Computer Aided Off-Grid Solar PV System Design

E. A. Egbivwie, V. O. Ughwumiakpor, A. P. Ayinuola

Marine Engineering School
Nigerian Naval Engineering College
Sapele, Delta State, Nigeria

Abstract- This paper is concerned with the design of a computer-aided off-grid solar photovoltaic system which involves a dynamic computation using visual basic 6.0 programming tool. The components of the design interface of the visual basic programming solution involves calculating the load, solar panel sizing and specification, battery selection and size specification, charge controller sizing and inverter specification. So many household occupants the world over do not have access to an electrical energy supply. Majority of these buildings are in remote areas and are not connected to the national grid due probably to the high capital expenditure costs involved in expanding the national grid as well as low electricity demand from the inhabitants of these areas. Off-grid solar systems which are autonomous electricity grids that are fed with energy from photovoltaic solar power systems therefore provide a viable alternative. A photovoltaic power system can be used to provide alternative source of electrical power to homes in order to meet their daily energy requirement through the direct conversion of solar irradiance into electricity. The process of acquiring off-grid solar PV system involves the design, selection and determination of the parameters of the different components employed in the system. The success of this process is based on factors such as geographical location of the off-grid solar system, weather condition, solar irradiance, and load requirement. This paper outlines the detailed procedures adopted in the specification of each component of the off-grid solar system and as a case study; a residence in Sapele town (Nigeria) with specific energy consumption was selected.

Index Terms- Off-grid PV system, load calculator, solar system components, visual basic programming.

I. Introduction

Solar energy refers to the energy provided by the sun which is the most important source of energy for life forms. It is radiant light and heat from the Sun that is harnessed using a wide range of technologies one of which is the photovoltaic (PV) cells technology. Solar energy has so many benefits; it is environmentally friendly, durable, noise free, electricity produced can be stored for later use, etc.

II. Off-grid PV solar system components

An off-grid photovoltaic solar power system consists of four major components which are inter-connected together to produce electricity, they are: solar PV array, charge controller, battery and inverter. Other minor components are cables and protection devices such as fuses, bus bars, lighting protection system, etc. Figure 1 below shows a schematic diagram of interconnected components of a typical off-grid photovoltaic solar power system.

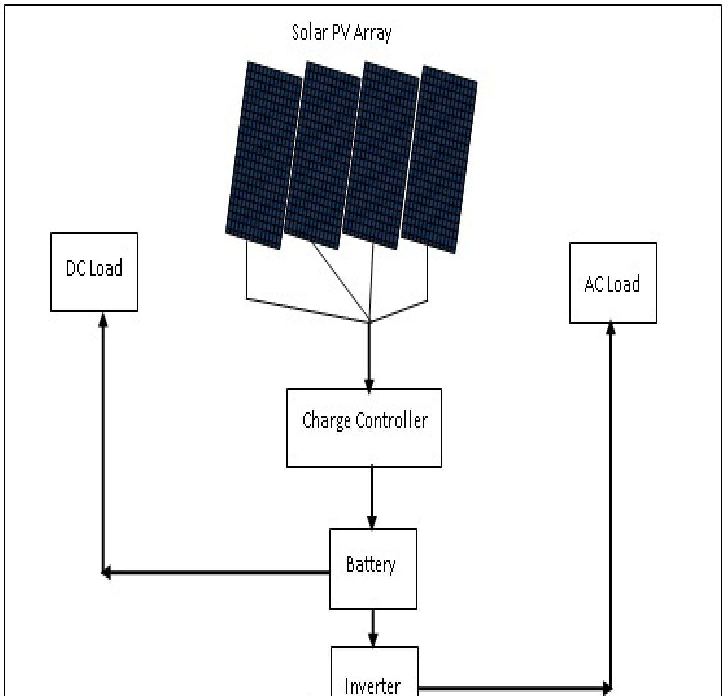

Figure 1. Off-grid solar system components

A solar PV array is a collection of several panels (or modules), which are made up of several solar cells that are responsible for generating current and voltage from the sun. Solar charge controllers are placed between the solar panel and battery storage in order to regulate the voltage and current coming from the solar panels and maintain the proper charging voltage on the batteries. Storage batteries are used to store energy during sunshine hours while being charged by the PV array and delivers current to load during non sunshine hours. Deep cycle Lead Acid batteries are recommended for off-grid solar power systems because of their high performance. The Inverter plays the role of converting DC power (coming from solar panel and batteries) to AC power.

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III. DESIGN METHODOLOGY

The design of the off-grid solar system is based on a dynamic computation approach using visual basic programming techniques. A user is allowed access into the program by providing a correct username and password in the Login page and clicking Ok as shown in Figure 2 below. When the user enters the wrong username and/or password, he is prompted to enter the correct username and/or password to successfully login to the household load calculator form.

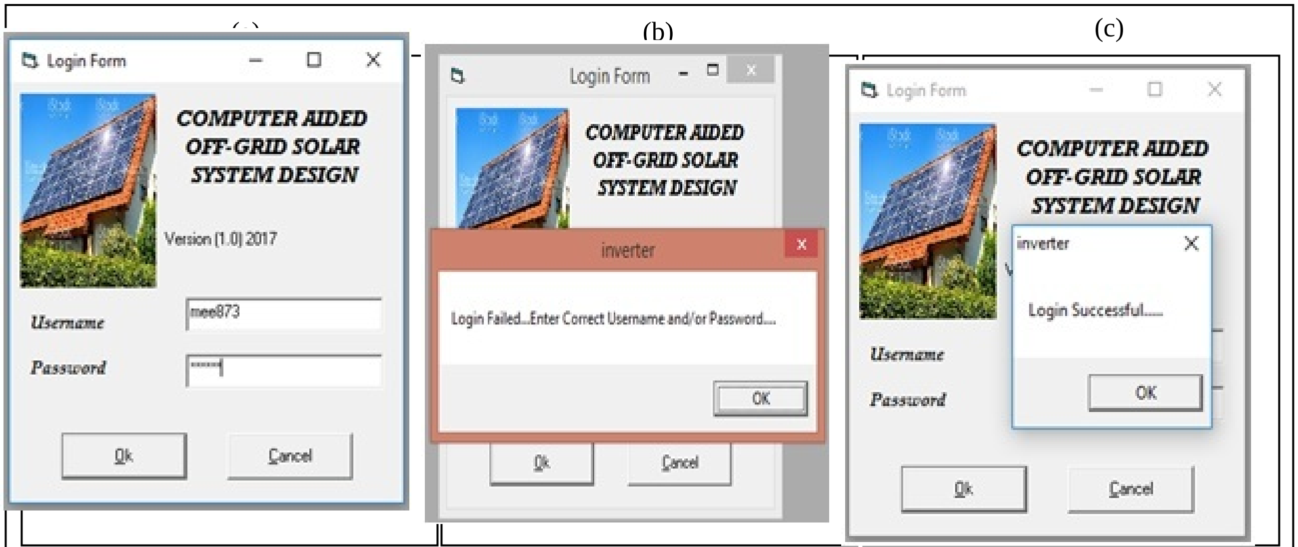

Figure 2. Off-grid PV solar system title screen and login form; (a) during login attempt, (b) during failed login (user enters incorrect username and/or password), and (c) after successful login

A household building in Sapele town is considered as case study for this paper. Sapele town is located in the south-south part of Nigeria at a latitude and longitude of 5.8751°N (5°55'0") and 5.6931°E (5°42'0") with an average solar radiation of 5.25 kilo-watt-hour per square meter per day and mean temperature of about 33°C.

The building of concern is a 2-bedroom bungalow apartment where the following appliances are needed to be powered: fan, light (Compact Fluorescent Lamp), television and satellite receiver. Table 1 below shows the list of appliances, their quantities, rated power and the number of hours to be put to use per day.

Table 1. List of appliances and their rated power

Serial	List of Appliances	Quantity	Rated Power (Watts	Resistive Loads	Inductive Loads	Hours/Day
1	Fan	1	100	-	✓	4
2	Light (CFL)	2	15	✓	-	6
3	TV	1	100	✓	-	2
4	Satellite receiver	1	18	✓	-	2

After successful login, the designer is directed to the first form of the program environment (household load calculator) where he is required to input the data shown in Table 1 and then the rated power output, energy used per day, and daily average energy demand are computed and results displayed accordingly (Figure 3) upon clicking on the Compute button.

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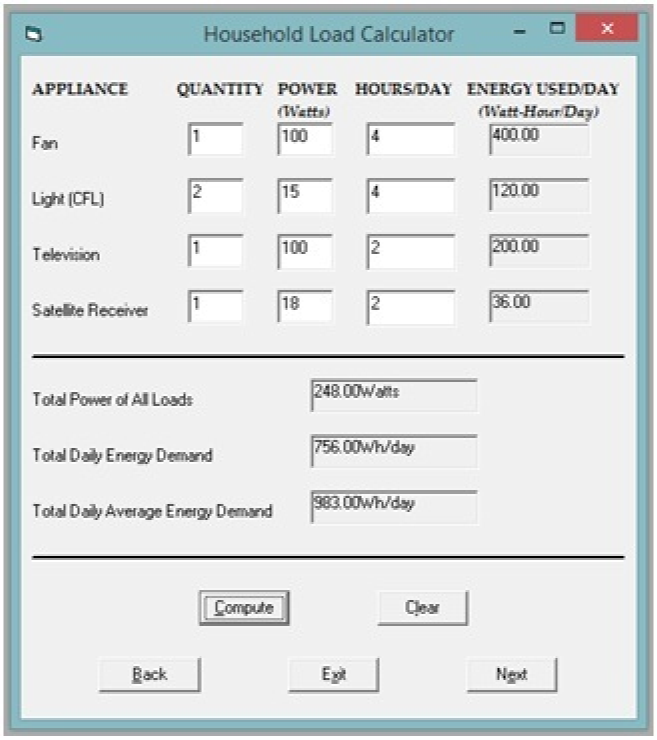

Figure 3. Off-grid solar PV system household load

The user is then required to click the 'Next' button to move to the solar PV array and charge controller specifications form (Figure 4) where he can input values for rated voltage and current of the module, average sun hours per day, DC voltage of system and charge controller factor of safety using Tables 2 and 3 as references.

Table 2. Summary of solar PV array specification

Solar module specification			
Trina Solar TSM-310PD14 (310W)		**Technology**: Polycrystalline Silicon	
Rated voltage of module (V_{mp}) = 37V;		Average sun hours available per day (H_S)= 6	
Rated current of module (I_{mp}) = 8.38A;		DC Voltage of system (V_{dc}) = 24V;	
Short circuit current of module = 8.85A;		Open circuit voltage of the module = 45.5V	
Total daily energy demand (ΣE) = 756.0Wh/day (from Figure3)			
Serial	**Parameter**	**Formula**	**Equation number**
1	*Daily average energy demand*	$E_{avg} = 1.3\ x\ \Sigma E$	(1)
2	*Average maximum power*	$P_{max} = \frac{E_{avg}}{H_s}$	(2)
3	*DC current of the system*	$I_{dc} = \frac{P_{max}}{V_{dc}}$	(3)
4	*Number of module strings in series*	$M_s = \frac{V_{dc}}{V_{mp}}$	(4)
5	*Number of module strings in parallel*	$M_p = \frac{I_{dc}}{I_{mp}}$	(5)
6	*Total number of modules (or array size)*	$M_T = M_s\ x\ M_p$	(6)

Table 3. Summary of charge controller specification

Charge controller specification Factor of safety (F_S) = 1.24; Charge controller voltage (V_{dc})= 24V			
Serial	**Parameter**	**Formula**	**Equation number**
1	*Charge controller current*	$I_{cc} = \frac{P_{max}}{V_{dc}} \, x \, F_s$	(7)

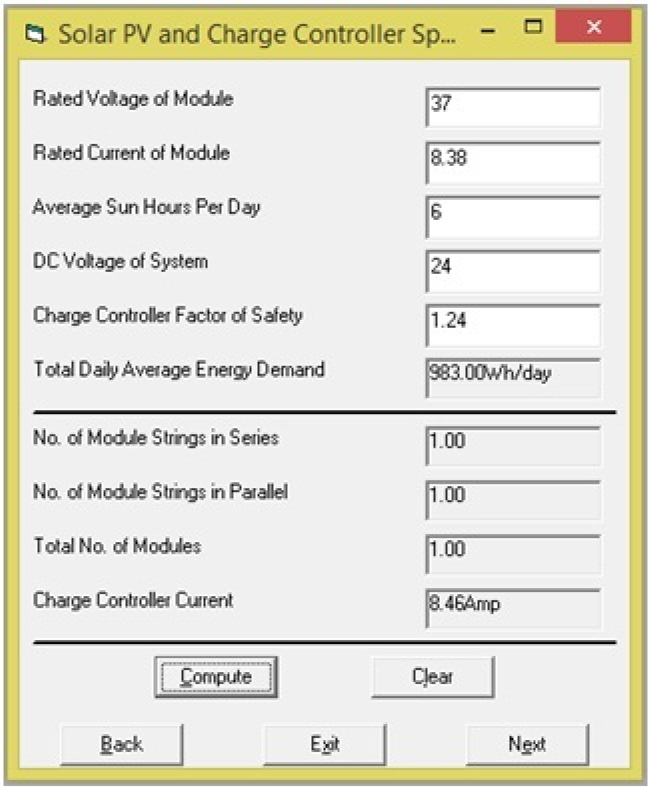

Figure 4. Solar PV array and charge controller specifications

The user then clicks on the 'Compute' button to display required results, followed by the 'Next' button to continue to the battery storage specification form shown in Figure 5 to input values for number of days of autonomy and maximum allowable depth of discharge from Table 4.

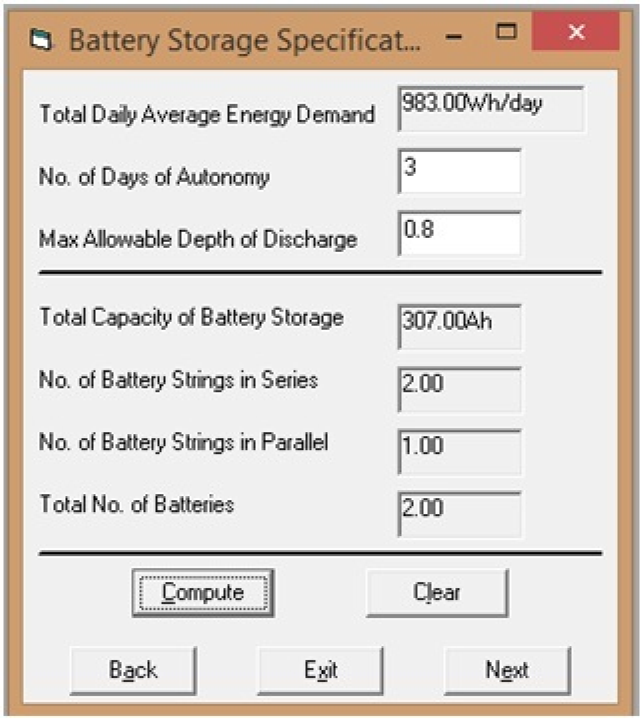

Figure 5. Battery storage specification

Table 4. Summary of battery storage specification

Battery storage specification
No. of days of autonomy (A_d) = 3; Max allowable depth of discharge (D_d) = 80% Rated DC voltage of one battery (V_i) = 12V; Capacity of battery (B_C) = 400Ah

Serial	Parameter	Formula	Equation number
1	*Estimated energy storage*	$E_{est} = E_{avg}\ x\ A_d$	(8)
2	*Safe energy storage*	$E_s = \frac{E_{est}}{D_d}$	(9)
3	*Total capacity of battery storage*	$B_{TC} = \frac{E_s}{V_i}$	(10)
4	*Number of battery strings in series*	$B_S = \frac{V_{dc}}{V_i}$	(11)
5	*Number of battery strings in parallel*	$B_P = \frac{B_{TC}}{B_C\ x\ B_S}$	(12)
6	*Total number of batteries*	$B_{TN} = B_P\ x\ B_S$	(13)

Upon clicking on the compute button, the total numbers of batteries as well as other values are computed based on the formulas given in Table 4 and the results displayed.

Again, the user clicks on Next to navigate to the inverter specification form, and from Table 5 he then enters values for inverter efficiency and power factor in the spaces provided on the form.

Table 5. Summary of inverter specification

Inverter specification
Efficiency of inverter (η_{IV}) = 90%; Input DC Voltage (V_{dc}) = 24V; Power Factor (PF) = 0.8; Lowest voltage of battery (V_B) = 10V

Serial	Parameter	Formula	Equation number
1	*Inductive loads*	P_I	(14)
2	*Resistive loads*	P_r	(15)
3	*Total power of all loads*	$P_T = P_r + P_I$	(16)
4	*Continuous power load to the inverter*	$P_{T1} = \frac{P_T}{\eta_{IV}}$	(17)
5	*Power to be delivered by inverter*	$P_{IV} = 1.25(P_T + 3.5\ x\ P_I)$	(18)
6	*Rated output power of inverter*	$P_{KVA} = \frac{P_{IV}}{PF}$	(19)
7	*Daily input energy to the inverter*	$E_{IV} = \frac{E_{avg}}{\eta_{IV}}$	(20)

By clicking on the compute button, the program calculates the daily input energy to the inverter and rated power output including other parameters of the inverter and displays the results in appropriate labels (see Figure 6).

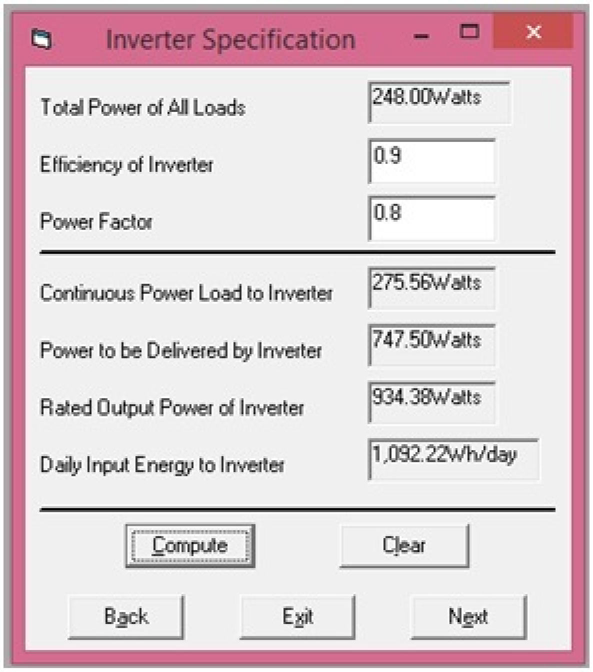

Figure 6. Inverter specification

The user then clicks on the Next button to navigate to the summary form shown in Figure 7.

IV. Results

A summary of results for components specifications is displayed when the user clicks on the 'Display Result' button on the summary form.

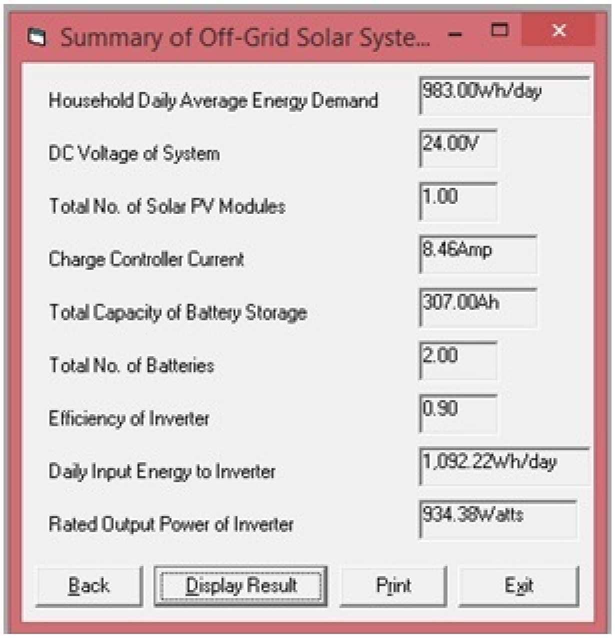

Figure 7. Summary of Off-grid solar PV system components specifications

V. Conclusion

The average solar radiation of Sapele town is enough to provide the energy requirement of a building in this area if it is efficiently tapped. Although the initial installation cost for this energy source is high, on the long run it is more economical and therefore, it is expedient for various governments to be involved in providing financial support for procurement and installation of PV system in order to make it a popular choice and propagate its use. The design of a off-grid solar system is time consuming and quite complicated as it involves the use of several variables and computations that are done manually. This paper therefore presents a simplified and shorter process of designing the off-grid solar PV system through the use of a more user friendly and dynamic computational approach.

Table 6. List of adapted variables with meanings and units

Serial	Variable	Meaning	Unit
1	ΣE	Daily energy demand	Watt-hour/day
2	E_{avg}	Daily average energy demand	Watt-hour/day
3	H_s	Average sun hours per day	hours/day
4	V_{dc}	DC voltage of system	Volts
5	P_{max}	Average maximum power	Watts
6	I_{dc}	DC current of system	Amperes
7	M_s	No. of modules in series	
8	M_p	No. of modules in parallel	
9	V_m	Rated voltage of module	Volts
10	I_m	Rated current of module	Amperes
11	M_T	Total no. of modules	
12	I_{cc}	Charge controller current	Amperes
13	F_s	Factor of safety	
14	E_{est}	Estimated energy storage	Watt-hour/day
15	A_d	Days of autonomy	

16	E_s	Safe energy storage	
17	D_d	Max allowable depth of discharge	
18	B_{TC}	Total capacity of battery storage	Ampere-hour
19	B_{TN}	Total no. of batteries	
20	B_C	Capacity of one battery	Ampere-hour
21	B_S	No. batteries in series	
22	B_P	No. of batteries in parallel	
23	V_i	DC voltage of one battery	Volts
24	P_T	Total power of all loads	Watt-hour/day
25	P_{IV}	Power delivered by inverter	Watts
26	P_r	Resistive loads (power)	Watts
27	P_i	Inductive loads (power)	Watts
28	P_{KVA}	Rated output power of inverter	Watts
29	PF	Power factor	
30	P_{T1}	Continuous power load to inverter	Watts
31	η_{IV}	Efficiency of inverter	
32	E_{IV}	Daily input energy to inverter	Watt-hour/day
33	I_B	Max continuous input current to inverter	Amperes

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AUTHORS

First Author: E. A. Egbivwie, OND, B.Eng (Mechanical Engineering), M.Eng (Applied Energy), Marine Engineering School, Nigerian Naval Engineering College, Sapele, Delta State, Nigeria. eddieit4u@gmail.com
Second Author: V. O. Ughwumiakpor, B.Eng (Mechanical Engineering), M.Eng (Thermal Power Engineering), Marine Engineering School, Nigerian Naval Engineering College, Sapele, Delta State, Nigeria.
Third Author: A. P. Ayinuola, B.Eng (Mechanical Engineering), M.Eng (Industrial Metallurgy and Corrosion Management), Marine Engineering School, Nigerian Naval Engineering College, Sapele, Delta State, Nigeria.

Correspondence Author - E. A. Egbivwie, eddieit4u@gmail.com, eddieit07@googlemail.com, +2348034309986