Original Research Article

System Design of a Customized Solar Photovoltaic Power System for a Microcontroller-based Weather Station in Minna, Nigeria

ABSTRACT

In atmospheric and meteorological studies, missing values in acquired research data possess serious challenge on the integrity of research output emanating from their use. Missing values or readings may arise due to temporal or permanent failure in power supply to the measuring weather station. In this work, effort was made to address the fundamental issue of remote power at a standalone solar powered weather stations by professionally applying solar photovoltaic power system installation technique and the requisite knowledge of local parameters of the installed location to design a customize power supply pack for the weather station. The protocol involves an elaborate electrical load assessment and analysis of the weather station, followed by an independent component wise design formulation leading to selection of suitable solar module, battery, charge controller and voltage regulator along with their outdoor installation design. It was recommended that physical implementation of the design be carried out in line with the system and installation design.

Keywords: solar photovoltaic (PV), system design, weather station, power supply, missing data/values.

1. INTRODUCTION

Most weather stations whether located in urban centers or remote areas are usually not powered using public power supply. This is because weather stations need to be up and running all day long for a round the clock acquisition of atmospheric parameters. Pubic power, even where they are available are prone to power rationing and outages. Therefore, reliable sources of alternative power are usually resorted to, in most cases solar power (Mukund and Omid, 2021; Kartika and Shah, 2016). Solar power is renewable, reliable, pollution free, environmentally friendly, cheap and maintenance free (Olatunde, *et al.*, 2016). However, the application of solar Photovoltaic (PV) in weather station comes with inherent challenge, as blanket power packs are usually deployed irrespective of installation location and their specifics. The effect of this approach is insufficient generation of required power by the solar module to keep the battery charged enough as to sustain the station during unfavorable weather conditions and at night (Weidong, 2017). As the battery flattens out, the weather station loses power and temporarily shut down, thus misses out on weather records for that duration and regains its functionality when solar insolation improves. These phenomena lead to the occurrence of missing data at such unfortunate intervals. The negative impact of such data gaps emanating from down-times on the integrity of the overall result cannot be over emphasized. In most cases, statistical methods were resorted to in order to overcome the challenge of missing data (Ibrahim *et al.,* 2022). In this work, rather than looking at statistical ways of normalizing such missing data, effort was made to address the fundamental issue of remote power at standalone weather stations. A general knowledge in electronic circuit design may not be sufficient to design a solar photovoltaic based power pack for a weather station. To do this, a sound idea of solar PV power system components, their behave in response to weather parameters at installed location, their design theories and a local knowledge of the location of deployment should be known before it can be successful deployed. In most cases, these details are not available to manufacturers and agents. As such, a blanket power pack is usually deployed irrespective of installation location and environmental specifics. There is the need to adopt professionalism in the field of solar photovoltaic power system design in the formulation of power packs for weather stations (Lupangu and Bansal, (2017). The aim of this work is to apply solar photovoltaic power system technique in designing a customize power supply pack capable of adequately sustaining a microcontroller-based weather station for a round the clock operation. To achieve this, a thorough load assessment and analysis of the weather station was conducted followed by an independent component-wise design formulation and installation design.

2. METHODOLOGY
2.1 Electrical Load Analysis

The load that the power supply pack is to adequately power is the weather station. A knowledge of the exact electrical power and energy demanded by the station is vital to designing a competent power pack that can supply the appropriate electric energy rating. To do this, it is imperative to obtain a detail design of the weather station. Figure 1 presents the block diagram of the weather station. It shows the signal flow through sections of the weather station.

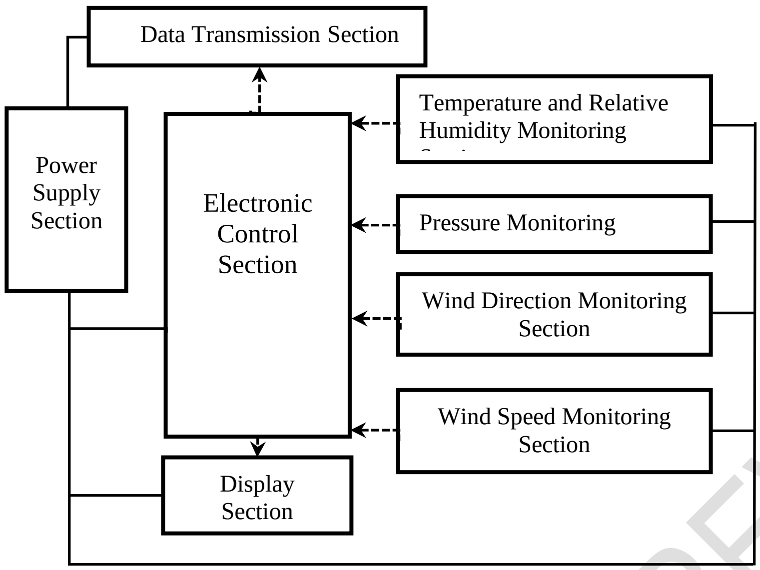

Figure 1: Block Diagram of the weather station (Ughanze, 2021)

The weather station consists of the following sections: power supply, electronic control, temperature and relative humidity, pressure, wind speed and wind direction monitoring sections. Other sections include the data transmission and the display sections (Ughanze *et al*., 2019). It is the power supply section also known as power pack that supplies the required electrical energy to other sections. To obtain the operating power capacity of a concerned sections, the major components of each section were identified and their specification in terms of current and voltage ratings were assessed from the operational manual and data sheets. The assessed parameters were manipulated in line with laid down design equations. This method was instrumental in identifying the overall power capacity of the weather station by summing individual sectional power capacities.

2.2 Solar PV Power System Design

The choice of Solar PV Power components to employ in terms of their capacities and configurations are not casually sourced but deliberately tracked in line with design equations and laid down solar PV technology conventions. The relevant components are solar module, solar battery and charge controller. Each having its individual step-by-step component sizing methodology before system matching such that they simultaneously work to generate the requisite power to effectively navigate the device through all stages of operation, all day and all night long.

3. RESULTS AND DISCUSSION

3.1 Load Assessment and Analysis

A section by section load audit of the weather station was carried out beginning with the electronic control section. The electronic control section has the microcontroller, ATmega 2560 rated as 50 mA/5V as its major components. Thus, the power P, consumed by the component is calculated using equation (1):

$$P = IV \tag{1}$$

where I and V are the current and voltage passing through the microcontroller. Substituting 50 mA and 5V respectively into equation (1) yield $0.025W$. Thus, the microcontroller requires 0.025W to operate. Similar calculation was carried out for other sections of the weather station and their respective electrical power consumption were computed. Table 1 presents the load assessment and analysis worksheet of the weather station.

Table 1: Load Assessment and Analysis Worksheet for the Weather Station

S/No	Section	Name of component	Component Value	Design Formula	Computation	Power (W)
1	Tempt. & RH Monitoring	DHT 22 sensor	40mA/5v	P=IV	40mA x 5V	0.02W
2	Atmospheric pressure	Bmp 180 sensor	$10\mu A/3.3V$	P=IV	$100\mu A\ x\ 3.3V$	0.00033W
3	Display	Nokia 5110 LCD	80mA/3.3V	P=IV	80mA x 3.3V	0.264W
4	Data Transmission	ESP8266 Wi-Fi Module	80mA/3.3V	P=IV	80mA x 3.3V	0.264W
5	Wind Direction Monitoring	Reed Switch (Anemometer Sensor)	1.25A/5V	P=IV	1.25A x 5V	6W
6	Wind Speed Monitoring	Continuous variable resistor (wind vane sensor)	10R/5V	$P=\frac{V^2}{R}$	5^2V/10R	2.5W
7	Electronic Control	ATmega 2560 microcontroller	50mA/5V	P=IV	50mA x 5V	0.025W
		Total				**9.0733W**

From Table 1, the overall power demand of the weather station was obtained from the summation of the power column, which amounted to 9.07 W. It is this power demand that the solar power pack intend to supply at all times.

3.2 Solar PV Power System Design

The design conceptualization of the power supply system is such as to provide the electrical energy demanded by the weather station for round the clock monitoring of atmospheric parameters. Consequently, the abundant energy of the tropical African sun, that is, solar energy was chosen to be used to power the weather station. The block diagram of the solar photovoltaic power supply system comprises of the following subsections: solar module, charge controller, solar battery and voltage regulation sub sections as shown in the block diagram of Figure 2.

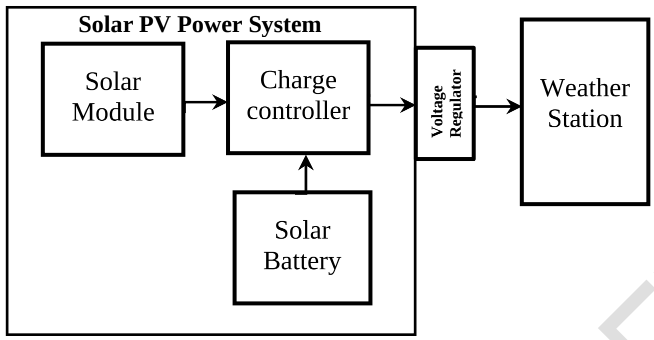

Figure 2: Block Diagram of the Solar PV Power System

The design description for each section is presented in the following subsections.

3.2.1 Solar Module

Solar module converts the radiant energy of the sun into electrical energy. The choice of solar module to use in terms of their number, configuration and electrical specifications is dependent on a series of calculations and estimation processes as shown below (Gauri *et al*., 2017):

3.2.1.1 Average peak power of Module

To evaluate the average peak power ($P_{Ave,peak}$) of the required, the location of deployment of the device is crucial. Nigeria usually experiences wet and dry weather; thus, average radiation shall be taken into account. The average peak power ($P_{ave,peak}$) extractible by a solar panel was worked out using equation (2);

$$P_{Ave,peak} = \frac{E_{dd}}{T_{sh}} \quad (2)$$

where T_{sh} is the number of sunshine hours in the location of deployment of the weather station. Nine (9) sunshine hours are obtainable in Minna, Niger State, Nigeria. While E_{dd} is the daily average energy demand. This can be obtained using equation (3);

$$E_{dd} = Pt \quad (3)$$

where P is the power rating of the load (weather station) earlier obtained using equation (1) and was further computed and summed up as expressed in Table 1 as 9.07 W. While t is the duration of time (in hours) when the device is to be operational (Okonkwo and Nwokoye, 2014). The station was conceived for a 24 hours daily measurement of atmospheric parameters. Therefore, equation (3) yielded $217.68\ Wh/day$. Substituting (3) into (2) to obtain the average peak power as 24.19 W. This implies that a solar panel with power rating of 24.19W can sufficiently supply the electrical energy required by the weather station on design. However, a 50W solar panel was selected in order to provide for sufficient allowance for a robust and rugged power system.

3.2.1.2 Total dc current of the system

The total dc current of the system (I_{dc}) is a guide to the selection of the maximum power current of the solar module. It is calculated by dividing the average peak power $P_{Ave\ peak}$ by the dc voltage V_{dc} of the system as shown in equation (4).

$$I_{dc} = \frac{P_{Ave.peak}}{V_{dc}} \qquad (4)$$

The highest voltage rating among all the major components shown in Table 1 is 5V. Therefore, the weather station was designed to operate on $5V_{dc}$ as its maximum voltage. Substituting this value into (4) yields $4.84\ A$. This value is well above the current requirement for each component used in the design as shown in Table 1. From the result arrived at in equation (2) and (4), a guide to the power capacity and maximum power current has been obtained. Also, a choice was made for a monocrystalline type of solar module for its high efficiency. As such a monocrystalline module having model DE-SM50P36 was chosen to generate the required energy to drive the weather station for continuous atmospheric data acquisition. The electrical and physical specifications of the chosen module is shown in Table 2.

Table 2. Specification of Solar Module DE-SM50P36

Specification	Value
Maximum Power P_m	50 W
Maximum power current I_{pm}	7.23 A
Maximum power Voltage V_{pm}	18.0 V
Open circuit voltage (V_{oc})	21.5 V
Short circuit current (I_{sc})	7.74 A
Irradiance (E)	$1000\ \mathrm{W/m^2}$
Module Temperature (T_c)	25^0C
Length	67 cm
Width	54 cm
Height/thickness	3.0 cm
Weight	4.35 kg

It is obvious from Table 2 that the P_m, I_{pm}, V_{pm} values of 50 W, 7.23 A and 18 V are comfortably above the calculated values for the average peak power of 24.19 W, total dc current of 4.84 A and maximum voltage of 5 V respectively. Furthermore, it is necessary to determine the number of the selected module to be connected in series and parallel. To compute these, the maximum power voltage, V_{pm} and maximum power current I_{mp} were respectively extracted from Table 2 and expressed as shown in Table 3. The solar module computations including those of the number of modules in series and in parallel and their total number N_t were summarized as shown in Table 3.

Table 3: Computed Specification of PV Array

Parameters	Formula	Calculation	Computed value
Required daily energy demand (E_{rd})	$E_{rd} = E_d$	217.68	217.68Wh/day
Average peak power	$P_{ave.peak} = \frac{E_{rd}}{T_{sh}}$	$\frac{217.68}{9}$	24.19W
Total Dc current (I_{dc})	$I_{dc} = \frac{P_{ave.peak}}{V_{dc}}$	$\frac{24.19}{5}$	4.84A
Number of series modules (N_{sm})	$N_{sm} = \frac{V_{dc}}{V_{pm}}$	$\frac{12}{18}$	0.67 ~ 1
Number of parallel modules (N_{pm})	$N_{pm} = \frac{I_{dc}}{I_{mp}}$	$\frac{4.84}{7.23}$	0.67 ~ 1
Total Number of modules (N_t)	$N_t = N_{sm} \times N_{pm}$	1×1	1

The value of 0.67 obtained for the number of modules in series and in parallel were respectfully approximated to 1 as the number of modules cannot be less than 1. The total number of modules to be used is a product of the number of modules in series and in parallel, which amount to a single quantity of the chosen module.

3.2.2 Solar Battery

The battery is the power bank of the entire system. The electrical energy generated by the solar module is stored in the battery. The choice of battery to select is determined by two of its specifications; these are the battery voltage V_b and battery capacity C_b. These and other battery characteristics were computed below:

3.2.2.1 Battery voltage (V_b)

The battery voltage is usually set by the choice of solar module selected. The 50 W solar module has a Maximum power voltage (V_{pm}) of 18 V. However, its nominal voltage is 12 V, as it is designed to function in harmony with other 12 V system components. Hence, a 12 V battery voltage was selected.

3.2.2.2 Estimated energy storage (E_{est})

The estimated energy storage (E_{est}) ability of a battery is determined using equation (5);

$$E_{est} = E_{dd} \times D_{aut} \quad (5)$$

Where D_{aut} is the number of days of autonomy. It refers to the number of days a battery can sustain without charging via solar (Ibrahim, 2024 and Silas *et al.*, 2024**)**. One day of autonomy was chosen owing to the fact that the study area usually experiences a high propensity of daily sunshine. Daily average energy demand E_{dd} was earlier calculated from equation (3) as

217.68Wh/day. Therefore, E_{est} was calculated as 217.68Wh/day. This implies that the daily energy demanded by the weather station is equal to the estimated energy stored in the battery. This energy reserve is sufficient considering the fact that the stored energy is mostly required from sun set. During the day, the energy requirement does not drain the battery as the sun's energy is constantly being converted by the solar module for battery recharge operations; thus, serving as instant replacement for previous discharges.

3.2.2.3 Safe energy store in the battery (E_{safe})

The Safe energy store in the battery is given by equation (6) as;

$$E_{safe} = \frac{E_{est}}{D_{disc}} \tag{6}$$

where D_{disc} is the maximum depth of discharge of the battery. It is the percentage of the total capacity of a battery that can be discharged. In this work, it was chosen as 50%. 50% depth of discharge of the battery means only half of the capacity of the battery bank is permitted to be discharged (Ughanzi, 2021). It is unsafe to the service life of a battery and an unconventional design practice to completely discharge or drain a battery flat. Equation (6) is therefore a battery protection parameter. Although it increases the battery bank capacity and cost of the design. Equation (6) becomes;

$$E_{safe} = \frac{217.68\, Wh}{0.5} = 435.36\, Wh/day$$

3.2.2.4 Total Battery capacity (C_{tb} ***)***

To obtain the total capacity of a battery bank, equation (7) applies

$$C_{tb} = \frac{E_{safe}}{V_b} \tag{7}$$

where V_b is the battery voltage. It should match up with the nominal voltage of the feeding solar module which has earlier been decided as 12 V. C_{tb} was computed as $36.28\ Ah$.

With this value as a guide, a battery capacity of 50 *Ah* was selected. The allowance is for a robust power reserve and commercial availability. At the end of the battery sizing, a 12 V, 50 *Ah* capacity battery was arrived at. A deep cycle, rechargeable lead acid battery type will ensure suitable energy storage at the weather station due to its long discharge duration (Saleh *et al.,* 2015).

3.2.3 Charge Controller

The charge controller acts as a switching device between the solar module and the battery. It regulates the output voltage from the solar panel to the required charging voltage of the battery (Mohammad and Sumit, 2015). The specification of the charge controller to use depends on the rating calculation of its current and voltage.

The charge controller current I_{cc} is obtained using equation (8) (Ibrahim, 2024).

$$I_{cc} = I_{sc} \times N_{pm} + F_{safe} \tag{8}$$

where, I_{sc} is the short circuit current of the module = 7.74A (from Table 2)

N_{pm} is the number of parallel module = 1 (from Table 3)

F_{safe} is the safety allowance of the charge controller. Usually a factor, 20% of ($I_{sc} \times N_{pm}$) is added in most cases to cater for occasional fluctuations and current surge from the solar array. Equation (8) yields;

$$I_{cc} = 7.74 \times 1 + 1.55 = 9.29\ A$$

A 9.29 Ampere charge controller is not commercially available. Therefore, a 10A rated charge controller was selected. The Solar photovoltaic based schematics for the designed power supply system is shown in Figure 3.

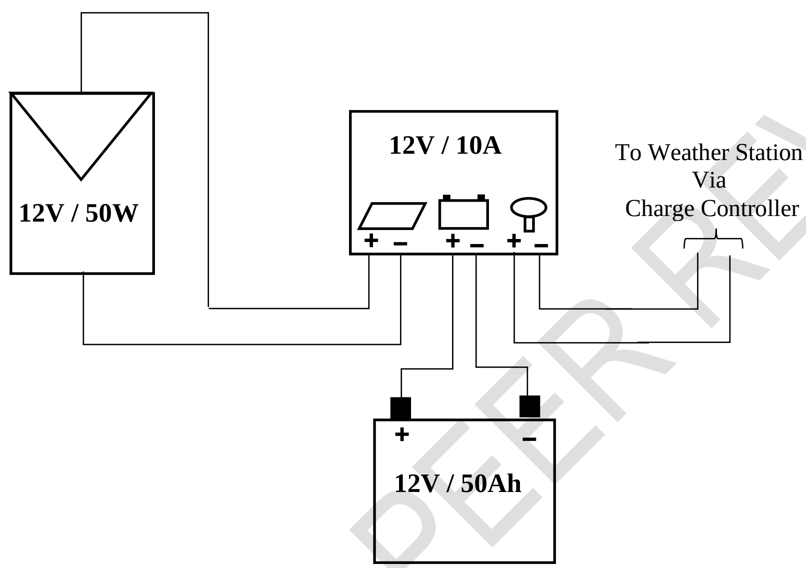

Figure 3: Schematic Connection

3.2.4 Voltage Regulation

The 12V dc output level of the charge controller needs to be pegged to a level tolerable by the constituent components of the weather station. A voltage regulator plays this role effectively. From the load analysis worksheet of Table 1, a maximum voltage of 5V is sufficient for all components. As such LM317K (LM317K datasheet, 2024), an adjustable voltage regulator with output ranging from 1.25 V to 37 V and output current of 1.5 A was adjusted to step down the 12 V output available at the charge controllers' output to 5 V. The output at this stage is ready for transmission through connecting cable to the weather station power inlet for distribution to various mentioned sections as represented by the solid lines and blocks respectively of Figure 1.

3.2.5 Installation Design

Solar modules are mounted in three ways: roof top, ground or pole mounting with each having their individual advantages and disadvantages **(**Olatunji, 2016**)**. In this work, the fixed pole mounting was adopted because of the flexibility with which the conditions governing module installation can be achieved. The conditions to satisfy are those of orientation and tilt. The installation location is Minna, Niger State, Nigeria. It lies between Latitudes 09°40' 7.63" N and 09° 39' 59.72" N and Longitudes 06° 30' 0.32" E and 06° 36' 34.05" E (Ibrahim *et al.*, 2022). In line with convention, modules are mounted oriented in the direction opposite the hemisphere which they belong (Lupangu *et al.,* 2017). Minna is in the Northern hemisphere, hence the right module orientation is south facing. Regarding the tilt, modules are tilted in the degree of the latitude of the location. Minna is located on latitude 9^{o}, hence the module was tilted at 9^{o}. Having satisfied these conditions, next is to transfer the obtained orientation and tilt to a steel pole of diameter 3 cm and height 5 cm as shown schematically in Figure 4. A right-angle steel material was used to form a rectangular frame 67 x 54 cm, which is the exact physical dimension of the module (Table 2) and inclined it at the tilt angle of 9^{o} to the pole. The rectangular frame is to provide a structure into which the solar module will be slotted. Under the rectangular frame is an attached 20 x 15 x 10 cm plastic box which will sufficiently house the other solar PV components (solar battery, charge controller and the attached voltage regulator). The slotted solar module will sufficiently shade the plastic box and its content from rain and direct sunlight. The choice of a plastic is to prevent its content from heating up easily. Figure 4 shows the standalone monopole installation design for the solar power system.

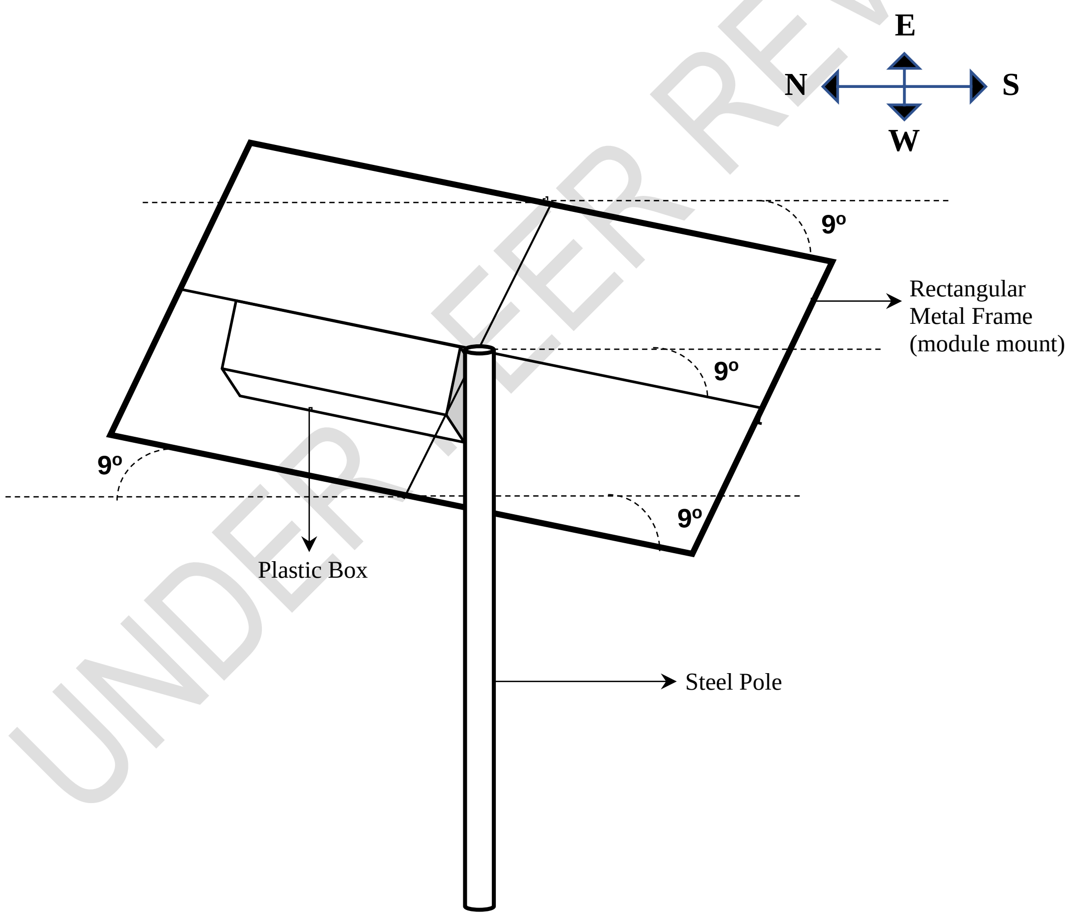

Fig 4-Standalone Monopole for Solar Power Mounting

A spot that is free of trees, storey buildings and other high-rise structures that tends to serve as potential shades over the installation is appropriate for the installation of the steel pole. Such a spot is well exposed to direct solar radiation from sun rise to sun set. During installation of the pole, a compass should be used to ensure that the tilted rectangular module mounting frame provided is oriented due south while the base of the steel rod is buried in concrete. This will ensure that the structure is maintained at the required convention regarding orientation and tilt.

4. CONCLUSION

Weather stations are crucial for monitoring atmospheric conditions, providing essential data for weather forecasting and climate studies. Solar PV system provide a reliable, renewable energy source that ensures their continuous operation, thereby enhancing data accuracy. A system design of a solar PV power pack competent to sustain a microcontroller-based weather station has been articulated. Carefully arrived at following the solar photovoltaic power system design protocol of load audit and step-by-step system component design. It is expected that the efficiency which characterizes solar PV systems will now be associated with the weather station, keeping it operational all day and all night long. Hence, eliminating the familiar missing atmospheric data phenomena arising from power supply failure at base stations. It was recommended that physical installation be carried out in line with design and installation schematics.

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