Available online at http://scik.org
J. Math. Comput. Sci. 10 (2020), No. 5, 1808-1833
https://doi.org/10.28919/jmcs/4775
ISSN: 1927-5307

AN EFFECTIVE ENERGY SAVING DESIGN STRATEGY TO MAXIMIZE THE USE OF ELECTRICITY

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Abstract. Electrical service design is an important aspect of modern building constructions. The purpose of this paper is to give a convenient and economical approach to electrical service design in order to save energy. This paper designed and analyzed the internal electrical services of a duplex that included the lighting, generator power source and inverter sizing design which has been absent in most designs. The design parameters were modeled to meet the economic standards; hence specific values were given to different equipment. The result of the whole analysis and design was depicted in an AutoCAD format and it is seen that the design resulted in lesser energy consumption as compared to previous research. Though internal electrical services design might be a tedious process, but with this approach the process was made less demanding and easy. The work described is of tutorial significance.

Keywords: AutoCAD; generator power; inverter; modelling; saving energy.

2010 AMS Subject Classification: 91B74, 93A30.

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Received June 15, 2020

1. INTRODUCTION

Energy efficiency improvement can be clearly seen in the energy consumed homes in developing countries such as Cameroon and Nigeria. The improper electrical installation in buildings today is causing problems to the end users. This is very risky and can lead to loss of life and property and needs to be prevented. Due to these issues, there is a need for appropriate design of electrical installation for all purposes (i.e. residential, commercial and industrial holdings) to be adhered to, in order to help in the eradication. The energy efficiency has proved to be a cost-effective strategy for residential buildings without necessarily increasing energy consumption.

Modern appliances such as freezers, ovens, dryers etc, use significantly less energy than older appliances. Energy efficient refrigerators, for example, use forty percent less energy than conventional models did in 2001. For this reason, if all households in Europe changed ten-year old and above appliances to new ones, 20 billion kWh of electrical energy would be saved annually [1]. Equipment/facilities that might be found in homes include air conditioners, fans, adequate lighting, refrigerators, electric cookers, water heaters etc. For all of these equipment/facilities to be put into use, adequate electric power supply has to be available in the building with proper sizes of conductors and accessories [2]. Electrical designs are implemented according to the type of building needed.

The engineer carries out design calculations that would help in drawing an electric plan for the structure, showing the fittings and also provide protection schemes for the building and equipment. It also gives the types of materials to be used and the cost of the whole installation. This paper gives a proper design modeling for energy efficiency, aimed at designing electrical serving for a duplex that would be cost effective.

The objectives of the study are as follows:

(a) to show the location of different loads in the building and hence calculate the estimated total load drawn by a building.

(b) to carry out calculation for alternative power supply that can be used in case of power outage.

(c) to conduct a standard inverter sizing for the design.

(d) to install smart systems that will automatically turn off some appliances when not in use to save energy and

(e) to compute a comprehensive BEME for the installation.

It is important to note that this paper is limited to a duplex in Binshua Village in Donga Mantung Division of Cameroon and may not be appropriate for any other type of building such as a church or industrial building. This is because every designed project has different features and varying regulations might apply. Also, this paper is restricted to the use of Computer Aided Design (CAD) and not the conventional paper and pencil drawing. The design software to be used is the AUTOCAD 2016 version.

2. Some Related Works

Since the inception of electricity as a means to ease life and also as a result of damage to life and property that emanates from improper electrical installation, electrical design has been in existence to guide engineers in the electrical installation process. Electrical design has evolved over the decades from using scratch paper, to draft schematics, to the use of CAD software.

a) The handmade diagram age: The original wiring diagram was simply a crude graphical diagram with every component visually represented on drafting paper. This allowed the engineer to see the outline of the entire design and how they are interconnected [3].

b) The digital age with CAD Software: The digital age's progression has developed CAD software, with advanced features, to aid electrical engineers in their design process. The development of CAD programs has even made virtual modelling for components much easier than traditional old school drafters making blue prints [3].

2.1 Literature Review

According to Ejele [4], a hostel designed about forty years ago in the University of Nigeria, Nsukka was redesigned using AutoCAD because the building was old and needed some renovation work. A Bill of Engineering Measurement and Evaluation (BEME) were made after the design. The number of lightening points was calculated and shown in the design. The work did consider the use of energy saving equipment hence the total load drawn was very high.

According to Adeshina [5], a two bedroom twin flat residential building was designed. The work only included the calculations for the lighting points and the voltage drop in the cable. The work however did not make provision for the sizing and load balancing of the distribution board. Also there was no design for the rating of the generator to be used in the work.

In a project carried out by Eze [6], a 2-storey office building was designed using the AutoCAD software and the calculations for the total load and lighting point was done. Also, calculations were done to choose the correct rating for the choice of generator in case of power failure. However, the design did not account for the use of an inverter and the rating of the inverter in case a generator is not selected as the choice of alternative power supply.

In summary, it is seen that the reviewed works, the calculations for the number of lighting points were done correctly and that is the formula to be used in the proposed design. Also in the designs, the correct sizes of cables and distribution boards were used and the BEME was done correctly. But, hardly was any reference made to the relevant IEE regulations [7] to further stress the need for obeying regulations during electrical installation. Also, the works that included inverters did not show how the inverter can be properly sized, they just stated only the ratings of inverters to be installed. These are the gaps that will be exploited in this design. Also, the proposed design will include a smart design for the duplex such that when some appliances are not in use, they will be automatically turned off.

2.2 Design Related Modeling of Cable Selection

A cable is a length of insulated single conductor or two or more of such conductors, each provided with its own insulation which are laid up together. There are different types of cables, some of which are discussed below:

a) Poly vinyl chloride (PVC) cable: this cable is a thermo plastic cable as its insulation softens at temperatures above about 70^0C. The insulation (PVC) is manmade, tough, incombustible, and chemically none reactive and does not deteriorate with age. Thus, it is recommended for this paper.

b) Multi-core cable: This cable is made up of two or more insulated conductors with protective covering.

c) Tough rubber sheathed (TRS) cable: This is made of specially toughened rubber which is resistant to acid and alkaline.

d) Neoprene cable: Its insulation is similar to TRS and capable of withstanding direct sunlight and most weather conditions.

e) Heat resisting, oil resisting and flame retardant cable: These are used in conditions damaging to PVC cables [8].

Cables can carry loads according to its size so proper sizing of the cables to be used in electrical design is very important for the reliability of the entire network. Once the load current is known, using an ambient temperature of 30^0C, the size of the cable can be determined as shown in Table 1 [9].

Table 1: Current rating for PVC cable enclosed in conduit on a wall at 30^0C

Cross Sectional Area (MM^2)	Two Cables Single Phase (A)	Voltage Drop (mV/A/M)	Three Cables Three Phase (A)	Voltage Drop (mV/ A/M)
1	13.5	44	12	38
1.5	17.5	29	15.5	25
2.5	24	18	21	15
4	32	11	28	9.5
6	41	7.3	36	6.4
10	57	4.4	50	3.8
25	101	1.80	89	1.55
35	125	1.30	110	1.10
50	151	1.00	134	0.85
70	192	0.72	171	0.61
95	232	0.56	207	0.48

To ensure that the heat generated by the load during operation is properly dissipated without damage to the cable, it is also important to multiply the current carrying capacity of the cable by the temperature factors given in Table 2 [10].

Table 2: Correction Factors (Operating Temperature 70^{0}C).

Ambient Temperature (^{0}C)	25	30	35	40	45	50	55	60	65
Correction Factor	1.03	1.00	0.94	0.87	0.79	0.71	0.61	0.50	0.35

If the ambient temperature of the area where the cable is used is below or above 30^{0}C but within 25^{0}C and 65^{0}C the current rating of the Table is multiplied by the correction factor to give a new current rating I_C:

$$I_{nc} = I_{oc} \times k \qquad (1)$$

where; I_{nc} = New current rating , I_{oc} = Old current rating and k = Correction factor

Finally, the voltage drop in the cable is calculated. The voltage drop at any point of supply between the power supply terminal and installation should not be more than 2.5% [11] of the supply voltage. This means that for a 240V supply the voltage drop should not be more than 6V. Voltage drop, V_D is calculated using equation (2):

$$V_D = L_C \times V_{DM} \times I_{nc} \qquad (2)$$

where; V_D = Voltage Drop, L_C = Length of circuit , V_{DM} = Voltage drop per meter & I_{nc} = New current rating

If the voltage drop obtained is less than or equal to 6V [12], the cable can be used but if it is greater than 6V, another cable must be used.

Despite the formulas used to calculate cable sizes, lighting is always carried out using 1.5mm^2 cables and power circuits to socket outlets using 2.5mm^2 or 4mm^2 cables. Cooker circuits, water heaters, and other large current-using equipment use 6.0mm^2 or 10mm^2 or 16mm^2 cables [6]. This is a standard that has been accepted generally and will be used in the proposed design.

2.3 Design Related Modeling of Illumination and Lightning

Light is that radiant energy which produces a sensation of vision upon the human eye. Illumination can be defined as the luminous flux received per unit area and luminous flux is the light energy radiated per second from a luminous body. Different buildings/rooms have different illumination levels as shown in Table 3 [13]. This is to prevent glare or dark areas and to ensure that activities are carried out properly without endangering the human eye and preventing accidents.

Table 3: Recommended Indoor Lightening Levels

Home Space	Illumination (lux)
Bedrooms	150
Living rooms	250
Internal corridors	200
Public areas	Illumination (lux)
Entrance lobbies	200
Public corridors	200
Stairwells	200
Support spaces	Illumination (Lux)
Toilets	200
Communication rooms	200
Electrical/generator rooms	200
Specialty areas	Illumination (Lux)
Kitchen	500
Dining areas	150-200

In order to adhere to the recommended lightening levels when designing illumination for buildings, a suitable color of light should be chosen and also the number and wattage of bulbs to be used per room and the spacing of the bulbs is calculated.

The formula for calculating the total output lumen required in a room is as shown in equation (3) [14]:

$$L = \frac{I_L \times A}{M_f \times C_u} \tag{3}$$

where; L = Lumen, I_L = Illumination (lux), A = Area of working space (m.sq), M_f = Maintenance Factor and C_u = Co-efficient of Utilization

The formulas for calculating the total number of lamps needed in a room is as shown in equation (4) and (5):

$$L_p = \frac{I_L \times A}{L \times C_u \times M_f} \tag{4}$$

$$L_P = \frac{P_t}{P_L} \tag{5}$$

where; L_p = Number of lamps, P_t = Total lamp power (watts), P_L = Power of each lamp (watts).

The different brightness levels for different types of bulbs and the power they consume can be seen from Table 4. This Table is very instrumental in the choice of bulb to be used in any electrical design.

Table 4: Energy consumption chart for different bulbs

Brightness (Lumen)	**220+ (Watts)**	**400+ (Watts)**	**700+ (Watts)**	**900+ (Watts)**	**1300+ (Watts)**
Incandescent	25	40	60	75	10
Halogen	18	28	42	53	70
Compact Florescent Lamp	6	9	12	15	20
LED	4	6	10	13	18

Light Emitting Diode (LED) bulbs will be used in this paper, as they have higher lighting efficiency, generate less heat and consume less energy than other indoor lamps.

2.4 Design Related Modeling of Selection of Distribution Board

The current rating of the distribution board is obtained from the total current of the building or area which the distribution board is going to be supplying. The current can be obtained by first applying diversity factor to the power demand of the building/area and then applying the formula in equation (6):

$$I = \frac{P}{1.73 \times V \times P_F} \tag{6}$$

where; P = power in watts, V = Voltage and P_F = power factor of 0.8

2.5 Design Modeling for Device Protection

(a) Circuit Breakers- A circuit breaker (CB) is a device which has a rating similar to that of a fuse and is about the same physical size as a fuse carrier of the same rating. Circuit breakers are preferred to fuses because it resets to its initial state after tripping without the use of special tools. The CB has a toggle switch by which it can be operated manually. This switch is thrown into the off position when the overload device trips the breaker, and the CB is reset by the same switch. CBs can, therefore, combine the functions of switch and fuse, and in some cases this is a very useful and economical. The rating of circuit breaker to be used should be at least 100% greater than or equal to the design current of the circuit which it is connected to.

(b) Lightening Protectors- Over voltages can occur in an installation due to lightning strikes. A simple lightening protector system consists of an air terminal and a down conductor. The lightening protection system should be able to capture the lightning strike, channel it to the earth and dissipate the energy properly.

(c) Earthing- Earthing is the means by which parts of electrical circuits and accessible conductive parts of electrical equipment in the vicinity of an electrical installation are connected to the earth. Earthing protects people from electric shock as it provides a discharge path for fault current and also protects equipment from surges due to lightning strike. A solid copper grounding rod, also called grounding electrode, driven into the soil outside of the house and connected to the main electrical panel by a single earth-grounding wire is the primary method of earthing modern household electrical systems.

2.6 Design Modeling for Alternative Power Source and Diversity Factor

It is necessary for houses to have an alternative source of power due to the unreliability of most developing power system. It is important to use an alternative power supply with the correct ratings to ensure that all the equipment in the building would be accommodated. To get the current rating of the alternative source, equation (6) will be used where P will be the total power of the building. To get the power rating, the total power would be divided by a power factor of 0.8.

The diversity factor is the probability that a particular piece of equipment will come on at the time of the facility's peak load. It is very costly to add all connected loads when calculating full load current in an installation as not all the loads will be used at the same time. The formula for diversity factor is as shown in equation (7): (In some developed countries, the Average Diversity Maximum Demand (ADMD) figure of 1.5kW is used for design purposes)

$$D.F = \frac{A_L}{T_L} \times 100\% \qquad (7)$$

Where; $D.F$ = Diversity Factor, A_L = Actual connected load and T_L = Total load

The diversity factor for some circuits is shown in Table 5 [5]. This may be modified by the engineer responsible for the design or installation:

Table 5: Allowance for diversity

Purpose of circuit	**Individual household installation**	**Shops, stores, offices and business premises**	**Small hotels, boarding and guest houses**
Lighting	66% of total current demand	90% of total current demand	75% of total current demand
Socket outlets and stationary equipment	100% of current demand of largest point of utilization + 40% of current demand at every other point	100% of current demand at largest point of utilization + 75% of current demand at every other point	100% of current demand at largest point of utilization + 75% of current demand of every point in the main rooms(dining rooms, etc) + 40% of current demand at every other point of utilization
Heating and power	100% of total current demand up to 10A + 50% of demand in excess of 10A	100% of full load of largest appliance + 75% full load of others	

2.7 Rules and Regulations guiding Electrical Installations

There are regulations to which electrical installation must conform. This is to ensure that the installation is safe and reliable. The regulations used in Nigeria are produced by the Institution of Electrical Engineers (IEE) and are known as the IEE regulations [7]. These regulations are neither elements of a statutory document nor would a criminal charge be brought for compliance failure. However, it would be unwise to neglect these guidelines as that might suggest incompetence on the part of the designer [15].

2.8 Electrical Design Systems and Wiring Methods

There are various arrangements of circuit and socket outlets that can be used in electrical design such as:

- Ring Circuit:- It starts at one distribution board, runs through a number of outlets and returns to the distribution board it started from [6].
- Radial Circuit:- This circuit starts at the distribution board, runs through a number of outlets and does not return to the distribution board.

The recommended types of internal wiring usually used are:

(i)Cleat wiring: This system of wiring comprises of ordinary insulated wires (occasionally, sheathed and weather proof cable) braided and compounded held on walls or ceilings by means of porcelain cleats, Plastic or wood. Cleat wiring system is a temporary wiring system therefore it is not suitable for domestic premises.

(ii) Wooden casing and capping wiring: Casing and Capping wiring system was famous wiring system in the past but, it is considered obsolete this days because of Conduit and sheathed wiring system. The cables were carried through the wooden casing enclosures. The casing is made up of a strip of wood with parallel grooves cut length wise so as to accommodate the cables.

(iii) Tough rubber sheathed (TRS) or poly vinyl chloride sheath wiring: Single core or double core or three core TRS cables with a circular oval shape cables are used in this kind of wiring. Mostly, single core cables are preferred. TRS cables are chemical proof, water proof, steam proof, but are slightly affected by lubricating oil. The TRS cables are run on straight teak wood batten with at least a thickness of 10mm.

(iv)Lead sheathed or metal-sheathed wiring: The type of wiring employs conductors that are insulated and covered with an outer sheath of lead aluminum alloy containing about 95% of lead. The metal sheath gives protection to cables from mechanical damage, moisture and atmospheric corrosion. The whole lead covering is made electrically continuous and is connected to earth at the point of entry to protect against electrolytic action due to leaking current and to provide safety. The cables are laid on wooden batten and fixed by means of link clips just as in tough rubber sheathed wiring.

(v) Conduit wiring: There are two types of conduit wiring according to pipe installation; Surface conduit wiring and concealed conduit wiring. If conduits are installed on the roof or wall, it is known as surface conduit wiring and if the conduit is hidden inside the wall slots with the help of plastering, it is called concealed conduit wiring [16]. The concealed conduit wiring method is the method that will be employed in this design.

2.9 Energy Saving Techniques

The following are some of the energy saving techniques that can be employed in electrical service design:

(i) Smart Thermostats: A step beyond the programmable thermostat, the new smart thermostats learn how and when the family uses the heating and air-conditioning system and follows the patterns for smartest energy savings. Since forty percent of home’s overall energy bill comes from heating and cooling, this system is a great way to make a huge difference with a little investment.

(ii) LED Lighting: Of all the energy-efficient lighting available, LED bulbs offer the brightest light for the least price. Halogen and Compact fluorescents are not well received among consumers for several reasons. LED is a good alternative, providing a consistent light for little money and they are safe.

(iii) Energy Management Systems: These systems allow one to control the entire home via remote control. The lights, stereo, heating and air system, appliances and security system can all be controlled from his/her remote or smart phone.

(iv) Charging Stations: One common cause of energy waste around the home is phantom power. This results from electronics that are plugged in but not turned on, sucking as much as eight percent of a home's power for nothing. Charging stations are available which automatically turn off and stop phantom power leaks when phones or other associated devices are fully charged.

(v) Smart Power Strips: Instead of having to unplug umpteen appliances and electronics around the house every night, consider a smart power strip that cuts phantom power from anything plugged into it. This is ideal for hard to reach plugs on the floor, in the back of the kitchen counter, under the computer desk and behind the television [17, 18].

These gadgets vary in price, but all are able to save the owner enough money on the power bill to justify the purchase price. All the above techniques will be applied in this design except the energy management system [19-21].

3. IMPLIMENTATION

The total load demand of the proposed building is estimated and this is used to design the distribution boards on each floor and also the load is balanced in the distribution board. The number of lighting points in each room is calculated. The estimated total load is used to determine the rating of the alternative source of power supply to be used. This could be a generator or an inverter. The proposed building, duplex, has two floors (ground and first floor). The ground floor has 2 rooms, 2 toilets, the kitchen, laundry room, living room, store room and dining. The first floor has 6 bedrooms (4 bedrooms, 2 master bedrooms), 4 toilets and a sit-out. Details are shown in appendix I.

3.1 Distribution Board Selection

To determine the rating of the distribution board, equation (9) is used. The total load on the ground and first floors are shown in Tables 6 and 7 respectively. With this knowledge, the total load can be calculated.

Table 6: Load summary for the ground floor

S/N	DESCRIPTION	LOAD (WATTS)	DIVERSITY FACTOR	LOAD (WATTS)
1	26 lighting points of 24 watts	624	0.7	438.6
2	10 lighting points of 11 watts	110	0.7	77
3	8 15A sockets of 1500 watts	12000	1	12,000
4	10 13A sockets of 300 watts	3000	0.6	1800
5	5 fans of 100 watts	500	0.7	350
TOTAL LOAD				14,815

The distribution board rating is given by equation (9):

$$DB_R = \frac{T_{LD}}{\sqrt{3} \times V_L \times PF} \tag{9}$$

where; DB_R = Distribution Board Rating, T_{LD} = Total Load, V_L = Line Voltage and PF = Power Factor

$$DB_R = \frac{14{,}815}{\sqrt{3} \times 415 \times 0.8} = 26 Amps$$

Hence, a 30A distribution board can be used for the ground floor.

Table 7: shows the load summary for the first floor

S/N	Description	Load (Watts)	Diversity Factor	Load (Watts)
1	20 lighting points of 24 watts	480	0.7	336
2	6 15A sockets of 1500 watts	9000	1	9,000
3	15 13A sockets of 300 watts	4500	0.6	2700
5	6 fans of 100 watts	600	0.7	420
TOTAL LOAD				12,454

$$DB_R = \frac{12{,}454}{\sqrt{3} \times 415 \times 0.8} = 22 Amps$$

Hence, a 30A distribution board can be used for the first floor.

For the Moulded Case Circuit Breaker (MCCB), the rating to be used is 30A + 30A = 60A

For the design, a 30A, 6-way distribution board is for each floor. The load is evenly balanced among the phases in the distribution board. This is done to avoid over-loading of any of the phases.

3.2 Calculation for Alternative Power Source

To know the rating for the alternative source of energy, the total power demand for the whole building must be ascertained. The total power demanded for the whole building can be obtained from adding the power demand from each floor as seen in Table 8. The alternative power source could be a generator or an inverter.

- **GENERATOR**

The rating of the generator can be obtained from by using the value of the total load of the building. The total load is gotten by summing the loads of the ground and first floors.

Table 8: Load summary for the whole building

S/N	Description	Load (Watts)	Diversity Factor	Load (Watts)
1	46 lighting points of 24 watts	1104	0.7	772.8
2	10 lighting points of 11 watts	110	0.7	77
3	14 15A sockets of 1500 watts	21,000	1	21,000
4	25 13A sockets of 300 watts	7500	0.6	4500
5	11 fans of 100 watts	1100	0.7	770
TOTAL LOAD				27,269

$$GR = \frac{T_{LD}}{PF \times 1000}$$

where: GR = Generator Rating (kVA), T_{LD} = Total Load and PF = Power Factor

$$GR = \frac{27,269}{0.8 \times 1000} = 34kVA$$

- **INVERTER**

The rating for the inverter can be obtained using the total load of the house excluding the power (15A) sockets using equation (10).

$$T_{IL} = T_{LL} + T_F + (0.6 \times T_s) \quad (10)$$

where:

T_{IL} = Total inverter load, T_{LL} = Total Lighting load, T_s = Total 13A socket load and T_F = Total power drawn by fans

$$T_{IL} = 850 + 770 + (0.6 \times 2700\ \ ) = 4320W$$

Hence; a 4500W inverter is required. But giving an allowable tolerance of 11% [14], a 5000W inverter is selected.

(II) Solar panel array sizing

A suitable solar panel datasheet is analyzed as shown in Table 9. The datasheet shows the electrical characteristics of the solar panel and equation (11) can be used to determine the number of panels needed with details as shown in appendix IIa.

Table 9: Data sheet of the SUNPOWER SPR-435NE-WHT-D solar panel.

S/N	Property	Designation	Value
1	Peak power	P_{max}	435W
2	Rated Voltage	V_{mpp}	72.9V
3	Rated Current	I_{mpp}	5.97A
4	Open Circuit Voltage	V_{oc}	85.6V
5	Short Circuit Current	I_{sc}	6.43A
6	Maximum System Voltage	UL	600V
7	Series Fuse Rating		20A
8	Grounding		Positive grounding not required

Hence, in sizing the solar panels, 21 panels of 435W, 72.9V were cascaded. This consists of 3 series string of panels, with each string containing 7 panels connected in parallel.

(II)Battery Bank Sizing

Battery bank sizing is the process of determining the number of batteries to be installed in the battery bank as shown in equation (14) and (15).

$$T_{Wh/day} = T_{IL} \times 24hours \tag{14}$$

where; $T_{Wh/day}$ = Total watt hour per day, T_{IL} = Total inverter load and $T_{Wh/day} = 5000 \times 24 = 120{,}000 Whr/day$

$$T_{Ah/day} = \frac{T_{Wh/day}}{V_{BB}} \tag{15}$$

where: $T_{Ah/day}$ = Total watt hour per day, V_{BB} = Battery bank voltage

In battery connection, when the batteries are connected in series, the effective voltage is the sum of individual battery voltages, whereas in parallel connection, the battery voltage is unaffected, while the total Ah is the sum of the individual Ah of the battery.

The number of batteries in series is given by equation (17):

$$N_S = \frac{V_{BB}}{V_B} \tag{17}$$

The number of batteries in parallel is given by equation (18):

$$N_p = \frac{N_T}{N_S} \tag{18}$$

where: N_S = Number of batteries in series, V_{BB} = Battery bank Voltage, V_B = Voltage of selected battery, Np = Number of batteries in parallel and N_T = Total number of batteries

$$N_S = \frac{48}{12} = 4batteries$$

$$N_P = \frac{9}{4} = 2batteries$$

Hence, in sizing the battery bank, 8 batteries rated 12V, 530Ah are cascaded. 4 strings are connected in series; each string contains 2 batteries connected on parallel.

4. RESULTS AND DISCUSSIONS

4.1 *Load Description*

At the completion of the design, it is discovered that the ground floor required 36 lighting points, eight 15A sockets, ten 13A sockets and 5 fans. The first floor required 20 lighting points, six 15A sockets, 6 fans and fifteen 13A sockets. This results in a total of 56 lighting points, fourteen 15A sockets, twenty-five 13A sockets and 11 fans.

The total estimated load demand for the ground floor is 14.8kW, while that of the first floor is 12.5kW. The total estimated load demand for the whole building is 27.3kW. For proper load scheduling, the recommended distribution board to be used for both floors is the 6-way, 30A T.P.N (Three phase and neutral) distribution board. The 60A Molded case circuit breaker (MCCB) is recommended for the design, to serve as over-current protection for the whole building.

For the alternative power supply source, a 34kVA generator is recommended to power the entire load in the building. A 5kW inverter is also recommended to power only the lighting points, fans and 13A sockets. In sizing the solar inverter to be used in the building; 21 solar panels of 435W, 72.9V are cascaded. This consists of 3 series strings of panels, with each string containing 7 panels connected in parallel. Also, the battery bank sizing resulted in cascading 8 batteries rated 12V, 530Ah. 4 strings are connected in series; each string contains 2 batteries connected on parallel.

4.2 *Bill of Engineering Measurement and Evaluation (BEME)*

The bill of engineering measurement and evaluation provided in Table 10 is a list of the quantity and cost of materials needed for the implementation of the design. It also includes the cost of labour and contingency cost as shown in appendix IIb.

From, the above analysis, the total cost for the whole design is estimated to be about N1, 130,000 only, which is about $ 3138.89 only.

5. Conclusion and Recommendations (Including Tutorial Significance)

5.1 Conclusions

This paper based on the governing principles and regulations of electrical services design. The design was carried out using the AutoCAD software from which the estimated total load drawn by the building was calculated to be 27.3kW. The total load was used to propose a 34kVA generator or a 5000kW inverter for the building. The key point of this design is the use of energy saving equipment and techniques in designing to consume far less energy compared to other designs of similar nature using other non-energy saving techniques. After preparing the bill of quantities, it is seen that the design is more expensive than its counterparts; this is because energy saving techniques requires a very high initial cost, but over five years it will be more economical than other techniques.

5.2 Recommendations

Software like fine ELEC, Revit Electrical, Solid Works Electrical should be used alongside or in place of AutoCAD for a design of this sort. The combination of the design and calculation in a fully integrated environment making all the required calculation for any electrical installation directly from the drawings, and thus producing all the results, calculation sheets, bill of material and costs, and also the technical report as well as the final drawing (i.e. panel drawing, plan views, etc). This will surely simplify and eliminate error occurring by reading values directly from produced drawings. Also, home automation can be included in future designs such that appliances in the building can be controlled remotely using a smart phone.

CONFLICTS OF INTEREST

The authors declare that they have no con³icts of interest.

APPENDIX- I

A. Interior Illumination

For the lighting, the 24watt LED bulb which produces 3700 lumens is used. The number of lighting points is calculated using equation (4),

$$L_p = \frac{I_L \times A}{L \times C_u \times M_f} \tag{4}$$

The length and width of each room in Appendix I is measured using the dimension tool in AutoCAD. The area is hence calculated using equation (8):

$$A = L \times B \tag{8}$$

where: A = Area of the room, L = Length of the room and B = Width of the room

B. Ground Floor Illumination

The following calculations are done to determine the number of lighting points in each area in the ground floor.

1. Bedroom:

Area = *3.7×3.8 = 14.1*, Maintenance Factor = 0.8, Utilization Factor = 0.5 and the Recommended Illumination level = 200

Then the $L_P = \frac{200 \times 14.1}{3700 \times 0.8 \times 0.5} = 2\ lamps$

2. Laundry and Store Rooms:

Area = 1.5×3.2 =4.8, Maintenance Factor = 0.8, Utilization Factor = 0.5 and the Recommended Illumination level = 150

Then the $L_P = \frac{150 \times 4.8}{3700 \times 0.8 \times 0.5} = 1\ lamp$

3. Stairwell:

Area = 2.0×3.6 =7.2, Maintenance Factor = 0.8, Utilization Factor = 0.5 and Recommended Illumination level = 200

Then the $L_P = \dfrac{200 \times 7.2}{3700 \times 0.8 \times 0.5} = 1\, lamps$

4. Kitchen:

Area = 3.3×3.5 =4.8, Maintenance Factor = 0.8, Utilization Factor = 0.5 and Recommended Illumination level = 500

Therefore the $L_P = \dfrac{500 \times 11.2}{3700 \times 0.8 \times 0.5} = 4\, lamps$

5. Dining Room:

Area = 3.2×3.6=11.5, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 200

Then the $L_P = \dfrac{200 \times 11.5}{3700 \times 0.8 \times 0.5} = 2\, lamps$

6. Living Room:

Area = 4.2×5.9 =24.8, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 250

Therefore the $L_P = \dfrac{250 \times 24.8}{3700 \times 0.8 \times 0.5} = 4\, lamps$

7. Lobby:

Area = 6.5×1.4 =9.1, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 150

$$L_P = \frac{200 \times 9.1}{3700 \times 0.8 \times 0.5} = 2\, lamps$$

C. First Floor Illumination

1. Bedrooms:

Area = 3.9×3.3=12.9, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 200

$$L_P = \frac{200 \times 12.9}{3700 \times 0.8 \times 0.5} = 2\, lamps$$

2. Toilets:

Area = 1.3×2.1=4.0, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 200

$$L_P = \frac{200 \times 4.0}{3700 \times 0.8 \times 0.5} = 1\ lamp$$

3. Master Bedrooms:

Area = 3.9×4.2=16.4, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 200

$$L_P = \frac{200 \times 16.4}{3700 \times 0.8 \times 0.5} = 2\ lamps$$

4. Lobby:

Area = 3.3×5.8=19.1, Maintenance Factor = 0.8, Utilization Factor = 0.5 & Recommended Illumination level = 200

$$L_P = \frac{200 \times 19.1}{3700 \times 0.8 \times 0.5} = 3 \quad lamps$$

5. Sit-out:

Area = 3.3×2.1=6.9, Maintenance Factor = 0.8, Utilization Factor = 0.5& Recommended Illumination level = 200

$$L_P = \frac{200 \times 6.9}{3700 \times 0.8 \times 0.5} = 1\ lamp$$

D. Exterior Illumination

For the exterior lighting, the 11watt LED flood light which produces 700 lumens is to be used. The maintenance factor is assumed to be 0.8 while the coefficient of utilization is assumed to be 0.5. The illumination level is 15lux and the measured area of the building is 210m^2. The number of lighting points is calculated using equation (4).

$$L_P = \frac{12 \times 210}{700 \times 0.8 \times 0.5} = 10\ lamps$$

APPENDIX -II (a)

Equation (11) can be used to determine the number of panels needed.

$$N_{Panel} = \frac{T_{IL}}{P_R \times \eta \times I_F} \qquad (11)$$

where: N_{Panel} = Total number of solar panels, P_R = Power rating of each panel, η = Efficiency &

I_F = Illumination factor

Using an efficiency of 75% and an illumination factor of 0.7, the total number of solar panels is given by

$$N_{Panel} = \frac{5000}{435 \times 0.75 \times 0.7} = 22\, panels$$

The number of panels in series is given by equation (12):

$$N_S = \frac{V_T}{V_{mpp}} \qquad (12)$$

where: N_S = Number of panels in series, V_T = Total Array Voltage & V_{mpp} = Maximum solar panel voltage

$$N_S = \frac{220}{72.9} = 3$$

The number of panels in parallel is given by the equation (13):

$$N_p = \frac{N_{panel}}{N_s} \qquad (13)$$

where: N_p = Number of solar panels in parallel.

$$N_p = \frac{22}{3} = 7\, Panels$$

Taking the battery bank voltage to be 48V;

$$T_{Ah/day} = \frac{120{,}000}{48} = 2{,}500\, Ah/day$$

Assuming the expected number of days in a row without sunshine to be 1 day and the battery should not discharge more than 50%, the total Ah per day is given by:

$$T_{Ah/day} = \frac{2{,}500 \times 1}{0.5} = 5{,}000\, Ah/day$$

Then numbers of batteries are determined by equation (16)

$$T_B = \frac{T_{Ah/day}}{B_{Ah}}$$ (16) where: T_B = Total number of batteries, B_{Ah} = Ah of selected battery

Using a 12V, 530Ah battery; $T_B = \frac{5{,}000}{530} = 9\, batteries$

APPENDIX –II (b)

Table 10: Bill of Engineering Measurement and Evaluation

S/N	Material Description	Units	Quantity	Unit Cost (₦)	Total Cost (₦)
1	20mm^2 of triple A pipe	Bundles	8	5000	40,000
2	25mm^2 of triple A pipe	Bundles	6	9000	54,000
3	3 phase 6-way distribution board	Nos	2	30,000	60,000
4	Looping box (20mm)	Packets	5	200	1,000
5	3x3 Knockout box	Nos	39	50	1,950
6	Lightning Arrester	Nos	1	5,000	5,000
7	20mm^2 male bush	Packets	6	300	1,800
8	20mm^2 coupler	Packets	3	200	600
9	Ceiling rose	Nos	11	100	1,100
10	Cement	Bag	2	2500	4,000
11	PVC gum	Nos	3	1000	3000
12	Change over switch	Nos	1	1,500	1,500
13	6x3 adaptable box	Nos	6	500	3,000
14	1.5mm^2 Cable	Bundles			
	Red Coil		6	10,000	60,000
	Black coil		6	10,000	60,000
15	MCCB	Nos	1	5,000	5,000
16	2.5mm^2 Cable	Bundles			
	Red coil		3	18,000	54,000
	Black coil		3	18,000	54,000
17	Three gang, one way switch	Nos	7	500	3,500
18	T.V Cable	Bundles	1	5.000	5,000
19	Earth rod	Nos	1	3,500	3,500
20	4mm^2 Cable	Bundles			
	Red coil		1	25,000	25,000
	Black coil		1	25,000	25,000
21	13A Socket outlet 3x3	Packets	2.5	450	1,150
22	15A socket outlet 3x3	Packets	1.5	800	1,200
23	One gang, one way switch	Packets	20	300	6,000
24	Two gang, one way switch	Nos	9 piece	400	3,600
25	11 watt LED lights	Nos	10 pieces	5,000	50,000
26	24 watt LED bulbs	Nos	46 pieces	3,000	138,000
27	TV Socket	Nos	9 pieces	400	3,600
28	Labour	Weekly	3 weeks	100,000	300,000
29	Sub total				975,500
30	Contingency	Percentage	10		98,000
31	Sub total				1,073,500
32	VAT	Percentage	5		54,000
33	Grand total				1,127,500

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