Computer-Aided Design Of A Stand Alone Photovoltaic System: A Case Study Of Faculty Of Engineering Bayero University Kano.

Ishaq M., Ibrahim U.H., Abubakar, H., A.A. Baba

Abstract: In this paper, the electrical energy demand (load) of the Faculty of Engineering Bayero University Kano (BUK) was estimated based on watt-hour energy demands. A stand alone Photovoltaic (PV) system was designed based on 10% of the estimated load to supplement power supply to the faculty. Based on the equipment selected for the design, 96 PV modules, 24 batteries, 5 voltage regulators and an inverter will be required to supply 10% of the electrical energy demand by the faculty. A computer program was developed for the system for ease of design. The cost estimate of the system N2 788 272 is relatively high when compared to that of standby fuel generator used by the faculty. The payback period of the system is estimated to be 3.6 years, which is obviously much shorter than the lifespan of the selected PV module.

Key Words: Photovoltaic System, Stand-alone, Electrical Energy Demand, Cost Estimate, Payback Period, Computer-Aided

1.0 Introduction

Photovoltaic (PV) is the conversion of energy that comes from the sun into electricity through a phenomenon known as the photoelectric effect. Energy from the sun as light is transformed into electricity when it touches a solar cell. Many homes particularly in the developed economies are today powered by photovoltaic systems. In homes that are far from utility grids, photovoltaic systems are frequently the most cost-effective sources of power. Even if utility grid is closed by, some home owners choose PV systems because it gives them more autonomy and provides a way of minimizing the effects of increase in utility rate. PV system is an attractive alternative energy to conventional sources of electricity for many reasons: it is safe, silent, non-polluting, renewable, its fuel is free, and highly modular in that its capacity can be increased incrementally to match with gradual load growth, reliable with minimal failure rates, it contains no moving parts, it requires no special training to operate and it has projected service life times of 20 to 30 years [1].

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The Faculty of Engineering Bayero University Kano is plagued with recurrent outages of power from the grid to the extent that every department in the faculty has to provide its power using standby fuel generators of different sizes and capacities. There is need to search for alternative energy sources for the faculty due to fast depletion of fossil fuel and its corresponding pollution of the environment. Therefore, a stand-alone photovoltaic system is being considered as one of the alternatives sources of electricity generation for the faculty. Stand alone PV System is a PV system which uses photovoltaic technology only and is not connected to utility grid. Stand alone PV systems can directly power Direct current (DC) appliances or they can include power- conditioning equipment such as an inverter to convert DC power to alternating current (AC) which is required by some appliances. Batteries can be used to store electricity for used at night or cloudy days (days of autonomy).Stand alone PV system provides affordable electricity in area where conventional electricity grids are unreliable or non-existing. The geographical location of Faculty of Engineering Bayero University Kano makes it one of the relatively sun-reach remote regions on the globe. It is located in the northern part of Nigeria between latitude 12^0N and longitude 9^0E [2].This implies that the solar panels must be mounted facing the south to capture the maximum amount of solar energy. The minimum peak sun hour per day for BUK is 4.5 [2].

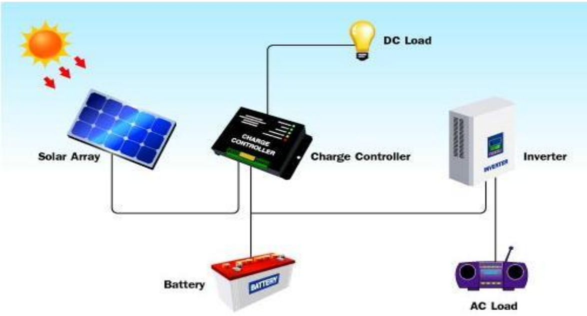

Figure 1: Schematic Diagram of a Typical Stand alone PV system

2.0 Methodology

The electrical appliances (loads) available at the faculty were first itemized with their power ratings and time of operation during the day to obtain the total energy demand in Watt-hour per day by the faculty. The total energy demand obtained was then used to size the proposed stand alone photovoltaic system.

2.1 Load Estimation of the Faculty of Engineering BUK

The faculty of engineering BUK comprises four departments and Deans Office; Agricultural Engineering, Civil Engineering, Electrical Engineering and Mechanical Engineering. Table 1.0 shows the summary of the daily energy demand by Department of Agricultural Engineering. All the appliances assessed where AC appliances.

Table 1.0 Estimated Daily Energy demand for Department of Agricultural Engineering

Appliances	Rated power (W)	Quantity	Total rated power (KW)	Hours used per day (h)	KWh/day
Lightning bulbs	8	80	0.640	8	5.120
	26	40	1.040	8	8.320
	36	24	0.864	8	6.912
Fans	50	5	0.250	8	2.000
	65	79	5.135	8	41.080
Computers	75	50	3.750	4	15.00
Refrigerators	150	2	0.300	8	2.400
Photocopying machine	1200	1	1.200	4	4.800
Water Dispenser	500	2	1.00	8	8.000
Electric Kettle	2500	1	2.500	2	5.000
Printers	160	2	0.320	2	0.640
Scanners	55	2	0.110	2	0.220
Total			17.109		99.492

Similar estimations as in Table 1.0 were also made for other departments in the faculty and Deans' office and then the estimated total energy demand per appliance per department in kW and kWh/day were calculated as shown in Table 2.0 and Table 3.0 respectively.

Table 2.0 Estimated Total Energy demand Per Appliance Per Department in kW

Appliances	Departments					
	Agricultural	Civil	Electrical	Mechanical	Deans' office	Total
Lighting bulbs	4.272	15.260	5.059	17.559	4.623	46.773
Fans	5.385	1.170	3.990	4.180	0.960	15.685
Computer	3.750	3.500	5.880	6.800	1.050	20.980
Refrigerators	0.300	0.395	0.300	0.280	0.150	1.425
Photocopying machine	1.200	1.200	1.200	1.200	1.200	6.000
Water Dispenser	0.500	0.500	0.500	0.500	0.500	2.500
Electric Kettles	2.500	2.500	2.500	2.500	2.500	12.500
Televisions	-	-	1.000	-	-	1.000
Printers	0.320	0.320	0.320	0.320	0.320	1.600
Scanners	0.110	0.110	0.110	0.110	0.110	0.550
Total	17.109	24.955	20.859	33.449	11.413	107.785

Table 3.0 Estimated Total Energy Demand per Appliance per Department in kWh/day

Appliances	Departments					
	Agricultural	Civil	Electrical	Mechanical	Deans' office	Total
Lighting bulbs	20.352	21.08	80.472	123.472	16.984	262.360
Fans	43.080	9.360	31.920	33.440	7.680	125.480
Computers	15.000	14.000	20.000	21.400	1.400	71.800
Refrigerators	2.400	3.160	2.400	2.240	1.200	11.400
Photocopying machine	4.800	4.800	4.800	4.800	4.800	24.000
Water Dispenser	8.000	4.000	4.000	4.000	4.000	24.000
Electric Kettles	5.000	5.000	5.000	5.000	5.000	25.000
Televisions	-	-	8.00	-	-	8.000
Printers	0.640	0.640	0.640	0.640	0.640	3.200
Scanners	0.220	0.220	0.220	0.220	0.220	1.100
Total	99.492	62.26	157.452	194.493	41.924	555.621

2.2 Selection of System Voltage
The system voltage is selected based on the requirements of the system. As a general rule the system voltage increases with increased daily load. However in a standalone PV system, the voltage is also dependent on the inverters that are available. When loads require ac power, the dc system voltage should be selected after studying available inverter characteristics. Since the total ac-load is greater than 5000W, the system voltage selected is 48Vdc [3]

2.3 Selection of PV Module
In selecting a PV module for PV system, the main criteria are the performance warranty in case of any problems, module replacement ease; compliance with natural electrical and building codes and manual should be available to see the quality and characteristics of the module. The ENP Sonne High Quality 180 Watt, 24V monocrystalline module was chosen in this design.

2.4 Determination of PV Array size
The PV array output power$(P_{pv\,array})$ can be determined by equation 1. [4]

$$P_{pvarray} = \frac{E_L}{\eta_{b.o} \times K_{Loss} \times H_{tilt}} \times PSI \quad (1)$$

E_L =Estimated average daily load energy consumption in kWh/day =556kWh/day (Table 3.0)

H_{tilt} = Average solar radiation in peak sun hour's incident for specified tilt angle.

PSI = Peak solar intensity at the earth surface (1kW/m^2)

η_{bo} = Efficiency of balance of system

K_{Loss} = A factor determined by different losses such as module temperature, losses, dust, etc

$$\eta_{bo} = \eta_{inverter} \times \eta_{wire\,losses} \quad (2)$$

In this work $\eta_{inverter}$ and $\eta_{wire\,losses}$ are taken as 85% and 90% respectively

$$\eta_{bo} = 0.95 \times 0.90 = 0.855$$

$$K_{Loss} = f_{man} \times f_{temp} \times f_{dirt} \quad (3)$$

Where,

f_{man} = Manufacturer's tolerance

f_{temp} =Temperature de-rating factor

f_{dirt} =De-rating due to dirt

f_{temp}, is given by equation 4 [5]

$$f_{temp} = 1 - [Y(T_{cell.eff} - T_{STC})] \quad (4)$$

Y = Power temperature co-efficient

$T_{cell.eff}$ = Average daily temperature in ^oC

$T_{cell.eff}$ can be determined by equation 5

$$T_{cell.eff} = Ta.day + 25 \quad (5)$$

Where,

$T_{a.day}$= day time average ambient temperature in ^oC

The minimum peak sun hour per day (H_{tilt}) for BUK is 4.5 [2]

The peak solar intensity (PSI) at the earth surface is 1KW/m^2
From equation 4,

$$f_{temp} = 1 - [Y(T_{cell.eff} - T_{STC})]$$

Based on the manufacturer specification for the selected module,$T_{cell.eff} = 45^oC$

$Y = 0.48\%/0C$, $T_{STC} = 25^0C$ and $f_{man} = 97\%$

$$f_{temp} = 1 - \left[\frac{0.48}{100}(45 - 25)\right] = 0.904$$

f_{dirt} is taken as 95% in this work

From equation 3,

$$K_{Loss} = f_{man} \times f_{temp} \times f_{dirt}$$

$$K_{Loss} = 0.97 \times 0.904 \times 0.95 = 0.833$$

$$P_{pvarray} = \frac{556 \times 10\%}{0.855 \times 0.833 \times 4.5} \times 1 = 17.35kW$$

2.5 Number of modules in series
The number of modules in series N_{ms} can be determined by equation 6 [6]

$$N_{ms} = \frac{V_{system}}{V_{module}} \quad (6)$$

$$N_{ms} = \frac{V_{system}}{V_{module}} = \frac{48}{24} = 2modules$$

2.6 Number of modules in parallel
The number of modules in parallel N_{mp} is determined by equation 7. [7]

$$N_{mp} = \frac{P_{pv\,array}}{N_{ms} \times P_{module}} \quad (7)$$

$$N_{mp} = \frac{17.35 \times 10^3}{2 \times 180} = 48modules$$

Total number of modules N_{mt} is given by equation (8)

$$N_{mt} = N_{ms} \times N_{mp} = 2 \times 48 = 96\text{ modules} \quad (8)$$

2.7 Determination of Battery bank capacity
The storage battery capacity can be calculated using equation 9. [8],

$$C_x = \frac{N_c \times E_L}{DOD_{max} \times V_{system} \times \eta_{out}} \quad (9)$$

Where,

$C_x =$ Required battery capacity

$N_c =$ Number of days of autonomy
$E_L =$ Estimated load energy in Wh

$DOD_{max} =$ Maximum depth of discharge

$\eta_{out} =$ Battery loss

2.8 Determination of the required battery bank capacity
Batteries used in all solar systems are sized in ampere hours under standard test condition of 25°C. The depth of the discharge is a measure of how much of the total battery capacity has been consumed. In this design the day of autonomy is taking as 4 days and the maximum allowable depth of discharge is taken as 75%

The battery bank capacity required (C_x) is given by;

$$C_x = \frac{N_c \times E_L}{DOD_{max} \times V_{system} \times \eta_{out}}$$

In this design, $\eta_{out} = 0.85$

$$C_x = \frac{4 \times 556 \times 10^3 \times 10\%}{0.75 \times 48 \times 0.85} = 7268 \text{ Ah}$$

2.9 Specification of Battery type to be used
The battery selected is ROLLS SERIES 4000 BATTERIES, 12MD325P. The battery has a capacity of 325AH and a nominal voltage of 12V.

From equation (10), number of batteries required (N_{breq}) is;

$$N_{breq} = \frac{C_x}{C_{selected}} \quad (10)$$

$$N_{breq} = \frac{7268}{325} = 22 \text{ batteries}$$

Number of batteries in series is given by equation 11

$$N_{bs} = \frac{V_{system}}{V_{battery}} \quad (11)$$

$$N_{bs} = \frac{48}{12} = 4 \text{ batteries}$$

Number of batteries in parallel is given by equation 12

$$N_{bp} = \frac{N_{breq}}{N_{bs}} \quad (12)$$

$$N_{bp} = \frac{22}{4} = 6 \text{ batteries}$$

2.10 Determination of Inverter size
In sizing the inverter, the actual power drawn from the appliances that will run at the same time must be determined as first step. Secondly, we must consider the starting current of large motors by multiplying their power by a factor of 3. Also to allow the system to expand, we multiply the sum of the two previous values by 1.25 as a safety factor ($ʆ_{safety}$) [8]

$$P_{total} = (P_{RS} + 3P_{LSC}) \times 1.25 \quad (13)$$

Where,

$P_{total} =$ Inverter power rating (size)

$P_{RS} =$ Power of appliances running simultaneously =107.785 kW [2]

$P_{LSC} =$ Power of large surge current appliances =0

The input rating of the inverter should never be lower than the total watt of appliances.

$$P_{total} = (P_{RS} + 3P_{LSC}) \times 1.25$$

$$P_{total} = (107.785 \times 10\% + 3 \times 0) \times 1.25 = 14kW = 14kVA$$

The inverter to be used for this system should have capacity not less than 14kVA and a nominal voltage of 48VDC.

2.11 Determination of Voltage Regulator Size
The voltage regulator is typically rated against amperage and voltage capacities. The voltage regulator is selected to match the voltage of PV array and batteries. A good voltage regulator must have enough capacity to handle the current from PV array.

The rated current of the regulator is given by equation 14 [6]

$$I_{rated} = N_{mp} \times I_{sc} \times ʆ_{safety} \quad (14)$$

$$I_{rated} = 48 \times 5.38 \times 1.25 = 323 \text{ A}$$

The voltage regulator selected is Xantex C60 controller 60A, 12/24V. It has nominal voltage of 12/24VDC and charging load/current of 60 amperes. Number of voltage regulator required is given by equation (15)

$$N_{vreg} = \frac{I_{rated}}{I_{selected}} \quad (15)$$

$$N_{vreg} = \frac{323}{60} = 5 \text{voltage regulators}$$

2.12 Computer Program for the Design of the Stand alone Photovoltaic System

It is believed that by using computer-aided design approach in PV system, all the principles and techniques of the design can be demonstrated in fairly simple fashion. A computer program was developed using FORTRAN software for the system sized. Various details of this program are presented in the Appendix. Flow chart for the PV array sizing is shown in figure 2.0. Similar flow charts for sizing the battery bank, voltage regulators and the inverter were also drawn and a computer program was developed for easy and accurate sizing of the system.

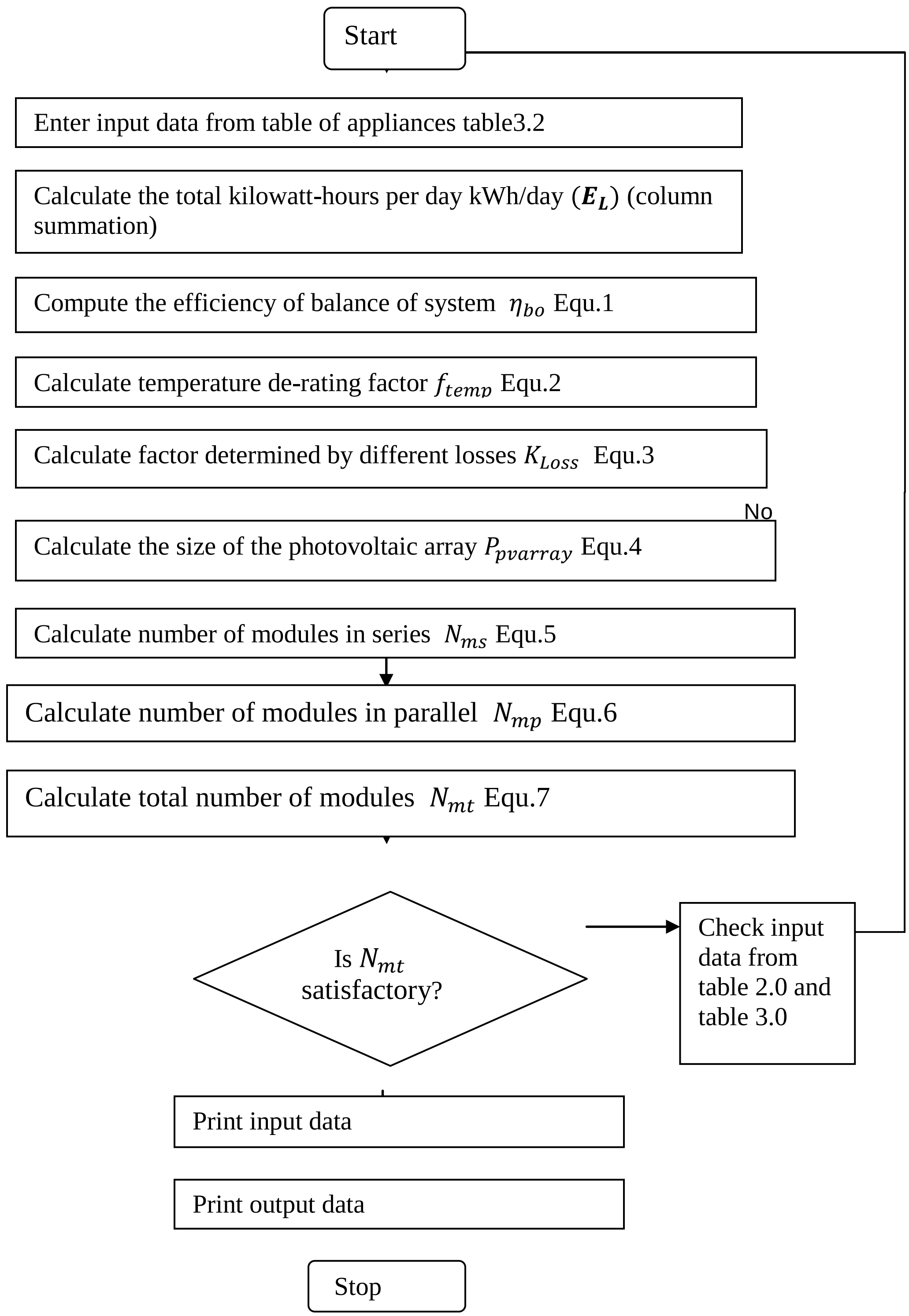

Figure 2.0 Flow Chart for PV Array Sizing

2.13 Determination of the System Cables Sizes
Selecting the correct size and type of wire will enhance the performance and reliability of photovoltaic system. The dc-wires between the photovoltaic modules and batteries through the voltage regulator must withstand the maximum current produced by these modules. This current is given by equation 14.

$$I_{rated} = N_{mp} \times I_{sc} \times \int_{safety} \quad (14)$$

$$I_{rated} = 48 \times 5.38 \times 1.25 = 323\text{ A}$$

The cross sectional area of the cable is given by equation 15.

$$A = \frac{\rho l I}{V_d} \times 2 \quad (15)$$

ρ = resistivity of copper wire which is taken as $1.724 \times 10^{-8}\Omega m$ (AWG)

In both AC and DC wiring for standalone photovoltaic system the voltage drop is taken not to exceed 4% value (NABCEP, 2005)

2.14 Determination of Cable Size for PV Modules through the Batteries Voltage Regulators

Maximum voltage drop $V_{d=} \frac{4}{100} \times 24V = 0.96V$

Let the length of the cable (l) = 1m

From equation (15)

$$A = \frac{\rho l I}{V_d} \times 2$$

$$A = \frac{1.724 \times 10^{-8} \times 1 \times 323}{0.96} \times 2 = 11.60mm^2$$

This means any copper cable of cross sectional area11.60mm^2, 323 A and resistivity $1.724 \times 10^{-8}\Omega m$ can be used for the wiring between PV modules and batteries through the voltage regulator.

2.15 Determination of Cables Size between the Battery Bank and the Inverter
Let the length of the cable (l) = 5m

The maximum current from battery at full load supply is given by I_{max} which is shown in equation 16 as:

$$I_{max} = \frac{\text{Inverter kVA}}{\eta_{inverter} \times V_{system}} \quad (16)$$

$$= \frac{14kVA}{0.85 \times 48} = 343A$$

Maximum voltage drop $V_{d=} \frac{4}{100} \times 48 = 1.92V$

$$A = \frac{1.724 \times 10^{-8} \times 5 \times 343}{1.92} \times 2 = 30mm^2$$

This means any copper cable of cross sectional area of 30mm^2, 343 A and resistivity $1.724 \times 10^{-8}\Omega m$ can be used for the wiring between the battery bank and the inverter.

2.16 Determination of Cable Size between the Inverter and the Load
Let the maximum length of cable (l) = 20m

The maximum current from inverter at full load on the phase (line) is given by equation 17 as:

$$I_{phase} = \frac{\text{Inverter kVA}}{V_{output} \times \sqrt{3}} \quad (17)$$

$$= \frac{14kVA}{220 \times \sqrt{3}} = 37A$$

maximum voltage drop $V_{d=} \frac{4}{100} \times 220 = 8.8V$

$$A = \frac{1.724 \times 10^{-8} \times 20 \times 37}{8.8} \times 2 = 3mm^2$$

This means that any copper of cross sectional area 3mm^2, 37A and resistivity $1.724 \times 10^{-8}\Omega m$ can be used for the wiring between the inverter and the load.

Table 4.0 Results obtained from the Sizing of the Proposed Off-grid PV System.

Component	Description of Component	Result
Load Estimation	Total Estimated Load	556 kWh/day
PV Array	Capacity of PV array	17.35 kW
	Number of modules in series	2
	Number of modules in parallels	48
	Total number of modules	96
Battery Bank	Battery bank capacity	7268 Ah
	Number of batteries in series	4
	Number of batteries in parallel	6
	Total number of batteries required	24
Voltage Regulator	Capacity of voltage regulator	323 A
	Number of voltage regulators required	5
Inverter	Capacity of the inverter	14 kVA
Wires	Between PV modules and batteries through voltage regulators	323 A,11.60mm2
	Between battery bank and inverter	343 A, 30 mm2
	Between inverter and load	37 A, 3 mm2

2.17 Cost Estimate of the System

The cost estimate of the system's components is summarized in Table 5.0

Table 5.0 Cost Estimate of the System's Components

Component	Model	Quantity	Unit price (Naira)	Cost per component (Naira)
Modules	ENP Sonne 180W, 24V	96	20 000	1 920 000
Batteries	ROLL12MD325P	22	15 000	330 000
Voltage Regulator	Xantrex C60	5	10 000	50 000
Inverter	SATCON 14kVA	1	12 000	12 000
SUBTOTAL				2 312 000
Other BOS Costs (wires, fuses, circuit breakers, etc)				462 400
TOTAL COST				**2 774 400**

Cost per Component = Quantity× Unit price

Other Balance of System Component (BOS) Cost = 20% of subtotal [9], [10]

The operating costs for solar PV installations are negligible, but the annual maintenance cost may amount to 0.5% to 1% of the capital cost of the system [9]

Maintenance cost of the PV system $= 0.5\%$ 0f $2\,774\,400 = N13\,872$

Overall cost of the system$= N2\,774\,400 + N13\,872 = N2\,788\,272$

2.18 Estimated Cost of the Fuel Generator used by the Faculty of Engineering BUK

The college has a 35kVA Caterpillar generator used to supplement power supply from the grid.

Hours used = 4 hours per day.

Total estimated hours used per annum $= 4 \times 365 = 1460$ hours

Total estimated fuel (diesel) consumption per hour $= 3$ litres per hour

Total estimated fuel consumption per annum $= 3 \times 1460 = 4380$ litres

Cost of diesel$=$ N160 per litre

Total estimated cost of fuel used per annum $= N160 \times 4380 = N700\,800$

Total estimated cost of maintenance per annum $= N10\,000.00$

Total running cost per annum $= N\,700\,800 + N10\,000 = N710\,800$

Cost of purchase of the fuel generator $= N55\,000$

Total estimated cost of the fuel the generator for the first year$= N710\,800 + N55\,000 = N765\,800$

2.19 Period

The payback period is given by equation 18 [11] as:

$$\text{Payback Period} = \frac{\text{Overal cost of the PV system}}{\text{Total estimated cost of the fuel generator for the first year}} \quad (18)$$

$$\text{Payback Period} = \frac{N2\,788\,272}{N765\,800} = 3.6\text{years}$$

3.0 Discussions

The daily electrical energy demand (load) by Faculty of Engineering Bayero University Kano was estimated based on the watt-hour energy demand of the appliances. The estimated load is 556 kWh/day. The proposed stand alone photovoltaic system was designed based on 10% of the estimated load. Based on the equipment selected for the design, a 17.35kW PV array capacity of 96 PV modules, 24 (12V, 325Ah) batteries, a 14kVA, 48V inverter and 5(60A, 24V) voltage regulators are needed to supply 10% of the estimated electrical energy demand by the faculty (Table 4.0). A computer program was developed for the system for easy sizing of the components of the system (PV array, voltage regulator, battery bank and the inverter).The proposed stand alone PV system requires copper wires of resistivity$1.724 \times 10^{-8}\Omega m$ andcross-sectional area 11.60mm2, 30 mm2 and 3 mm2 for its installation.It can be observed from Table 5.0 that the modules and the batteries are the two most costly components of a stand-alone photovoltaic system. Increasing the size of these components will increase the overall cost of the system. A cost estimate of the system provided in Table 5.0 shows that the initial cost of the system ($N2\,788\,272$) is relatively high but the payback period of the system is estimated to be 3.6 years, which is obviously much shorter than the lifespan of the selected PV modules which is 30 years [12]

4.0 Conclusions

In this paper, a stand-alone PV system was designed based on 10% of the Faculty of Engineering Bayero University Kano as a case study. Based on the equipment selected for the design, 96 PV modules, 24 batteries, an inverter and 5 voltage regulators are needed to supply 10% of the estimated electrical energy demand by the faculty. The use of computer had improved the speed and accuracy of the sizing. The cost estimate of the of the system $N2\,788\,272$ is relatively highwhen compared to that of fossil fuel generator used by the college but the payback period of the system is estimated to be 3.6 years, which is obviously much shorter than the lifespan of the selected PV modules of 30 years. In the long term, the implementation of a stand-alone PV system is both economically and environmentally preferable to fossil fuel generator because of its longer lifespan, minimal running cost and mitigation of environmental pollution.

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APPENDIX: COMPUTER PROGRAMME FOR THE PROPOSED STAND ALONE PV SYSTEM. PROGRAM PV

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C   A PROGRAM THAT DESIGN A STAND ALONE PV SYSTEM FOR FACULTY OF ENGINEERING, BAYERO
UNIVERSITY, KANO
              COMMON N, ND, I, K
              REAL P (11, 7), PKHD (11, 7), SUM1, SUM2, ETbo, ftemp, Kloss,
   + CVAL, CHVAL,EL, PRS, Irtd, Cx, T1, T2, T3, T4, T5, T6, T7, T8,
   + T11, T12, T13, T14, T15, TT1, TT2, TT3, TT4, TT5, TT6, TT7, TT8,
   + T21, T22, T23, T24, T25, Nms, Ppvar, Nmp, Nmt, Nbreq, Nbs, Nbp,
   + Nvreg, Ptot
              CHARACTER*20 FNAME, REPLY*1, AP*25, APP (11), DEPT (6), DDEPT
              INTEGER I, N, ND, K, U, RLEN
              PARAMETER (ETinv = 0.85, ETwlss = 0.90, Y = 0.0048,
   + Tclf = 45.0, TSTC = 25.0,fman = 0.97,  fdirt = 0.95,Htilt = 5.5,
   + PSI = 1.0, Vsyst = 120.00, Vmod = 24.00, Pmp = 180.0, NC = 5.0,
   + DODmx = 0.70, ETout = 0.85, Csltd = 375.0, Vbat = 12.0,
   + PLSC = 0, ISC = 5.38, fsfty = 1.25, Isltd = 60,
   + ftemp = 0.904,
   + U = 2, RLEN = 200)

C       CREATE A FILE FOR STORING OUTPUT FROM THIS PROGRAM
              PRINT*, 'PLEASE, ENTER OUTPUT FILE NAME (ANY NAME, NOT MORE
   + THAN 10 CHARACTERS LONG AND STARTING WITH AN ALPHABET)'
              READ*, FNAME

C       CREAT THE INPUT TABLES

3             PRINT*, 'PLEASE, ENTER THE NUMBER OF APPLIANCES, N AND THE
   + NUMBER OF DEPARTMENTS IN THE FACULTY, ND, SEPARATED BY A COMMA'
              READ*, N, ND
              DO 4 I = 1, N
              PRINT*, 'ENTER THE NAME OF APPLIANCE NUMBER', I
              READ*, AP
              APP (I) = AP

4             CONTINUE

C             CREATE HEADER NOW
              DO 5 K =1, ND
              PRINT*, 'ENTER THE NAME OF DEPARTMENT NUMBER', K
              READ*, DDEPT
              DEPT (K) = DDEPT

5             CONTINUE

C       CREATION OF TABLE 2.0 BELOW
              DO 7 K = 1, ND
              DO 6 I = 1, N
              PRINT*, 'ENTER THE ENERGY DEMAND (IN kW) FOR APPLIANCE
   + NUMBER', I, 'FOR DEPARTMENT NUMBER', K
              READ*, CVAL
              P (I, K) = CVAL

6             CONTINUE

7             CONTINUE
              T1 = P (1, 1) + P (1, 2) + P (1, 3) +P (1, 4) + P (1, 5)
              T2 = P (2, 1) + P (2, 2) + P (2, 3) +P (2, 4) + P (2, 5)
              T3 = P (3, 1) + P (3, 2) + P (3, 3) +P (3, 4) + P (3, 5)
              T4 = P (4, 1) + P (4, 2) + P (4, 3) +P (4, 4) + P (4, 5)
```

```
                T5 = P (5, 1) + P (5, 2) + P (5, 3) +P (5, 4) + P (5, 5)
                T6 = P (6, 1) + P (6, 2) + P (6, 3) +P (6, 4) + P (6, 5)
                T7 = P (7, 1) + P (7, 2) + P (7, 3) +P (7, 4) + P (7, 5)
                T8 = P (8, 1) + P (8, 2) + P (8, 3) +P (8, 4) + P (8, 5)
                T9 = P (9, 1) + P (9, 2) + P (9, 3) +P (9, 4) + P (9, 5)
                T10 = P (10, 1) + P (10, 2) + P (10, 3) +P (10, 4) + P (10, 5)
                T11 = P (1, 1) + P (2, 1) + P (3, 1) +P (4, 1) + P (5, 1)+
  + P (6, 1) + P (7, 1) + P (8, 1) + P (9, 1) + P (10, 1)
                T12 = P (1, 2) + P (2, 2) + P (3, 2) +P (4, 2) + P (5, 2)+
  + P (6, 2) + P (7, 2) + P (8, 2) + P (9, 2) + P (10, 2)
                T13 = P (1, 3) + P (2, 3) + P (3, 3) +P (4, 3) + P (5, 3)+
  + P (6, 3) + P (7, 3) + P (8, 3) + P (9, 3) + P (10, 3)
                T14 = P (1, 4) + P (2, 4) + P (3, 4) +P (4, 4) + P (5, 4)+
  + P (6, 4) + P (7, 4) + P (8, 4) + P (9, 4) + P (10, 4)
                T15 = P (1, 5) + P (2, 5) + P (3, 5) +P (4, 5) + P (5, 5)+
  + P (6, 5) + P (7, 5) + P (8, 5) + P (9, 5) + P (10, 5)
                PRS = T1+T2+T3+T4+T5+T6+T7+T8+T9+T10

C       NOW, CREATION OF TABLE 3.0
                DO 9 K = 1, ND
                DO 8 I = 1, N
                PRINT*, 'ENTER THE ENERGY DEMAND (INkWh/day) FOR APPLIANCE
  + NUMBER', I, 'FOR DEPARTMENT NUMBER', K
                READ*, CHVAL
                PKHD (I, K) = CHVAL

8               CONTINUE

9               CONTINUE
                TT1 = PKHD (1, 1) + PKHD (1, 2) + PKHD (1, 3) +PKHD (1, 4) +
  + PKHD (1, 5)
                TT2 = PKHD (2, 1) + PKHD (2, 2) + PKHD (2, 3) +PKHD (2, 4) +
  + PKHD (2, 5)
                TT3 = PKHD (3, 1) + PKHD (3, 2) + PKHD (3, 3) +PKHD (3, 4) +
  + PKHD (3, 5)
                TT4 = PKHD (4, 1) + PKHD (4, 2) + PKHD (4, 3) +PKHD (4, 4) +
  + PKHD (4, 5)
                TT5 = PKHD (5, 1) + PKHD (5, 2) + PKHD (5, 3) +PKHD (5, 4) +
  + PKHD (5, 5)
                TT6 = PKHD (6, 1) + PKHD (6, 2) + PKHD (6, 3) +PKHD (6, 4) +
  + PKHD (6, 5)
                TT7 = PKHD (7, 1) + PKHD (7, 2) + PKHD (7, 3) +PKHD (7, 4) +
  + PKHD (7, 5)
                TT8 = PKHD (8, 1) + PKHD (8, 2) + PKHD (8, 3) +PKHD (8, 4) +
  + PKHD (8, 5)
                TT9 = PKHD (9, 1) + PKHD (9, 2) + PKHD (9, 3) +PKHD (9, 4) +
  + PKHD (9, 5)
                TT10 = PKHD (10, 1) + PKHD (10, 2) + PKHD (10, 3)
  + +PKHD (10, 4) + PKHD (10, 5)
                T21 = PKHD (1, 1) + PKHD (2, 1) + PKHD (3, 1) +PKHD (4, 1) +
  + PKHD (5, 1)+ PKHD (6, 1) +PKHD (7, 1)+ PKHD (8, 1) + PKHD (9, 1)
  + + PKHD (10, 1)
                T22 = PKHD (1, 2) + PKHD (2, 2) + PKHD (3, 2) +PKHD (4, 2) +
  + PKHD (5, 2) + PKHD (6, 2) +PKHD (7, 2)+ PKHD (8, 2) + PKHD (9, 2)
  + + PKHD (10, 2)
                T23 = PKHD (1, 3) + PKHD (2, 3) + PKHD (3, 3) +PKHD (4, 3) +
  + PKHD (5, 3)+ PKHD (6, 3) +PKHD (7, 3)+ PKHD (8, 3) + PKHD (9, 3)
  + + PKHD (10, 3)
                T24 = PKHD (1, 4) + PKHD (2, 4) + PKHD (3, 4) +PKHD (4, 4) +
  + PKHD (5, 4)+ PKHD (6, 4) +PKHD (7, 4)+ PKHD (8, 4) + PKHD (9, 4)
  + + PKHD (10, 4)
                T25 = PKHD (1, 5) + PKHD (2, 5) + PKHD (3, 5) +PKHD (4, 5) +
  + PKHD (5, 5)+ PKHD (6, 5) +PKHD (7, 5)+ PKHD (8, 5) + PKHD (9, 5)
```

```
    + + PKHD (10, 5)
          EL=TT1+TT2+TT3+TT4+TT5+TT6+TT7+TT8+TT9+TT10

C     COMPUTATIONS
          ETbo = ETinv * ETwlss
          ftemp = 1 - (Y * (Tclf - TSTC))
          Kloss = fman * ftemp * fdirt
          Ppvar = (EL / (ETbo * Kloss * Htilt)) *0.1* PSI
          Nms = Vsyst / Vmod
          Nmp = (Ppvar *1000.000) / (Nms * Pmp)
          Nmt = Nmp * Nms
          PRINT*, 'EL =', EL, 'PRS =', PRS
          PRINT*, 'Nmt =', Nmt
          PRINT*, 'IS THE VALUE OF Nmt SATISFACTORY? PRESS "Y" FOR YES
    + AND "N" FOR NO'
          READ*, REPLY
          IF (REPLY .EQ. 'N') THEN
          PRINT*, 'THEN RE-ENTER INPUT VALUES'
          GOTO 3
          ELSE
          END IF

10        Cx = (NC * EL * 1000.000)*0.1 / (DODmx * Vsyst * ETout)
          Nbreq = Cx / Csltd
          Nbs = Vsyst / Vbat
          Nbp = Nbreq / Nbs
          PRINT*, 'Nbp =', Nbp
          PRINT*, 'IS THE VALUE OF Nbp SATISFACTORY?
    + PRESS "Y" FOR YES AND "N" FOR NO'
          READ*, REPLY
          IF (REPLY .EQ. 'N') THEN
          PRINT*, 'THEN RE-ENTER INPUT VALUES'
          GOTO 3
          ELSE
          END IF
               Irtd = Nmp * ISC * fsfty
               Nvreg = Irtd / Isltd
      PRINT*, 'Nvreg =', Nvreg
          PRINT*, 'IS THE VALUE OF Nvreg SATISFACTORY? PRESS "Y" FOR YES
    + AND "N" FOR NO'
          READ*, REPLY
          IF (REPLY .EQ. 'N') THEN
          PRINT*, 'THEN RE-ENTER INPUT VALUES'
          GOTO 3
          ELSE
          END IF

12        Ptot = ((PRS + (PLSC*3)) *0.1* 1.25
          PRINT*, 'Ptot =', Ptot
          PRINT*, 'IS THE VALUE OF Ptot SATISFACTORY? PRESS "Y" FOR YES
    + AND "N" FOR NO'
          READ*, REPLY
          IF (REPLY .EQ. 'N') THEN
          PRINT*, 'THEN RE-ENTER INPUT VALUES'
          GOTO 3
          ELSE
          END IF

C     INPUTS AND OUTPUTS

13    OPEN (UNIT= U, FILE= FNAME, STATUS= 'NEW', ACCESS='SEQUENTIAL',
+  FORM = 'FORMATTED', BLANK = 'NULL', RECL = RLEN)
          WRITE (2, *) ' '
```

```
            WRITE (2, *) ' '
            WRITE (2, *) '____________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, *) '          INPUT PARAMETERS'
            WRITE (2, *) ' ETinv = 0.85, ETwlss = 0.90, Y=0.48, Tclf =
+ 45, TSTC = 25, fman = 0.97, ftemp = 0.904, fdirt = 0.95'
            WRITE (2, *) 'Htilt = 5.5, PSI = 1, Vsyst = 120, Vmod = 24,
+ Pmp = 180, NC = 5, DODmx = 0.70, ETout = 0.85'
            WRITE (2, *) 'Csltd = 375, Vbat = 12, ISC = 5.38,
+ fsfty = 1.25, Isltd = 60, PLSC = 0
            WRITE (2, *) ' '
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, *) '          INPUT DATA'
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, *) ' TABLE 2.0: Estimated Energy Demand
+ Per AppliancePer Department in kW'
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, 30) 'APPLIANCES', 'ENERGY DEMAND IN kW'
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, 40) (DEPT(K), K = 1, ND), 'TOTAL'
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, 50) APP (1), P (1, 1), P (1, 2), P (1, 3), P (1, 4),
+ P (1, 5), T1
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, 50) APP (2), P (2, 1), P (2, 2), P (2, 3), P (2, 4),
+ P (2, 5), T2
            WRITE (2, *) ' '
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, 50) APP (3), P (3, 1), P (3, 2), P (3, 3), P (3, 4),
+ P (3, 5), T3
            WRITE (2, *) ' '
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, 50) APP (4), P (4, 1), P (4, 2), P (4, 3), P (4, 4),
+ P (4, 5), T4
            WRITE (2, *) ' '
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, 50) APP (5), P (5, 1), P (5, 2), P (5, 3), P (5, 4),
+ P (5, 5), T5
            WRITE (2, *) ' '
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
            WRITE (2, *) ' '
            WRITE (2, 50) APP (6), P (6, 1), P (6, 2), P (6, 3), P (6, 4),
+ P (6, 5), T6
            WRITE (2, *) ' '
            WRITE (2, *) '_______________________________________________________
+ ________________________________________________________________'
```

```
          WRITE (2, *) ' '
          WRITE (2, 50) APP (7), P (7, 1), P (7, 2), P (7, 3), P (7, 4),
     + P (7, 5), T7
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (8), P (8, 1), P (8, 2), P (8, 3), P (8, 4),
     + P (8, 5), T8
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (9), P (9, 1), P (9, 2), P (9, 3), P (9, 4),
     + P (9, 5), T9
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (10), P (10, 1), P (10, 2), P (10, 3),
     + P (10, 4), P (10, 5), T10
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) 'TOTAL', T11, T12, T13, T14, T15, PRS
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, *) ' TABLE3. 6: Estimated Energy Demand Per
   + Appliance Per Department in kWh/day'
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'

          WRITE (2, 30) 'APPLIANCES', 'ENERGY DEMAND IN kWh/day'
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, 40) (DEPT(K), K = 1, ND), 'TOTAL'
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (1), PKHD (1, 1), PKHD (1, 2), PKHD (1, 3),
     + PKHD (1, 4), PKHD (1, 5), TT1
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (2), PKHD (2, 1), PKHD (2, 2), PKHD (2, 3),
     + PKHD (2, 4), PKHD (2, 5), TT2
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) '
          WRITE (2, 50) APP (3), PKHD (3, 1), PKHD (3, 2), PKHD (3, 3),
     + PKHD (3, 4), PKHD (3, 5), TT3
          WRITE (2, *) ' '
          WRITE (2, *) '__________________________________________________
     + ____________________________________________________________'
          WRITE (2, *) ' '
```

```
          WRITE (2, 50) APP (4), PKHD (4, 1), PKHD (4, 2), PKHD (4, 3),
+ PKHD (4, 4), PKHD (4, 5), TT4
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ______________________________________________'

          WRITE (2, *) ' '
          WRITE (2, 50) APP (5), PKHD (5, 1), PKHD (5, 2), PKHD (5, 3),
+ PKHD (5, 4), PKHD (5, 5), TT5
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (6), PKHD (6, 1), PKHD (6, 2), PKHD (6, 3),
+ PKHD (6, 4), PKHD (6, 5), TT6
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (7), PKHD (7, 1), PKHD (7, 2), PKHD (7, 3),
+ PKHD (7, 4), PKHD (7, 5), TT7
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (8), PKHD (8, 1), PKHD (8, 2), PKHD (8, 3),
+ PKHD (8, 4), PKHD (8, 5), TT8
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) APP (9), PKHD (9, 1), PKHD (9, 2), PKHD (9, 3),
+ PKHD (9, 4), PKHD (9, 5), TT9
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
                 WRITE (2, *) ' '
          WRITE (2, 50) APP (10), PKHD (10, 1), PKHD (10, 2),
+ PKHD (10, 3), PKHD (10, 4), PKHD (10, 5), TT10
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, 50) 'TOTAL', T21, T22, T23, T24, T25, EL
          WRITE (2, *) ' '
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, *) '            OUTPUT'
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) 'ETbo =', Etbo, 'ftemp =', Ftemp, 'Kloss =',
+ Kloss, 'Ppvar =', Ppvar
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) ' '
          WRITE (2, *)'Nms =', Nms, 'Nmp =', Nmp, 'Nmt =', Nmt
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
          WRITE (2, *) 'Cx =', Cx, 'Nbreq =', Nbreq, 'Nbs =', Nbs,
+ 'Nbp =', Nbp, 'Irtd =', Irtd, 'Nvreg =', Nvreg
          WRITE (2, *) '___________________________________________________
+ ____________________________________________________________'
```

```
      WRITE (2, *) ' '
      WRITE (2, *) '______________________________________________________
     + _____________________________________________________________'
      WRITE (2,60) Irtd
      WRITE (2, *) 'Ptot =', Ptot
      WRITE (2, *) '______________________________________________________
     + _____________________________________________________________'
      WRITE (2, *) ' '
30    FORMAT (A17, 20X, A46)
40    FORMAT (21X, A16, 2X, A10, 2X, A15, 2X, A15, 2X, A16, 2X, A6)
50    FORMAT (A25, 4X, F8.3, 5X, F8.3, 5X, F8.3, 10X, F8.3, 11X,
     + F8.3, 7X, F8.3)
60    FORMAT (F10.3)
      CLOSE (U)
      END
```