossenbrink H, Mllejans H. A practical method for the energy rating of C-Si photovoltaic modules based on standard tests. Progress in Photovoltaics: Research and Applications. 2006;14(2):155-166.
DOI:10.1002/pip.658

[15] Chukwuka C, Folly KA. Technical and economic modeling of the 2.5kW grid-tie residential photovoltaic system . International Journal of Renewable Energy Research. 2013;2:412-419.

[16] Eleni P. Development of optimization algorithms for a smart grid community . Renewable Energy. 2014;74:782-795.
DOI:10.1016/j.renene.2014.08.080)

[17] Fourer R, Gay DM, Kernighan BW. A modeling language for mathematical programming. Management Science. 1990;36:519-554.

[18] Wikipedia contributors. Ampl — Wikipedia, the free encyclopedia; 2018.
Available:https://en.wikipedia.org/w/index.php?title=AMPL&oldid=869517754.
(Accessed 19-November-2018)

[19] Glorieux E, Franciosab P, Ceglarekb D. Quality and productivity driven trajectory optimisation for robotic handling of compliant sheet metal parts in multi-press stamping lines . Robotics and Computer Integrated Manufacturing. 2019;264-275.
Available:https://doi.org/10.1016/j.rcim.2018.10.004

[20] Wan W, Eason JP, Nicholsony B, Biegler LT. Parallel cyclic reduction decomposition for dynamic optimization problems. 2017;S0098-1354(17)30342-3.
Available:https://doi.org/doi:10.1016/j.compchemeng.2017.09.023

[21] Rosales CR, Fry MJ, Radhakrishnan R. Transfreight reduces costs and balances workload at georgetown crossdock. 2009;39(4):316-328.
(ISSN 0092-2102 EISSN 1526-551X 09 3904 0316)
Available:http://dx.doi.org/10.1287/inte.1090.0446

[22] IBM. Cplex optimizer. 2018. Available:https://www.ibm.com/analytics/ cplex-optimizer
(Accessed: February 3, 2019)

[23] Jadin MS, Nasiri IZM, Sabri SE, Ishak R. A Sizing Tool for photovoltaic Standalone System. arpn; 2015.
(ISSN 1819-6608)
Available:www.arpnjournals.com

[24] DSTC. Design and installation of grid-connected photovoltaic system training manual; 2017.
(Computer software manual)

[25] Carrasco JM, Franquelo LG, Bialasiewicz JT, Galvn E, Guisado RCP, Prats AM, Moreno-Alfonso N. Power-electronic systems for the grid integration of renewable energy sources: A survey. IEEE Transaction on Industrial Electronics. 2006;53(4).

[26] Websolar. Grid-tie solar system sizing. 2018.
Available:https://webosolar.com/blog/grid-tie-solar-system-sizing
(Accessed: February 18, 2019)

[27] Kwarteng M. Solar power can revolutionize ghana's dumsor; 2015.
(Accessed:18th February 2019)

[28] Pvgis data download; 2018.
Available:http://www.cs.cmu.edu/afs/cs.cmu.edu/project/learn
(Accessed: February 22, 2018)

[29] PURC. Public utilities regulatory commision (Ghana); 2018.
Available:http://www.purc.com.gh
(Accessed 2-May-2019)

Peer-review history:
The peer review history for this paper can be accessed here (Please copy paste the total link in your browser address bar)
http://www.sdiarticle3.com/review-history/49935