Electrical Energy Deficiency Solution Using Grid Connected Solar Photovoltaic System in Ghana - A Case Study at Accra East Region*

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Abstract

In an earlier paper on Photovoltaic (PV) proliferations, favourable government policies were discussed as a panacea to the deployment of PV systems in Ghana. Until recently, solar had not been considered as one of the solutions to Ghana's energy needs, hence the need to conduct a research into the deployment of Grid Connected Solar PV System (GCSPVS) of power supply as an alternative to augment power deficiency facing the country. The Accra East Region was used as a case study, due to its fast growing nature. The region also has all the power consumer sector category classifications as follows: residential; commercial; Special Load Tariff for Low Voltage (SLT-LV); and Special Load Tariff for Medium Voltage (SLT-MV). The 5-Parameter model technique was used for an effective GCSPVS for the group of customers who were to go on solar. The findings from the research revealed that, all the sector categories had deficiency with the commercial sector showing about 8.33% margin, while the residential sector had 2.19%. The SLT-LV and SLT-MV indicated 4.64% and 4.57% respectively, making the commercial sector reeling for intervention from government. The simulation of two standard solutions using the System Advisor Model (SAM) software for the sector with the highest deficiency were conducted in the research: a 34.4 DC kW GCSPVS for all institutions and companies as well as 3.4 DC kW GCSPVS for all other customers in the commercial sector. The policies proposed for government to undertake are: Investment Tax Credits; Production Tax Credits; Investment Based Incentive; Capacity Based Incentive; and Production Based Incentive, as well as financial benchmarks that will make PV systems competitive and viable.

Keywords: Grid Connected Solar Photovoltaic System, Energy Deficiency, Generation Capacity

1 Introduction

Electrical energy deficiency in Ghana has become a phenomenon, hence the need to take a second look at its solution by government. The introduction of Grid Connected Solar Photovoltaic System (GCSPVS) of power supply is one of the solutions to reduce the electrical energy deficiency. In an earlier paper written, the proliferations of PV systems were suggested and favourable government policies were discussed as a panacea for the deployment of PV systems in Ghana (Attachie and Amuzuvi, 2013).

It has been identified that, power crisis is resolved either by increasing tariffs or borrowing more funds to buy fuel to power the existing thermal plants in the short term, whiles in the long term, a lot of hydro and thermal plants are to be built to increase the generation capacity.

Until recently, solar had not been considered as one of the solution to Ghana's energy crisis, hence the need to conduct a research into the use of GCSPVS of power supply to boost electrical energy availability in Ghana.

Electricity generation is growing at a rate of 7% per annum and is expected to increase because annual domestic demand is even more than twice the 7% value stated. The provisional Grid Connected Generation (GCG) published by the Energy Commission (EC) in their 2014 report showed the total installed capacity is 2851.5 MW with 1580 MW being hydro, 1263.5 MW being thermal and for the first time 5.5 MW from solar.

The various levels of deficiency of power availability within the Electricity Company of Ghana (ECG) customers and how to solve this problem by the determination of which sector category government must help use the GCSPVS to boost the efficiency of power supply are not known. This paper attempts to unravel this, and shows the way forward in ameliorating its effect on the economy of Ghana and make savings.

1.1 Electrical Energy Deficiency Theory

Electrical energy deficiency simply means the lack or shortage of power to a customer. It can also be expressed as the inadequacy, short fall, or deficit of power generated, transmitted and distributed, as well as in the utilisation of power within a specific period. It must be noted that, to have adequate

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power means to have sufficient power to take care of maximum load demand as well as a reserve margin of about 25%, to prevent load shedding in case a power plant is to undergo maintenance (Oluwasuji *et al.,* 2020). In Ghana, due to insufficient reserve margin in the range of about 5%, any slight increase in power demand or one of the major power plants undergoing maintenance result in load shedding.

Table 1 illustrates Ghana's grid electricity supply share and growth to demand sector from 2000 to 2013. In Table 1, there are three main groups of customers (sectors) that contribute to demand and their total growth rate (%Gr) must match-up to the growth rate of the power generated within the same period. For example, in 2013 the total growth rate to demand sector was 10.7%, hence, there should have been a minimum of 10.7% corresponding growth rate in power generation to prevent deficiency.

In the ECG, a customer can belong to each of the following groups or sectors: Residential/Domestic; Commercial (Non Residential); Special Load Tariff for Low Voltage (SLT-LV); and Special Load Tariff for Medium Voltage (SLT-MV). The SLT-LV and SLT-MV together, are special load tariff customers classified as industrial customers. While the SLT-LV customers are metered at the low voltage side of the distribution network to check consumption, the SLT-MV customers are metered at the high tension side.

1.2 Installed Capacity of Photovoltaic System

Photovoltaic system of energy supply has become more attractive today due to low levels of installation cost, that are characterised by more companies manufacturing solar PV systems, and incentives given by various governments for individuals and cooperate organisations to shift to solar as their augmented means of energy supply.

Currently, European countries account for over 65% of the global installed capacity of photovoltaic system (Dinçer, 2011). Countries with relatively large installed capacities are Spain, Germany, United State, Japan and China. (Diniz *et al.*, 2011). In Ghana, the application of solar PV system is not widespread. Its total capacity is less than 5 MW (Chuhan-Pole *et al.*, 2018).

The passage of the Renewable Energy Act 2011 (Act 832), was aimed at providing fiscal incentives and the regulatory framework to encourage the private sector to go into renewable energy supply. Act 832 enabled the construction of a 2 MW grid connection solar farm at Navrongo in the Upper East Region by the Volta River Authority (VRA) and a 700 kW grid connected solar system at Nuguchi Memorial Institute of the University of Ghana. The total installed capacity for solar energy in Ghana is less than 0.08% of the total installed capacity of electric power in Ghana (Kumi, 2017).

Ghana depends on energy from fossil fuel sources, which causes pollution and degrades the environment, hence the need to invest in renewable energy sources as well. "Spain for instance, imported 80% of their energy needs for neighbouring countries in Europe but now have the largest installed capacity of solar PV systems in their energy mix" (Dinçer, 2011).

Table 1 Grid Electricity Supply, Share and Growth to Demand Sector from the Year 2000 to 2013 in Ghana

YEAR	DEMAND SECTORS										
	Industry			Non Residential			Residential			Total	
	1000 GWh	% Share	%Gr	1000 GWh	% Share	%Gr	1000 GWh	% Share	%Gr	1000 GWh	%Gr
2000	4.31	68.0	0.0	0.55	8.7	0.0	1.49	23.5	0.0	6.34	0.0
2001	4.33	66.4	0.5	0.58	8.7	5.5	1.61	24.7	8.1	6.53	3.0
2002	3.90	63.2	-9.9	0.60	9.8	3.4	1.67	27.1	3.7	6.17	-5.5
2003	2.21	48.6	-43.3	0.62	13.6	3.3	1.73	38.0	3.6	4.55	-26.3
2004	2.03	44.8-	8.1	0.66	14.6	6.5	1.78	39.3	2.9	4.53	-0.4
2005	2.54	49.2	25.1	0.70	13.6	6.1	1.92	37.2	7.5	5.16	13.9
2006	3.59	55.1	41.3	0.79	12.1	12.9	2.13	32.7	10.9	6.51	26.2
2007	2.70	48.3	-25.0	0.80	14.3	1.3	2.10	37.6	-1.4	5.59	-14.1
2008	2.97	48.2	10.0	0.93	15.1	16.3	2.27	36.9	8.1	6.16	10.2
2009	2.94	47.2	-1.0	0.88	14.1	-5.4	2.41	38.7	6.2	6.23	1.1
2010	3.16	46.1	7.5	0.97	14.1	10.2	2.74	39.9	13.7	6.86	10.1
2011	3.90	48.9	23.4	1.31	16.4	36.1	2.76	34.6	0.7	7.98	16.3
2012	4.15	51.2	7.7	1.15	14.2	-0.8	2.80	34.6	-5.8	8.24	1.5
2013	4.22	47.1	1.7	1.53	17.0	32.3	3.23	36.0	15.2	9.00	10.7
Note: Gr is growth rate											

(Source: Energy Commission-2014 Energy outlook for Ghana)

1.3 Effective Policy for Photovoltaic System

Countries that stood out as main users of solar photovoltaic system of energy supply was due to the incentives their governments, through policy, rolled out to benefit the private investor who was ready to invest in renewable energy. According to Zhang *et al.* (2011), the participation of government for the promotion of PV systems with long-term subsidies has critical importance, since the high price of this technology is still a limiting factor in its proliferation. Investments in public awareness are also important for its expansion. According to Zhang *et al.* (2011), a relaxation of legal requirements for installation of PV systems is another critical factor in efforts to spread this energy source. In 2005, the Spanish government created an incentive package by introducing the model 'feed-in tariff' (Dinçer, 2011). This form of incentive provides the purchase of energy generated by residential consumers and by that, 30% of Spain's needs of electricity are now supplied by renewable energy, of which solar PV forms the greatest part.

1.4 Grid Connected Solar Photovoltaic

Grid connected solar PV systems are modern, small-scale versions of the centralised electricity system. They achieve specific local goals, such as: reliability; carbon emission reduction; and cost reduction through diversification of energy sources. Like the bulk power, grid connected PV system of power generate and distribute electricity to consumers, but do so locally.

Solar PV system is an ideal way to integrate renewable energy sources at the community level and allow for customer participation in the electricity enterprise. Broadly, the expected benefits of implementing a nationwide grid connected solar PV system include, a reduced need to build new transmission lines and a better supporting system for the dispatch of energy. GCSPVS help consumers save money by allowing them to procure power in real-time at significantly lower costs, while using local generation to hedge peak power costs.

In addition, GCSPVS model usually includes third-party financing and long-term modernisation plans, which diminish the infrastructure improvement costs that are typically passed on to ratepayers. Similarly, local power generation is typically more efficient and reduces the distance energy must travel and thus passes on fewer costs from transmission losses, congestion pricing and customer service overhead, particularly when power costs are at their highest. They also allow local communities to increase their overall electricity supply quickly and efficiently, rather than having to wait for power companies to build centralised power plants that are costly and take much longer time to come online.

2 Resources and Methods Used

This paper being a follow up to an earlier publication (Attachie and Amuzuvi, 2013), uses the same materials and works published from conference proceedings, journals and internet sources accessed by using search engines from the world of science and technology. The materials used span from the year 1990 to date and cover both old and new technologies in the field of alternative energy engineering. However, in this paper, simulations were performed using the System Advisory Model (SAM) software, to confirm the viability in the use of GCSPVS to save Ghana financially and reduce the use of fossil fuels.

In the research, surveys of customers of ECG in the Accra East Region, for which point estimates for the years 2000 to 2013 were available for dependent and independent variables were included in the analysis. In doing so, the questionnaire *"Are there deficiencies in the supply of power during the last 3 to 4 years to the Accra East Region ECG customers as a result of their growth to demand sector"* was sent to ECG by writing officially to the Human Resources Department. The billing office provided customer information data for collection and analysis as shown in Fig. 1a.

This was one of the most difficult tasks encountered during the data collection period and caused a lot of man hours and delay in the gathering of the data for this research.

The number of hardcopies accessed was about seven thousand sheets as shown in Fig. 1b. The Information and Communications Technology (ICT) department of ECG also assisted with some historic records on customers. In all, about 70% out of the total number of customers were sampled with the names of customers withheld due to confidentiality issues.

(a) (b)

Fig. 1 Data Collection and Conversion into Digital Copy (a) Records to be Converted into Soft Copy; (b) Sample Document Converted into Digital Copy

2.1 Variables

Variables are the factors or conditions that can exist in different amounts or types. The research category variables used are divided into two parts; that is, dependent and independent variables. The dependent variables were recorded by the use of energy meters and the independent variables, are the variables that were recorded by examining the factors, which accounted for an increase in load by a power consumer.

2.1.1 Dependent Variable

The dependent variable, which was obtained from ECG Accra East region, is the power consumption of all customers sampled. The power consumption was based on meter readings recorded by the billing office of the ECG and documented also at the ICT section.

2.1.2 Independent Variable

Ghana's grid electricity supply, share and growth to demand sector since 2000 to 2013, which is used to determine the growth in the power sector in Ghana was gathered from the Energy Commission's 2014 energy outlook for Ghana. This was used to generate the expected power to be consumed by each group of customers per month as independent variable. The Ghana Energy Commission is the recognized institution in Ghana, responsible for securing a comprehensive national energy database for informed decision making to enhance energy polices in Ghana.

2.2 Analysis of Data

Secondary data generated from the primary data collected were used to test the hypothesis *"There are deficiencies in the supply of power during the last 3 to 4 years in Accra East region ECG customers as a result of their growth to demand sector"*. Also, the secondary data produced, from the averaging of primary data of various groups of customer's initial expected power to be consumed and their final power consumed; were compared by using the first year as baseline and the subsequent year compared to the first year.

The levels of deficiency within each group of customers were also compared and ranked according to the one with the highest deficiency by first subjecting their data to descriptive analysis (such as percentages, mean, frequency and standard deviation) and inference analysis using regression analysis as suggested by Hair Jr *et al.* (2014).

Simple bivariate regression analysis was used to select, which group of customers' needed government support. A regression of the final power consumed on the expected power to be consumed taken into account growth rate to demand was done and the decision rule for test of hypothesis (H_0) is rejected when $P<0.05$ and accepted when $P>0.05$ to validate deficiencies. The software used was Microsoft Excel tool for scientific analysis and Statistical Package for the Social Sciences (SPSS).

The group with the highest deficiency by ranking, becomes the first group for government assistance. The 5-parameter model technique for an effective GCSPVS was used to recommend a PV system for the group of customers who were to go on solar.

2.3 Model of Solar PV System Using the 5-Parameter Model Technique

The performance of PV cells can be modeled with an equivalent circuit shown in Fig. 2 (Duffie and Beckman, 1991). This circuit includes a series resistance (Rs) and a diode in parallel with a shunt resistance (Rsh). V represents the voltage at the load and I_L represents the load current. This circuit can be used for an individual cell, for a module consisting of several cells, or for an array consisting of several modules.

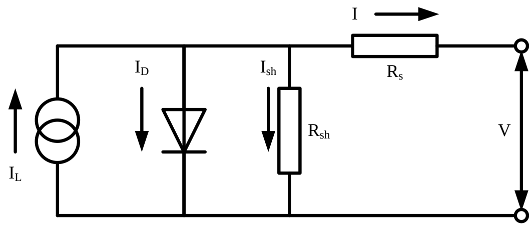


Fig. 2 Equivalent Circuit Representing the 5-Parameters

Application of Kirchoff's Current Law on the equivalent circuit, results in the flow of current to the load as shown in Equation (1) current flowing to the load.

$$I = I_L - I_D - I_{Sh} \quad (1)$$

If the diode current and the current through the shunt resistance (I_D and I_{Sh} respectively) are expanded, Equation (2) is obtained. Equation (3) is used to calculate the power (P).

$$I = I_L - I_0\left[e^{\frac{V+IR_s}{a}} - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (2)$$

$$P = I\,V \quad (3)$$

The five parameters (from which the 5-parameter model obtains its name) at Standard Rated Conditions (SRC) are a, I_L, I_0, R_s, and R_{sh}, where,
a= ideality factor;
I_L= light current;

I_0= diodes reverse saturation current;
R_s: series resistance; and
R_{sh}: shunt resistance.

To calculate the five reference parameters ($a_{,ref}$, $I_{0,ref}$, $I_{L,ref}$, $R_{s,ref}$, and $R_{sh,ref}$), five pieces of information are required as reference conditions (usually at SRC, where T_c= 25 ºC and *Geff*=1000 W/m²). The information is the short circuit current (I_{sc0}), open circuit voltage (V_{oc0}), current and voltage at the maximum power point (I_{mp0} and V_{mp0} respectively), and the slope of the I-V (current voltage) curve at the short circuit point is as shown in Fig. 3 (De Soto, 2004).

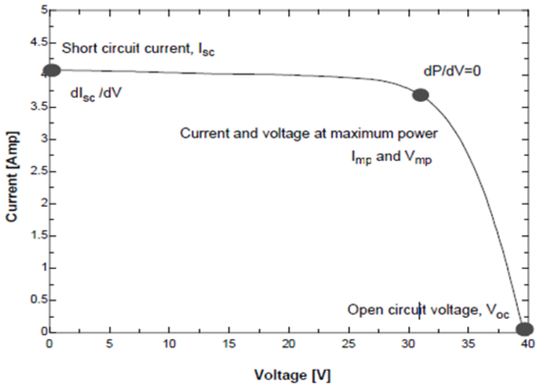


Fig. 3 Location of the Point of Interest for Calculating the Reference Parameters

The 5-parameter model presented was used to predict the energy production for specified cell parameters and operating conditions. At SRC, all cell types perform well and tend to have an I-V curve with the slope at short circuit current almost zero, indicating an infinite shunt resistance.

In order to use the 5-parameter modeling technique to model a PV system of power supply, a performance and financial model software was used to facilitate the decision making. The software known as the SAM makes it possible for one to predict performance and cost of energy estimates for grid-connected power projects based on installation and operating cost as well as system design parameters that are specified as inputs to the model.

SAM is an electric power generation model and assumes that, the renewable energy system delivers power either to an electric grid, or to a grid-connected building or facility. Creating a SAM file involves choosing both a performance model and a financial model to represent your project. For the purposes of this research, a performance model of flat plate PV technology was selected with a commercial financial model.

The following were inputted in the software during the modelling:

(i) Location and Resource;
(ii) Module;
(iii) Invertor;
(iv) Array;
(v) PV Sub Arrays;
(vi) Performance Adjustment;
(vii) PV System Cost;
(viii) Financing;
(ix) Incentives;
(x) Depreciation;
(xi) Utility Rate;
(xii) Electric Load; and
(xiii) Exchange Variable.

3 Results and Discussion

The graphs of Figs. 4 to 7, show the 2012 PAd and 2013 Pad i.e. final power consumed by a group of customers in 2012 and 2013 respectively, whiles 2012 PUd and 2013 PUd are the initial expected power to be consumed by a group of customers taken into account their growth rate to demand in 2012 and 2013 respectively.

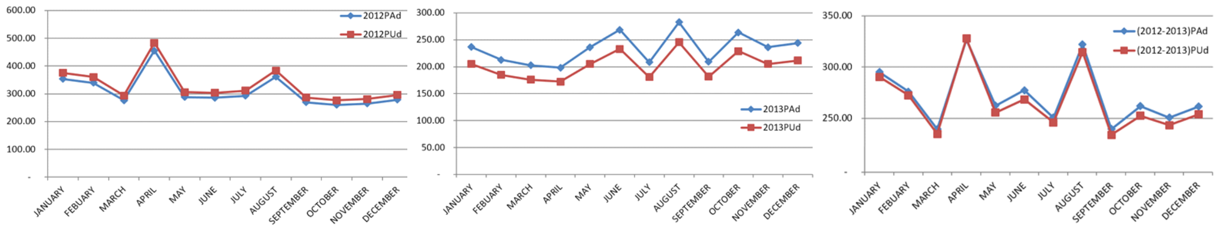
The percentage deficiency with respect to the initial expected power to be consumed was also compared and finally the total deficiency per month within the two-year period.

3.1 Results

The energy profile for the various sectors of the Accra East Region ECG customers are presented to evaluate deficiency in the following periods: 2012; 2013; and 2012 to 2013 for the residential; commercial; SLT-LV; and SLT-MV customers.

Also, Tables 2 to 8 shows the Sector Results Compared and Ranked for the following: yearly average for power consumed; yearly average for expected power to be consumed; deficiency ranking as a percentage of expected power to be consumed in 2012; deficiency ranking as a percentage of expected power to be consumed in 2013; deficiency ranking as a percentage of expected power to be consumed in a period of two years (2012 to 2013); deficiency per month in a period of two years (2012 to 2013); and total deficiency per month in a period of two years (2012 to 2013).

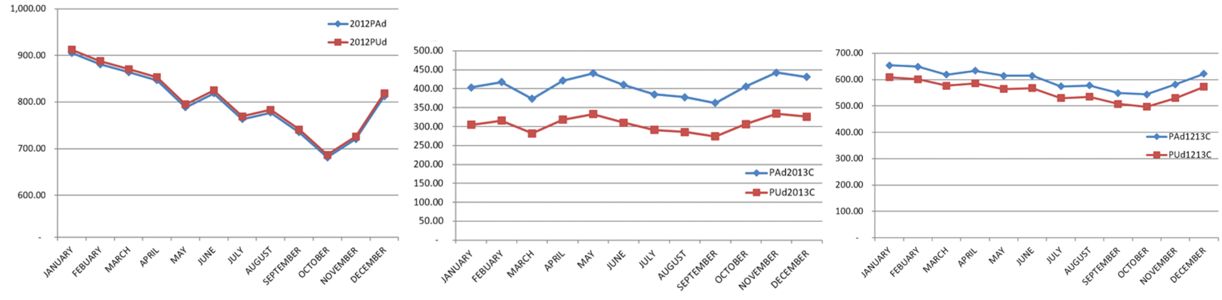
3.1.1 Residential Customers



(a) (b) (c)

Fig. 4 Monthly Consumption Profile for the Domestic Sector of the Accra East Region ECG Customers for; (a) 2012, (b) 2013, and (c) Overall Monthly Consumption Profile from 2012 to 2013

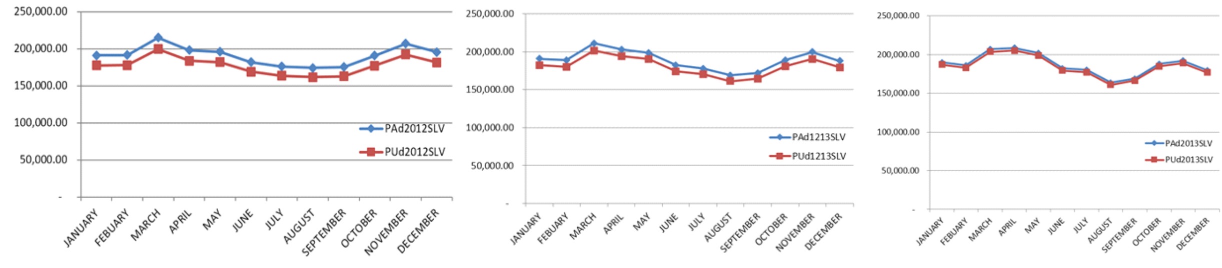
3.1.2 Commercial customers



(a) (b) (c)

Fig. 5 Monthly Consumption Profile for Commercial Sector of the Accra East Region ECG Customers for; (a) 2012, (b) 2013, and (c) Overall Monthly Consumption Profile from 2012 to 2013

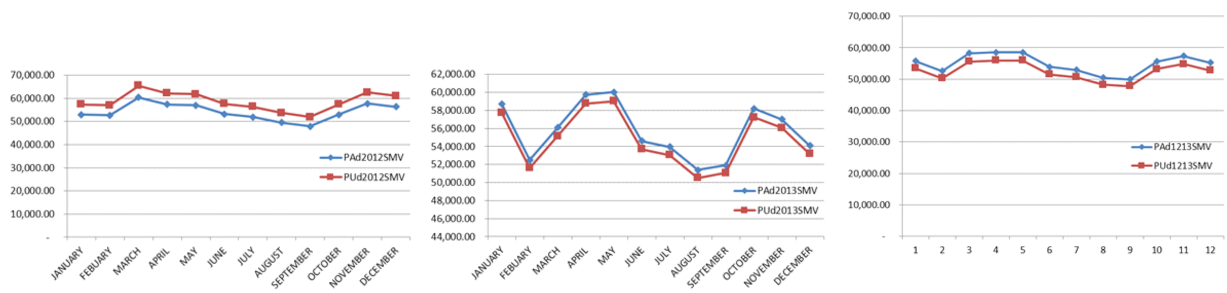
3.1.3 SLT-LV customers



(a) (b) (c)

Fig. 6 Monthly Consumption Profile for the SLT-LV Sector of the Accra East Region ECG Customers for ; (a) 2012, (b) 2013, and (c) Overall Monthly Consumption Profile from 2012 to 2013

3.1.4 SLT-MV customers



(a) (b) (c)

Fig. 7 Monthly Consumption Profile for SLT-MV Sector of the Accra East Region ECG Customers for; (a) 2012, (b) 2013, and (c) Overall Monthly Consumption Profile from 2012 to 2013

Table 2 Yearly Average for Power Consumed (Pac)

ITEM	SECTOR CATEGORY	2012Pac (kWh)	2013Pac (kWh)	(2012-2013)Pac (kWh)
1	Residential	310.65	233.25	271.95
2	Commercial	799.43	405.83	602.63
3	SLT-LV	191 184.15	187 361.62	189 272.89
4	SLT-MV	54 156.37	55 675.45	54 915.91

Table 3 Yearly Average for Expected Power to be Consumed (Pec)

ITEM	SECTOR CATEGORY	2012Pec (kWh)	2013Pec (kWh)	(2012-2013)Pec (kWh)
1	Residential	329.78	202.48	266.13
2	Commercial	805.88	306.75	556.32
3	SLT-LV	177 515.46	184 229.71	180 872.59
4	SLT-MV	50 284.47	54 744.79	52 514.63

Table 4 Deficiency Ranking as a Percentage of Expected Power to be Consumed in 2012

ITEM	SECTOR CATEGORY	2012Pac (kWh)	2012Pec (kWh)	% Deficiency Ranking
1	Residential	310.65	329.78	-5.8
2	Commercial	799.82	806.27	-0.8
3	SLT-LV	191 184.15	177 515.46	7.7
4	SLT-MV	54 156.37	50 284.47	7.7

Table 5 Deficiency Ranking as a Percentage of Expected Power to be Consumed in 2013

ITEM	SECTOR CATEGORY	2013Pac (kWh)	2013Pec (kWh)	% Deficiency Ranking
1	Residential	233.25	202.48	15.2
2	Commercial	405.83	306.75	32.3
3	SLT-LV	187 361.62	184 229.71	1.7
4	SLT-MV	55 675.45	54 744.79	1.7

Table 6 Deficiency Ranking as a Percentage of Expected Power to be Consumed in a Period of Two Years (2012 to 2013)

ITEM	SECTOR CATEGORY	(2012-2013)Pac (kWh)	(2012-2013)Pec (kWh)	% Deficiency Ranking
1	Residential	54 915.91	52 514.63	2.2
2	Commercial	602.63	556.32	8.3
3	SLT-LV	189 272.89	180 872.59	4.6
4	SLT-MV	54 915.91	52 514.63	4.6

Table 7 Deficiency per Month in a Period of Two Years (2012 to 2013)

ITEM	SECTOR CATEGORY	Overall Deficiency Per Month (kWh)	Overall Deficiency as a % of Expected Power to be Consumed
1	Residential	5.82	2.2
2	Commercial	46.32	8.3
3	SLT-LV	8,400.30	4.6
4	SLT-MV	2,401.28	4.6

Table 8 Total Deficiency per Month in a Period of Two Years (2012 to 2013)

ITEM	SECTOR CATEGORY	Average Number of Consumers	Deficiency Per Customer in (kWh)	Total Deficiency in kWh for 2 Years
1	Residential	27 148	5.82	158 001.36
2	Commercial	6 420	46.32	297 374.40
3	SLT-LV	130	8 400.00	1 092 000.00
4	SLT-MV	85	2 401.28	204 108.80
TOTAL				**1 751 484.56**

3.2 Discussion

3.2.1 Residential Customers

Residential customers are household customers and are the largest group of customers in the Accra East Region with 22,411 and 31,884 customers for the year 2012 and 2013 respectively. These numbers of customers constituting 90% of the residential customers were sampled in this research. In Fig. 4(a), the monthly profile for the expected power to be consumed in the year 2012 was found to be higher than that of the actual power consumed in that same year. This indicates that, the residential sector did not exceed the projected power to be consumed set by the Energy Commission and hence, deficiency was not experienced in the residential sector in 2012.Fig. 4(b) represents the consumption profile for residential customers in the year 2013, and it is obvious that, the actual power consumed exceeded the expected power to be consumed. As a result, deficiency in the supply of power to the residential sector was established. However, cumulatively, from 2012 to 2013 as shown in Fig. 4(c), the deficiency in the residential sector indicates a marginal proportion less than that in 2013 alone.

3.2.2 Commercial Customers

The commercial sector consisted of government ministries, hotels, individual properties and factories. The total average number of customers sampled was 6,420 and this constituted about 90% of the commercial customers during the year 2012 and 2013. 70% of the customers sampled were individuals and 30% were institutions and companies. Fig. 5(a) represent the consumption profile for both expected power to be consumed and power consumed in the year 2012.The profile shows no deficiency but the difference between the expected power to be consumed and actual power consumed is insignificant.

This means that, the set target by the EC was nearly exceeded in 2012. In 2013, however, the consumption profile as presented in Fig. 5b indicates a significant margin of deficiency. The overall power supply consumption profile to the commercial sector from 2012 to 2013 as indicated in Fig. 5c shows a significant deficiency margin.

3.2.3 SLT-LV Customers

SLT-LV as the name implies simply means special load tariff customers on the LV distribution network of ECG Accra East region. A total of about 130 customers constituting 90% of the SLT-LV customers of the Accra East Region were sampled and their profile for expected power to be consumed and power consumed plotted. In Fig. 6a, a significant deficiency was established in the year 2012 while in Fig. 6b, a marginal deficiency was recognised in 2013.This indicates that, the set target by the EC for the industrial sector was exceeded for both 2012 and 2013 as shown in Fig. 6c. However, the deficiency margin established in 2013 is more than that in 2012. In Fig.6, an all-round deficiency was established from the year 2012 to 2013.

3.2.4 SLT-MV customers

These are virtually a small group of special load customers who are on the medium voltage distribution network of ECG in the Accra East region. A total of 85 customers representing 90% were sampled. Fig. 7a indicates no deficiency, since the expected power to be consumed profile is higher than that of the actual power consumed, but same cannot be said for the year 2013. Fig. 7b showed a clear margin of deficiency, where the expected power to be consumed is less than the actual power consumed. Overall, (2012 to 2013) year as shown in Fig. 7c consumption profile, a significant deficiency was again recognised.

3.2.5 Deficiency Ranking

All customer sectors experience deficiencies. There was therefore, the need to rank the deficiency margins as a percentage of the expected power to be consumed so as to identify which sector was badly hit with deficiency. We note that, once the EC sets the thresholds for the percentage growth to power demand by each sector within a certain number of years, the power producers use the information to upgrade their installed capacity or buy more fuel to fire all their plants installed. Therefore, any deficiency in one of the sectors will affect the other such that, if the power generation cannot sustain the power demanded, then the resultant will be load shedding or total blackout resulting in power system failures.

Deficiency ranking for 2012 as shown in Table 2, saw the SLT LV and SLT MV to be the most deficient sectors with the same percentage deficiency of 7.7%, while the residential is the most efficient with a percentage of −5.8%. In 2013, however, the research showed that it was rather the commercial sector that was the most deficient with 32.3% as shown in Table 5 followed by the residential sector with 15.2% (Table 5). The SLT LV and SLT MV then became the most efficient sector in terms of their consumption as a percentage of their expected power consumed with a deficiency level of 1.7% (Table 5). Table 6 shows that, all the sectors revealed deficiency margins with the commercial sector leading by 8.3% and the residential sector trailing by 2.2%. The SLT-LV and SLT-MV both indicated a percentage of 4.6% as shown in Table 6 and Table 7.

The total deficiency per month for the various sectors of the Accra East customers stood at 1,751,484.56 kWh as presented in Table 8. This research can be repeated for different regions in Ghana to determine, which sector category needs government intervention in each region, since results will defer from region to region.

3.2.6 Solution to Deficiency

The solution to the above deficiency problem is the use of GCSPVS of power supply to power the commercial sector during daytime. This will enable the commercial sector stay off the use of fossil fuels in the supply of power during daytime and switch back to the use of fossil fuels for power supply from 5:00 p. m., when a lot of the workers have closed from work. This means that, power produced using fossil fuel will reduce during daytime, which will translate into fuel savings and fire the plants to full capacity in the night.

In solving the deficiency problem, a module of GCSPVS, which eliminates the deficiency in the commercial sector is being presented by using the 5-parameter model technique, and simulated after uploading the average monthly consumption profile of the commercial sector into the SAM software. Due to the sharp difference in the quantum of power consumed between the institution and companies as a unit, as well as the individuals all within the commercial sector, there was the need to sectionalise the solution into two standard units of GCSPVS: the institutions and companies as one unit; and the individuals as the other.

Ideally, each of the 6,401 customers in the commercial sector must be accessed individually, and a solar PV system provided for them. However, to undertake a transformational injection of power supply into the National Grid in the shortest possible time, standardisation was critical. As a result, two standard solutions were simulated by uploading the sectionalised consumption profile separately into the SAM software. The result was, a 34.4 DC kW GCSPVS for all institutions and companies as well as 3.4 DC kW GCSPVS for all other customers in the commercial sector. All the technical and financial details of the two solutions for the GCSPVS, which solves the deficiency problem in the commercial sector in particular, are summarised and shown in the findings in Table 9 and 11 respectively Fig. 6 and Fig. 7 respectively.

There were about 6,420 commercial customers as at 2013 sampled. Out of the number sampled, 70% were individual customers, while the remaining 30% were institutions and companies. With these two groups of customers being on the GCSPVS, about 81.534 MW of clean power can be generated. The value, 81.534 MW emanates from the individual customers, having 3.4 kW DC total capacity of solar PV system each (0.7×6,420×3.4 kW) = 15,279.6 kW, and the institutions and companies having 34.4 kW DC capacity of solar PV system each (0.3×6,420×34.4 kW) = 66,254.4 kW. In terms of savings per year, a 34.4 kW DC capacity PV system, saves about $923,911.00, while the 3.4 kW capacity PV system saves $94,003.00 as indicated in Table 10 and 12 respectively given that, all parameters used in the simulation stands same.

Table 9 Summary of the Technical and Financial Details of the 34.4 kW DC Grid Connected Solar PV System of Power Supply

System Advisor Model Report

Photovoltaic System — 34 DC kW Nameplate — ACCRA/KOTOKA_INTL, -
Commercial — $2.54/W Installed Cost — 5.6 N, -0.17 E GMT +0

Performance Model

Modules	
SunPower SPR-210-BLK-U	
Cell material	c-Si
Module area	1.2 m^2
Module capacity	215.3 DC Watts
Quantity	160
Total capacity	34.4 DC kW
Total area	199 m^2
Inverters	
Fronius USA, LLC: IG4000 NEG 240V	
Unit capacity	4 AC kW
Input voltage	150 - 400 VDC DC V
Quantity	8
Total capacity	32 AC kW
DC to AC Capacity Ratio	1.08
AC derate factor	0.99
Array	
Strings	8
Modules per string	20
String voltage (DC V)	820.0
Tilt (deg from horizontal)	20
Azimuth (deg E of N)	180
Tracking	fixed
Backtracking	-
Rotation limit (deg)	-
Shading	no
Soiling	yes
DC derate factor	0.96
Performance Adjustment	
Annual	none
Year-to-year decline	0.5%/yr
Hourly factors	no
Annual Results (in Year 1)	
Horizontal solar kW/m^2	1,895
Incident solar kW/m^2	0
DC GWh from array	0.053
Net to inverter	50,920 DC kWh
Gross from inverter	46,500 AC kWh
Net to grid	46,040 AC kWh
Capacity factor	15.3%
Performance factor	0.75

Financial Model

Project Costs	
Total installed cost	$87,362
Salvage value	$0
Analysis Parameters	
Project life	25 years
Inflation rate	14.5%
Real discount rate	5.2%
Project Debt Parameters	
Debt fraction	100%
Amount	$87,362
Term	25 years
Rate	7.5%
Tax and Insurance Rates	**(% of installed cost)**
Federal income tax	32.95%/year
State income tax	7%/year
Sales tax	5%
Insurance	0.5%/year
Property tax (% of assess. val.)	0.3%/year
Incentives	
Federal ITC	30%
Federal Depreciation	7-yr Straight Line
State Depreciation	7-yr Straight Line
Electricity Demand and Rate Summary	
Annual peak demand 101.3 kW	
Annual total demand 458,777 kWh	
Arizona Public Service Co: E-32 TOU (TIME-OF-USE L...	
Fixed fee: $20.3/month	
Flat rate (buy = sell) $20/kWh	
Monthly fixed TOU demand charge $0	
Monthly fixed demand charge $0	
Results	
Nominal LCOE	0.2 cents/kWh
Net present value	$6,635,000
Payback period	0.1 years

Table 10 34.4 kW DC Monthly Electricity Purchases and Savings per Year

Month	Without System, $	With System, $	Savings, $
Jan	595 380	507 662	87 718
Feb	585 212	503331	81 881
Mar	699 602	609 889	89 713
Apr	725 604	648 029	77 575
May	830 181	759 715	70 466
Jun	916 483	853 864	62 619
Jul	965 788	902 285	63 503
Aug	981 930	914 270	67 660
Sep	868 699	795 594	73 105
Oct	801 385	718 896	82 489
Nov	683 550	600 219	83 331
Dec	562 978	479 127	83 851
Annual	**9 216 792**	**8 292 881**	**923 911**

Table 11 Summary of the Technical and Financial Details of the 3.4 kW DC Grid Connected Solar PV System of Power Supply

System Advisor Model Report

Photovoltaic System — 3.44 kW Nameplate — ACCRA/KOTOKA_INTL, -
Commercial — $2.60/W Installed Cost — 5.6 N, -0.17 E GMT +0

Performance Model

Modules	
SunPower SPR-210-BLK-U	
Cell material	c-Si
Module area	1.2 m^2
Module capacity	215.3 DC Watts
Quantity	16
Total capacity	3.4 DC kW
Total area	19 m^2
Inverters	
Fronius USA, LLC: IG4000 NEG 240V	
Unit capacity	4 AC kW
Input voltage	150 - 400 VDC DC V
Quantity	1
Total capacity	4 AC kW
DC to AC Capacity Ratio	0.86
AC derate factor	0.99
Array	
Strings	2
Modules per string	8
String voltage (DC V)	328.0
Tilt (deg from horizontal)	20
Azimuth (deg E of N)	180
Tracking	fixed
Backtracking	-
Rotation limit (deg)	-
Shading	no
Soiling	yes
DC derate factor	0.96
Performance Adjustment	
Annual	none
Year-to-year decline	0.5%/yr
Hourly factors	no
Annual Results (in Year 1)	
Horizontal solar kW/m^2	1,895
Incident solar kW/m^2	0
DC kWh from array	5320.000
Net to inverter	5,090 DC kWh
Gross from inverter	4,730 AC kWh
Net to grid	4,680 AC kWh
Capacity factor	15.5%
Performance factor	0.77

Financial Model

Project Costs	
Total installed cost	$8,954
Salvage value	$0
Analysis Parameters	
Project life	25 years
Inflation rate	14.5%
Real discount rate	5.2%
Project Debt Parameters	
Debt fraction	100%
Amount	$8,954
Term	25 years
Rate	7.5%
Tax and Insurance Rates	**(% of installed cost)**
Federal income tax	32.75%/year
State income tax	7%/year
Sales tax	5%
Insurance	0.5%/year
Property tax (% of assess. val.)	0.3%/year
Incentives	
Federal ITC	30%
Federal Depreciation	7-yr Straight Line
State Depreciation	7-yr Straight Line
Electricity Demand and Rate Summary	
Annual peak demand 3.4 kW	
Annual total demand 15,292 kWh	
Arizona Public Service Co: E-32 TOU (TIME-OF-USE L...	
Fixed fee: $20.3/month	
Flat rate (buy = sell) $20/kWh	
Monthly fixed TOU demand charge $0	
Monthly fixed demand charge $0	
Results	
Nominal LCOE	0.2 cents/kWh
Net present value	$677,100
Payback period	0.1 years

Table 12 3.44 kW DC Monthly Electricity Purchases and Savings per Year

Month	Without System, $	With System, $	Savings, $
Jan	19 865	10 951	8 914
Feb	19 526	11 206	8 320
Mar	23 339	14 224	9 115
Apr	24 206	16 313	7 893
May	27 692	20 516	7 176
Jun	30 569	24 183	6 386
Jul	32 212	25 736	6 476
Aug	32 750	25 856	6 894
Sep	28 976	21 532	7 444
Oct	26 732	18 340	8 392
Nov	22 804	14 333	8 471
Dec	18 785	10 262	8 523
Annual	**307 456**	**213 452**	**94 004**

Taken the total number of customers in Accra East ECG commercial customers into account with 70% being individuals and 30% being institutions and companies, the savings made on the part of the individual customers within the commercial sector would be in the region of about $422,453,976.00 per year (i.e. 0.7×6,420×94,004), while that of the institutions and companies is $1,779,452,586.00 per year (i.e. 0.3×6,420×923,911). This is certainly a must do project and can be replicated in all the ECG regional office level to save a lot of money for the country.

3.2.7 Summary of Findings

The research findings emanating from the study of power supply deficiency within the Accra East Region ECG customers are as follows:

(i) Deficiency was found in all the 4 sector categories of customers being Residential, Commercial, SLT-LV, and SLT-MV;
(ii) Among the 4 sector categories of customers, the residential sector was the group having the highest number of customers with an average of 31,884 customers sampled;
(iii) The commercial sector was found to have the highest deficiency with a margin of about 8.3% of its expected power to be consumed;
(iv) The SLT-LV and the SLT-MV sectors, both had deficiency margins with respect to their expected power to be consumed in the region of about 4.6%. These two sectors were also found to be the group of customers whose billing records were properly documented;
(v) The sector category of ECG customers in the Accra East region selected for the Ghana government to deploy grid connected solar PV system of power supply is the commercial sector;
(vi) The commercial sector customers in Accra East Region were found to consist of individuals, institutions and companies;
(vii) The individual customers form about 70%, while the institutions and companies form about 30% out of a total of 6,420 customers sampled;
(viii) Two standard solution for grid connected solar PV system of power supply were provided for the commercial sector due to the load difference between the individuals and the institutions and companies;
(ix) A standard 4 kW AC grid connected solar PV system of power supply was recommended for the individual customers who form about 70% and a standard 35 kW AC grid connected solar PV system of power supply for both the institution and companies;
(x) Cash flow for the standard 4 kW grid connected solar PV system of power supply is found to be far better than that of the 35 kW grid connected solar PV system; and
(xi) Savings of about $923,911.00 and $94,004.00 are expected to be made per year for both the standard 35 kW and standard 4 kW grid connected solar system of power supply respectively for each customer.

4 Conclusion and Recommendation

Conclusion

In conclusion, one can confidently say there is power supply deficiency within the Accra East Region ECG customers as a result of their growth rate to demand and one of the best way in solving this power supply challenge is the use of the grid connected solar photovoltaic system of power supply. This system of power supply has the potential of saving Ghana a lot of money, that otherwise would have been used for the purchase of gas or crude, to power thermal plants that we are currently relying on and costing the nation a lot of money. We would also have saved our planet by the use of this system.

This research can be replicated in all the regional blocks of ECG, namely; Accra East, Accra West, Ashanti, Western, Tema, Central, Volta and Eastern regions with those sectors of customers having the highest deficiency rankings in all the regions, made to go on the grid connected solar photovoltaic system of power supply through effective policies.

Recommendation

Some of the recommended policies government could employ are what we call the incentive package policies, which are being applied by countries like the United State of America, Canada, and Germany. The implementation of one or more of such policies must be based on customers' will and financial status. The policies are: Investment Tax Credits; Production Tax Credits; Investment Based Incentive; Capacity Based Incentive; and Production Based Incentive.

The implementation of the policy measures will catapult the country into an accelerated growth in the economy and provide sustainable jobs for engineers and technicians in the field of renewable energy engineering and allied disciplines.

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