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Design and Construction of Solar-Powered DC Milking Machine for Dairy Cattle

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Abstract: The design and construction of the solar-powered DC milking machine will enable dairy farmers in rural communities effectively milk their cattle, utilizing clean and affordable energy. Design spark mechanical and RETScreen software were initially used to design and simulate the feasibility of the milking machine based on the available materials and energy requirement for the system. The solar-powered DC milking machine was designed and constructed from locally available materials such as DC motor, mechanical compressor, belt and pulley, Dispenser bottle, PVC, multipurpose garden hose and rubber tubes to provide farmers with a clean, sustainable and efficient means of milking cattle.

Keywords: *Milking Machine; Energy; Direct Current; Alternating Current; RETScreen.*

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I. INTRODUCTION

The need for an energy efficient milking machine has become exceedingly significant as the currently available ones which utilizes Alternating Current (AC) are quite expensive and unsustainable. Dairy producers in Nigeria, particularly within the Northern region lack access to sustainable and affordable milking machine as milking is still done manually and in an unhygienic condition. The use of specific milking technologies has the potential to enhance both the quantity of milk produced and the quality of milk obtained from dairy cattle (Petrovsk & Jonkus 2014).

The dairy industry plays a crucial role in providing a reliable supply of milk and dairy products to satisfy global consumption demands. Nigeria is estimated to have the 4th largest cattle population in Africa, with around 20 million cattle, which includes approximately 2.35 million cows designated for dairy production (Kayode, 2019). In light of the increasing scale of dairy farming operations, the need for efficient and reliable milking machines has become paramount. Milking machines automate the milking process thereby enhancing productivity, milk quality, and animal welfare. The advent of milking machines has fundamentally transformed the dairy sector by providing a more efficient and productive method to the milking of cows.

These machines are engineered to extract milk from dairy animals such as cows, goats, and sheep thereby reducing the labor and time required for hand milking. According to research conducted by Tse et al., (2018), the utilization of milking machines has demonstrated an increase in milk yield when compared with traditional hand milking methods.

Milking machines are available in various designs and configurations to suit different farm sizes and production needs. Some machines are portable and can be used in small-scale dairy farms, while others are fully automated and designed for larger commercial operations. The benefits of milking machines are numerous. They help reduce the physical strain on farmers by eliminating the need for hand milking, increasing efficiency and productivity. They also ensure a more hygienic milking process, reducing the risk of contamination and improving milk quality. Milking machines result to increase milk yield compared to hand milking and have shown to impact positively on milk quality and hygiene standards in addition to being economically advantageous (Jacobs & Siegford, 2012).

Milking process has been automated with the advent of technology. The production of high-quality milk can be achieved without inflicting harm on the cow's udder by following the appropriate milking protocols (Chaudhary et al., 2001). Electrical milking machines are available in various forms and capacities. These machines are rather expensive and sometimes too technical for the layman.

One important aspect of milking machine design is the choice of power source. While AC has traditionally been used, the design of DC milking machine will go a long way in securing a sustainable future in the dairy sector due to their numerous advantages. Solar energy is accessible to the entire global populace; as a result, this renders it an exceedingly high and appropriate substitute for conventional fuel sources. The use of renewable energy has become significantly important in the fight against climate change and the mitigation of greenhouse gas emissions (Yakub et al 2022).

Direct current systems eliminate the need for inverters for energy conversion, provide enhanced control, energy efficiency, and compatibility with renewable energy sources, making them an appealing choice for modern dairy farms. With the simplicity of the energy conversion process, the direct current appliances working at suitable voltage and the efficiency of the energy conversion can be increased at the same time (Makarabbi et al., 2014).

The system consists of a cluster (the assembly that is manually attached to the cow), a milk tube, a pulse tube and pulsator, a vacuum pump or blower, and sometimes a recorder jar that measures yield. Together, the system allows milk to flow through a pipeline into a receiving bucket in preparation for shipping to a processing plant. An important part of the milking machine such as the cluster consists of teatcups or shells, milk liner that actually performs the milking action, and a claw that separates the teatcups and connects them to the milk and pulse tubes. Based on several researches carried out, the pulsation frequency, ratio and vacuum level settings of the milking machine have shown to have a significant impact on the milk yield, milking time, and overall udder health (Edwards et al., 2013; Ferneborg et al., 2015; Gasparik et al., 2018; Kaskous, 2018; Parilova et al., 2011).

The milking machine installation consists of a pipework system linking various vessels and other components which together provide the flow paths for air and milk. During operation, milk is drawn from the cow's teats because a vacuum is created within the cup device, forcing the milk through the teat canal. The pulsator alternates the pressure, first by creating a vacuum (milk phase), and then applying air, which causes the flexible liner in the cup to collapse and massage the teat (rest phase). The main purpose of the pulsation is to limit the formation of congestion and oedema in the teat tissue while milking with machine (Mein et al., 2004). The alternating process of milk-and-rest is continued in a rhythmic pattern for the cows' health and good milk productivity.

➢ *Objectives*

The specific objectives of this research are to:

- Design a solar-powered DC milking machine based on climatic data and energy requirement for the system.
- Construct the solar-powered DC milking machine.

II. MATERIALS AND METHOD

➢ *Materials*

The materials used for the design and construction are as follows:-

- *Materials for Design of Solar-Powered DC Milking Machine*

Application software such as Renewable Energy Technology Screen (RETScreen) and design spark mechanical were used to obtain climatic data of the study area and design of a 3-dimension (3D) model of the milking machine.

- *RETScreen*

The RETScreen Software was used to evaluate the feasibility of the solar-powered DC milking machine and its greenhouse gas emission reduction potentials. It is comprehensive, user-friendly and can be used to analyze the potential benefits and costs of various renewable energy technologies. With the application of RETScreen software, the feasibility of distributed energy system can be analysed (Pan et al., 2017).

- *Design Spark Mechanical*

Design Spark Mechanical is a powerful and user-friendly 3D Computer Aided Design (CAD) modeling software which was used to create a precise and detailed 3D model design of the solar powered DC milking machine. Automotive prototyping can be achieved with Computer Aided Design by intergrating with additive manufacturing (Vido et al., 2024).

- *Materials for Construction of Solar-Powered DC Milking Machine*

Both electrical and non-electrical related components were used in the construction of the powered DC milking machine.

- *Electrical Related Components*

The electrical related components used in this work are shown in Table 1

Table 1 Electrical Related Components

S/N	Appliance Name	Type	Quantity
1	DC motor	Electrical	1
2	Solar module	Monocrystalline	1
3	Battery	Deep cycle gel	1
4	Charge controller	PWM	1
5	DC Circuit breaker	Electrical	1
6	DC Cable	4-mm	4

Table 1 showing the electrical components

- *Non-Electrical Related Components*

The non-electrical components used in this work are shown in Table 2

Table 2 Non-Electrical Related Components

S/N	Name	Quantity
1	Mechanical suction pump	1
2	Teat Cups	4
3	Milk Liners	4
4	Milk Claw	1
5	Milk Bucket	1
6	Milk Hose	1
7	Pulsator	1
8	Pulse Tube	4
9	Vacuum Tube	1
10	Belt & Pulley	1
11	Wheel Cart	1

Table 2 showing the non-electrical components

- *Data Sheet of the Components, Models and Manufacturers*

The components of the solar-powered DC milking machine models and manufacturers are as shown in the Table 3

Table 3 Components, Models and Manufacturers

S/N	Components	Models	Manufacturer
1	DC motor	Model 775	Dongguan Shitai Ep Technology Co., Ltd,
2	Solar module	QS-200M	Mantech Electronics
3	Battery	SHB12V~100AH	Total Energy Solution
4	Charge controller	TTN-W20A	TTN Electric
5	DC Circuit breaker	NB1-63DC	Chang song Electric Co., Ltd.
6	DC Cable	4mm 2-Core DC Cable	Novelsolar
7	HiJet Mechanical suction pump	88320-97508	Guangzhou Berlin Auto Parts Manufacturing Co., Ltd
8	Teat Cups	model 32mm x 3.0mtrs	BATHIJA group
9	Milk Liners	-	-
10	Milk Claw	-	Geeta Plastic Products Nigeria Limited
11	Milk Bucket	CWAY 18.9L	CWAY Group
12	Milk Hose	1/2 inch RENG176999	Sinopulse
13	Pneumatic Pulsator	L80 Pulsator	Hong jie sheng firm
14	Pulse Tube	RENG176999	Sinopulse
15	Vacuum Tube	RENG176999	Sinopulse
16	Belt	B35 v-belt	Gates
17	Frame (Wheel Cart)	4x4 Square Tube Steel	Yuantai Derun Steel Pipe Manufacturing Group

Table 3 showing the non-electrical components

- *DC Motor*

The DC motor or direct current motor is used to convert electrical energy into mechanical energy through the interaction of magnetic fields. The DC motor speed reference is accurately adhered to, and can withstand load disturbances. The motor operates using direct current (Lin et al., 2024).

- *Solar Module*

A 12V 200W solar module was used to convert sunlight into direct current (DC) to power the DC load based on energy requirement of the system. The solar module specification is given in Table 4.

Table 4 Solar Module Specifications

Panel Particulars	Rating
Maximum Power	200W
Power Tolerance	± 3%
Maximum Power Voltage	18.0V
Maximum Power Current	11.11A
Open Circuit Voltage	22.14V
Short Circuit Current	11.67A

Table 4 showing the solar module specification

- *Deep Cycle Gel Battery*

A 12V 100Ah Deep cycle gel battery was used to provide steady supply of current and voltage to the machine to enable efficient milking at all times. The battery capacity can be determined by getting the estimated energy storage required to power the DC load which is equal to the product of the daily average energy demand and the number of autonomy days (Aliyu & Guda, 2015).

- *Charge Controller*

A PWM (Pulse Width Modulation) charge controller was used in the solar-powered system to manage the flow of electricity to the machine. The aim of the charge controller sizing is to ensure its ability to withstand the product of the total short circuit current of the photovoltaic modules connected in parallel by a safety factor (Osuagwu et al., 2022).

- *DC Circuit Breaker*

The DC circuit breaker was used to automatically interrupt the flow of current to the machine. Micro-electro mechanical system have shown to have a low actuation voltage below 8V and high performance. It also enables manual control of the system (Li et al., 2020).

- *DC Cable*

DC cables were used to transmit DC electrical energy from the solar module to the charge controller, battery, circuit breaker and DC load. Based on the Electric field finite-element analyses, the electric field within direct current cable terminals can be mixed together through the utilization of glyceryl monooleate (GMO) grafted ethylene-propylene-diene monomer (EPDM) as a reinforcing insulation material (Li et al., 2022).

- *Mechanical Suction Pump*

Mechanical suction pump was used to extract milk from the cow's udder under controlled pressure. The vacuum pump functions by extracting air from a closed system and creating a partial vacuum (Nørstebø et al., 2019).

- *Teat Cups*

A set of four teatcups were connected to a pulsator which regulated the vacuum pressure to simulate the sucking action of a calf. This helped to stimulate milk flow and ensures that the cow is milked efficiently and comfortably. Each of the teat cups are characterized by an outer shell, a rubber liner, a short milk tube and a short pulsation tube (Nørstebø et al., 2019).

- *Milk Liners*

A set of four rubber milk liners were connected to the pulsator which controls the vacuum pressure and pulsation rate of the milking machine. The liners were used to transport milk from the teat cups to the milk cluster. Square milk liners in comparison with conventional round liners significantly improve milking performance, without adverse effect on cow comfort (Herath et al., 2024).

- *Milk Claw*

The milk claw was used to collect milk from the individual teat cups connected to the cow's udder. The milk claw was designed to allow air to enter the system, which is important for maintaining a consistent vacuum level and preventing excessive vacuum pressure on the cow's teats. machine-on time can be reduced using a high cluster removal level without a loss of extracted milk (Stauffer et al., 2020).

- *Milk Bucket*

A water dispenser bottle was used as milk bucket to collect milk extracted from the cow's udder during the milking process. The milk flows directly into the milk bucket from the cluster. It is suggested that AMS incorporated device units, have similar or improved accuracy when calibrated regularly and set up according to the manufacturer's instruction compared with CMS devices (Kamphuis et al., 2015).

- *Milk Hose*

The milk hose was used to transfer the milk from the milk claw to the milk bucket. It also helped in allowing controlled air intake into the system to regulate the vacuum level and prevent excessive vacuum pressure on the cow's teats. Decreased milk yield and milk flow, increased machine-on time and the frequency of liner slip, had no influence on udder health, and improved teat condition only slightly when milking at a milkline vacuum of 38 kPa compared with 48 kPa for a high-level milking system (Rasmussen & Madsen, 2000).

- *Pulsator*

An L80 pneumatic pulsator was used to create a pulsating vacuum required for milking. It compressed and retracted the milk liners to create a rhythmic suction motion that helps to extract milk from the cow's udder. It is essential to commence the reduction of the pulsation chamber vacuum before attachment of the milking cluster in order to prevent the secretion of milk during the pre- stimulation phase (Neuheuser et al., 2017).

- *Pulse Tube*

A set of four pulse tube were used to carry the pulsating air pressure from the pulsator to the teat cups attached to the cow's udder during the milking process. The diameter of the teat base is measured midway from the teat length after stimulation (Reinemann & Mein, 2011).

- *Vacuum Tube*

A vacuum tube was used to carry the vacuum pressure used to extract milk from the cow's udder. Increase in peak flow rate has been associated with a more constant vacuum at the teat tip during periods of high milk flow and have also shown to affect milk flow patterns (Ambord & Bruckmaier, 2010).

- *Belt and Pulley*

The belt and pulley system was used to transfer motion and power from the DC motor to the suction pump. It consists of a flexible belt that loops around the pulley. The scenario without of sliding needs the application of a concentrated force at the juncture where the belt departs from the pulley (Oborin, 2020).

- *Wheel Cart*

A wheel cart was incorporated in the design to allow easy movement with the machine from one place to another**.** It has a 4x4 square tube steel frame to make it sturdy and a platform to hold the machine and can be pulled and pushed by hand.

➢ *Methods*

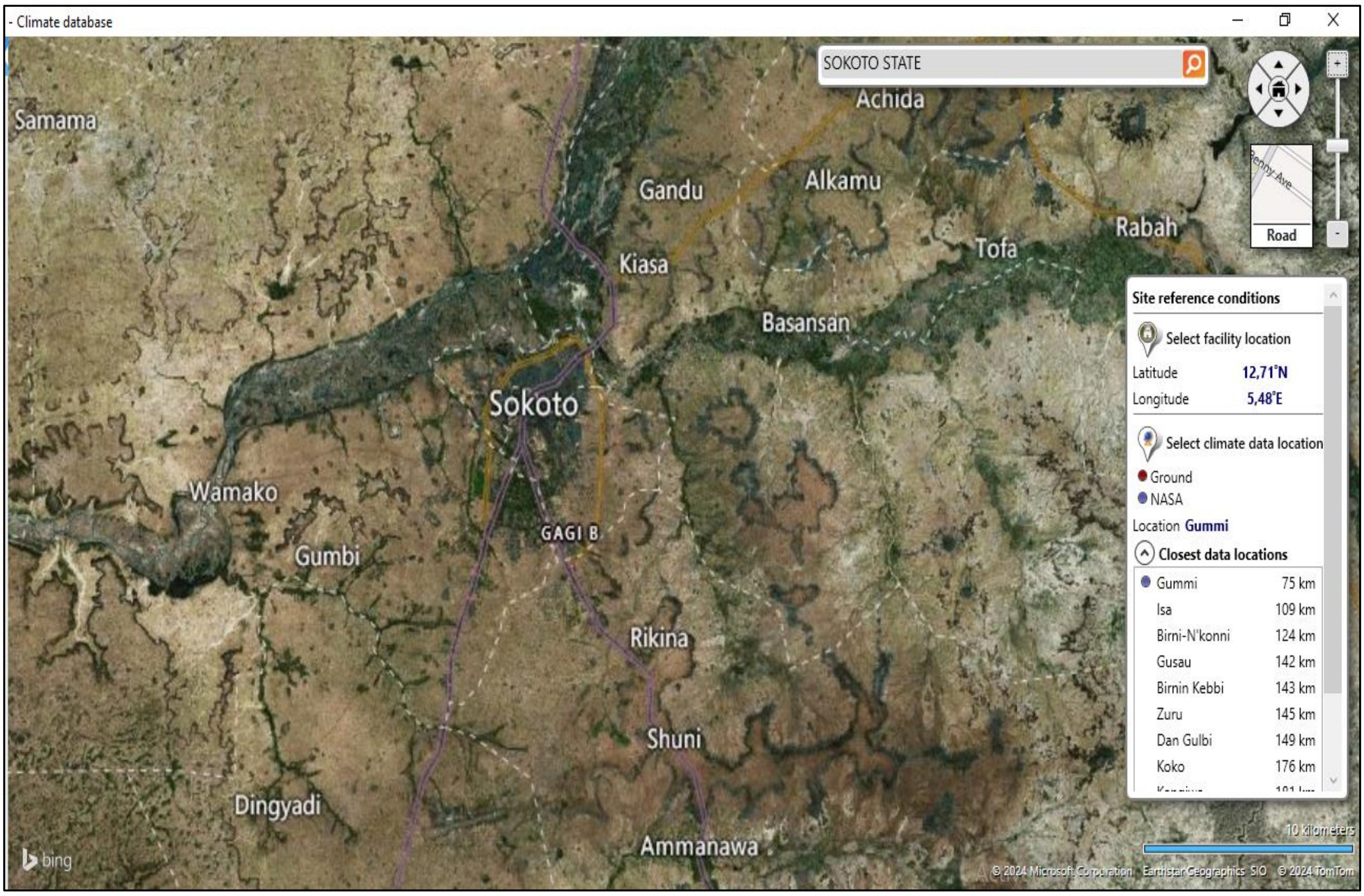
A 3D model of the milking machine was designed using design spark mechanical based on the climatic data of the host location which would be obtained from NASA (National Aeronautics and Space Administration) using RETScreen. The energy requirement for the design was determined by the average DC load, which gave us information on the solar module size, battery capacity and charge controller size. The machine was constructed from locally available resources such as, reusable bottle dispenser, PVC pipe and rubber liner.

- *Design of Solar-Powered DC Milking Machine*

The solar powered DC milking machine was designed based on the climatic data, energy requirement and need of the end users. The design will incorporate the principle of operation and all components required for the prototype (Chandler et al., 2003).

- *Climatic Data and Geographical Location of the Host Community*

The Climatic data and geographical location for this research were obtained from NASA (National Aeronautics and Space Administration) using RETScreen Software. These data include: the latitude, the longitude, temperature, wind speed, rain fall precipitation, relative humidity and the direct solar radiation of the location. Plate 3.1 shows the geographical location of the host community obtained from RETScreen.



Site reference conditions

Select facility location

Latitude 12,71°N

Longitude 5,48°E

Select climate data location

● Ground

● NASA

Location Gummi

Closest data locations

● Gummi	75 km
Isa	109 km
Birni-N'konni	124 km
Gusau	142 km
Birnin Kebbi	143 km
Zuru	145 km
Dan Gulbi	149 km
Koko	176 km

Plate 1 The Geographical Location of the Host Community Obtained From Retscreen

Table 5 Geographical Data of the Host Location (Sokoto)

Geographical data	Results
Latitude	12.78ºN
Longitude	5.48ºE
Elevation	294.87m

Table 5 Showing the Geographical Location of Host Location

- *Latitude of Sokoto*

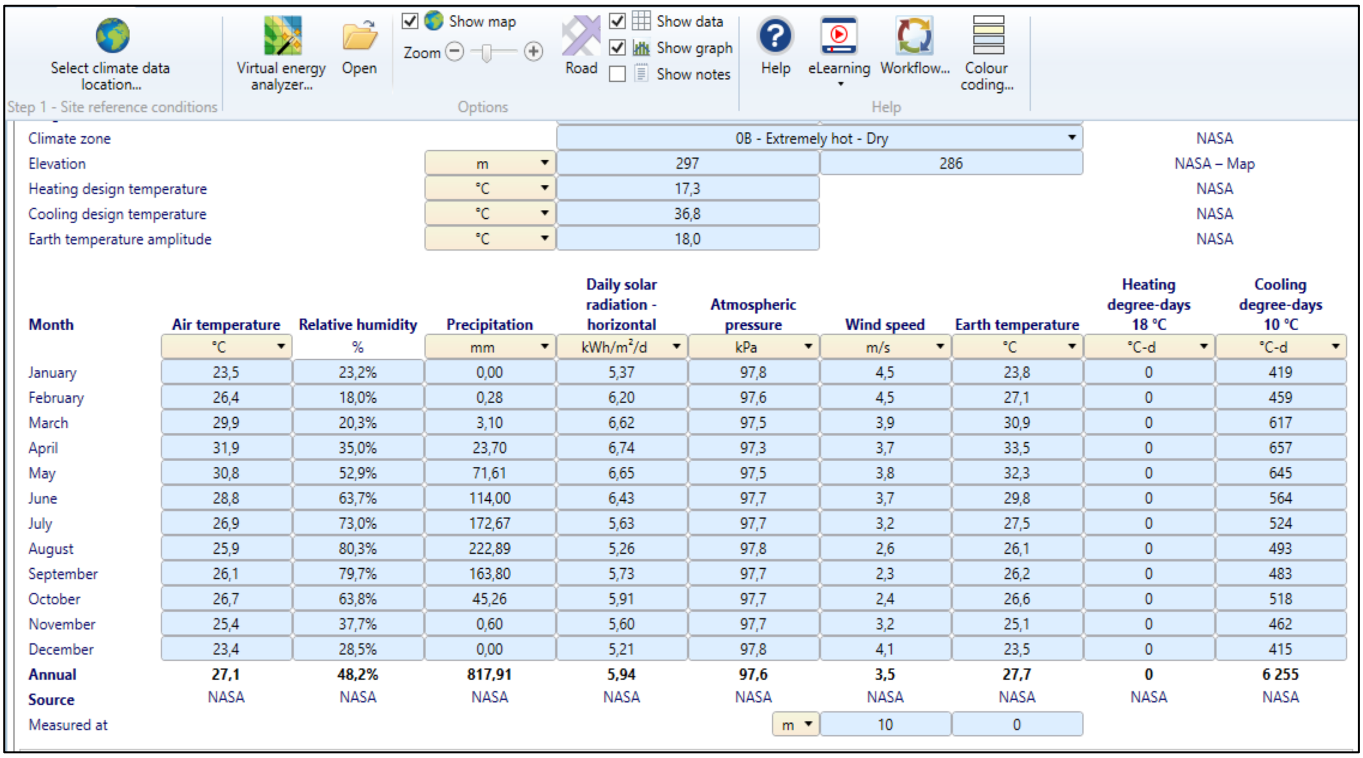
Sokoto state has a latitude of approximately 12.78° N. This latitude indicates that Sokoto is situated in the northern hemisphere, just north of the equator. Being close to the equator means that the city experiences a tropical climate with generally warm temperatures throughout the year. The latitude of Sokoto also plays a role in determining the length of daylight hours, with the city experiencing relatively consistent day lengths due to its proximity to the equator.

- *Longitude of Sokoto*

Sokoto state has a longitude of approximately 5.48° E. This longitude places Sokoto in the eastern hemisphere, indicating that the city is located to the east of the prime meridian, which runs through Greenwich, England. The longitude of Sokoto is crucial for determining its position on the Earth's surface relative to other locations around the world. Additionally, the longitude of Sokoto influences the overall geographical and navigational coordinates.

- *Elevation*

Sokoto state has an elevation of approximately 294 meters above sea level. This elevation indicates that Sokoto is situated at a relatively low altitude, which can influence factors such as climate, weather patterns, and vegetation in the region. The elevation of Sokoto is important for understanding the city's topography and its susceptibility to flooding, as well as for various planning and infrastructure considerations. The climatic data of Sokoto obtained from RETScreen is shown in Plate 2.



Climate zone		0B - Extremely hot - Dry		NASA
Elevation	m	297	286	NASA – Map
Heating design temperature	°C	17,3		NASA
Cooling design temperature	°C	36,8		NASA
Earth temperature amplitude	°C	18,0		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	23,5	23,2%	0,00	5,37	97,8	4,5	23,8	0	419
February	26,4	18,0%	0,28	6,20	97,6	4,5	27,1	0	459
March	29,9	20,3%	3,10	6,62	97,5	3,9	30,9	0	617
April	31,9	35,0%	23,70	6,74	97,3	3,7	33,5	0	657
May	30,8	52,9%	71,61	6,65	97,5	3,8	32,3	0	645
June	28,8	63,7%	114,00	6,43	97,7	3,7	29,8	0	564
July	26,9	73,0%	172,67	5,63	97,7	3,2	27,5	0	524
August	25,9	80,3%	222,89	5,26	97,8	2,6	26,1	0	493
September	26,1	79,7%	163,80	5,73	97,7	2,3	26,2	0	483
October	26,7	63,8%	45,26	5,91	97,7	2,4	26,6	0	518
November	25,4	37,7%	0,60	5,60	97,7	3,2	25,1	0	462
December	23,4	28,5%	0,00	5,21	97,8	4,1	23,5	0	415
Annual	**27,1**	**48,2%**	**817,91**	**5,94**	**97,6**	**3,5**	**27,7**	**0**	**6 255**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Plate 2 Climatic Data of Sokoto Using RETScreen

Table 6 The Daily Solar Radiation per Month

Months	Daily solar radiation per month (kWh/m^2/d)
January	5.37
February	6.20
March	6.62
April	6.67
May	6.65
June	6.43
July	5.63
August	5.26
September	5.73
October	5.91
November	5.60
December	5.21
Annual	5.94

NASA (RETScreen)

Table 6 Showing the Daily Solar Radiation per Month

- *Daily Solar Radiation and Air Temperature of Sokoto per Month*

The daily solar radiation and air temperature data of the study area was obtained from NASA (National Aeronautics and Space Administration) using RETScreen Software and computed in order to show the Column of the yearly solar radiation and air temperature variation. This was aimed at collecting adequate information and data to incorporate in the design of electrical part of the milking machine such as the solar module, charge controller and battery. The solar radiation and air temperatures of host location for the entire year are presented in Figure 1.

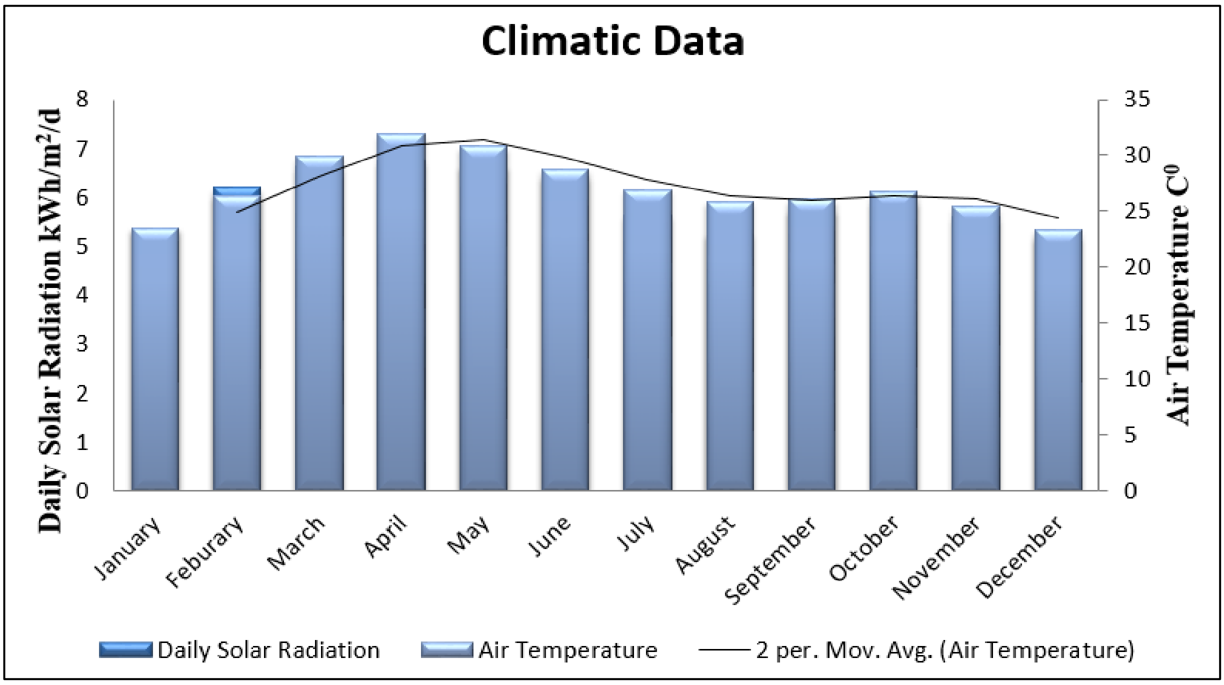


Fig 1 Showing the Daily Solar Radiation and Air Temperature of Sokoto

The average daily solar radiation for Sokoto is around 5 to 6 kWh/m^2/d throughout. However the highest solar radiation was recorded in the months of April and May (6.67-6.65 kWh/m^2/d) while the lowest daily solar radiation was recorded in the months of December and January (5.21-5.37 kWh/m^2/d) with Sokoto receiving an average of 6-7 hours sunshine. The solar radiation received by photovoltaic panels is highly affected by the sunshine duration (Bao & Bao, 2024). Thus the daily solar radiation of Sokoto region can be convenient for solar PV generation.

The daily average air temperature for Sokoto is around 23 to 31ºC throughout. However, the highest air temperature was recorded in the month of April (31.9ºC) while the lowest air temperature was recorded in the month of December (23.4ºC). Solar module has a temperature rating of 25ºC, According to Vivek et al (2015) more solar energy is harvested by the solar module at temperature equal to 25ºC. Therefore with Sokoto experiencing a surge in temperature around April (31.9ºC), a solar module rating higher than the DC load would be needed to maintain efficiency of the system, knowing that increase in temperature leads to increase in current and a decrease in voltage.

- *Energy Requirement for the System*

The average DC load of the system was used as the initial parameter to determine the energy requirement for the design of milking machine.

- *Dc Load (Dc Motor)*

A 12V 80W DC motor was incorporated in the design for extraction of milk from the cow's udder.

Machine milking takes 4-7 minutes, however, for the sake of redundancy we assume 8 minutes. Therefore assuming a small scale dairy farmer has 10 cows, that would require 80 minutes (1 hour 20mins).

Milking twice a day (morning and evening) would take 2 hours 40mins `~ 3hours.

Using a DC motor of 80W

Therefore,

DC Motor = 80W

Hours of operation = 3 Hours

Daily Energy Requirement was expressed by the Equation: $E_D = P_W \times H_D$

$$E_D = 80W \times 3\ Hours = 240Wh$$

- *Solar Module*

The Solar module capacity was determined using the Equation: $N_{sm} = E_D/(C_{sm} \times S_{Hrs})$

Based on availability and future expansion, 200Wp module was selected.

$$N_{sm} = 240\ Wh/(200\ W_p \times 7\ hours_p) = 0.17\ round\ up\ to\ one\ piece$$

Therefore, a piece of 200WP solar module was used.

- *Battery Capacity*

Estimated Energy requirement is determined using Equation 3.3: $E_{est} = E_D \times D_{aut}$

- ✓ No of days of Autonomy (D_{aut}) was taken to be unity, and the Daily Energy Requirement (E_D) was determined as 240Wh
- ✓ Therefore, $E_{est} = 240 \times 1 = 240Wh$
- ✓ The safe energy storage (E_{safe}) was determined using the Equation: $E_{safe} = E_{est}/DoD$
- ✓ The maximum allowable depth of discharge (DoD) for this system was taken as 50% for better long battery life.
- ✓ Therefore, $E_{safe} = 240/0.5 = 480Wh$
- ✓ The Ah Capacity of the battery was determined using the Equation: $E_{Ah} = E_{safe}/V_{DC}$
- ✓ The DC System voltage (V_{DC}) is 12V (voltage of the battery and also the nominal voltage of the module.
- ✓ Therefore, Ah Capacity of the battery, $E_{Ah} = 480\ Wh/12V = 40\ Ah$
- ✓ To make up for rainy days, days with diffuse radiation and energy loss during conversion, and also availability, we recommended a piece of 12V, 100Ah Battery for the system.
- ✓ Therefore we will need a 100Ah Deep Cycle Gel Battery

- *Charge Controller*

The size of the charge controller (I_{CC}) was determined using the Equation: $I_{CC} = I_{sc} \times N_{pm}$

- ✓ From the data sheet of the module as shown in Table 3.4: $I_{sc} = 11.67A$
- ✓ Only, one piece of module was used, therefore, number of modules in parallel, $N_{pm} = 1$
- ✓ Therefore, the size of the charge controller $I_{CC} = 11.67 \times 1 = 11.67A$

Considering a safety factor (tolerance) of about 25%, based on suitability and availability, a piece of 12V, 20A Charge controller was used in this work.

- *3D Prototype Design*

The Design Spark Mechanical software was utilized in the prototyping phase due to its provision of a sketch grid facilitating the creation of three-dimensional designs. The File option was chosen from the menu bar, as we were engaging in the initiation of a new design, while concurrently ensuring that the design tab on the ribbon bar was activated. The plan view, located within the design options of the ribbon bar associated with the sketch tools, was selected, which presented options for various geometric shapes such as rectangles, squares, and cylinders on the sketch grid. The design model was manipulated by tilting it from one angle to another through the action of holding and dragging on the worksheet. Numeric input via the keyboard was employed to establish the dimensions, and the tab key was utilized to alternate between axes. The home view was activated (located at the top left of the ribbon bar) followed by the selection of the Pull tool from the ribbon. In order to augment the thickness of our design, a left-click was performed on the square sketch surface, subsequently pulling the shape upward by several millimeters in the direction indicated by the yellow arrow via left-click and drag. This process was iteratively conducted using a variety of shapes and measurements until the desired three-dimensional model was realized.

- *Construction of Solar-Powered DC Milking Machine*

The solar-powered DC milking machine was constructed from locally available resources such as PVC pipe, reusable water dispenser bottle, rubber liners, suction pump, solar module, charge controller, battery, tubes, and pressure regulator e.t.c with various measurements and parameters.

III. RESULTS AND DISCUSSION

➢ *Design of Solar-Powered DC Milking Machine*

- *The 3D Prototype Design*

The three-dimensional prototype design was executed utilizing DesignSpark Mechanical, as it offered a sketch grid conducive to the development of three-dimensional design models. The File section was selected from the menu bar, as we were in the process of initiating a new design, while also ensuring that the design tab on the ribbon bar was activated. The plan view, accessible through the design options on the ribbon bar from the sketch tools, was selected, presenting various options for geometric shapes such as rectangles, squares, and cylinders on the sketch grid. This iterative process was conducted employing diverse specifications, shapes, and design interfaces until the design was finalized. The three-dimensional model of different sections of the prototype is depicted in Plate 3.

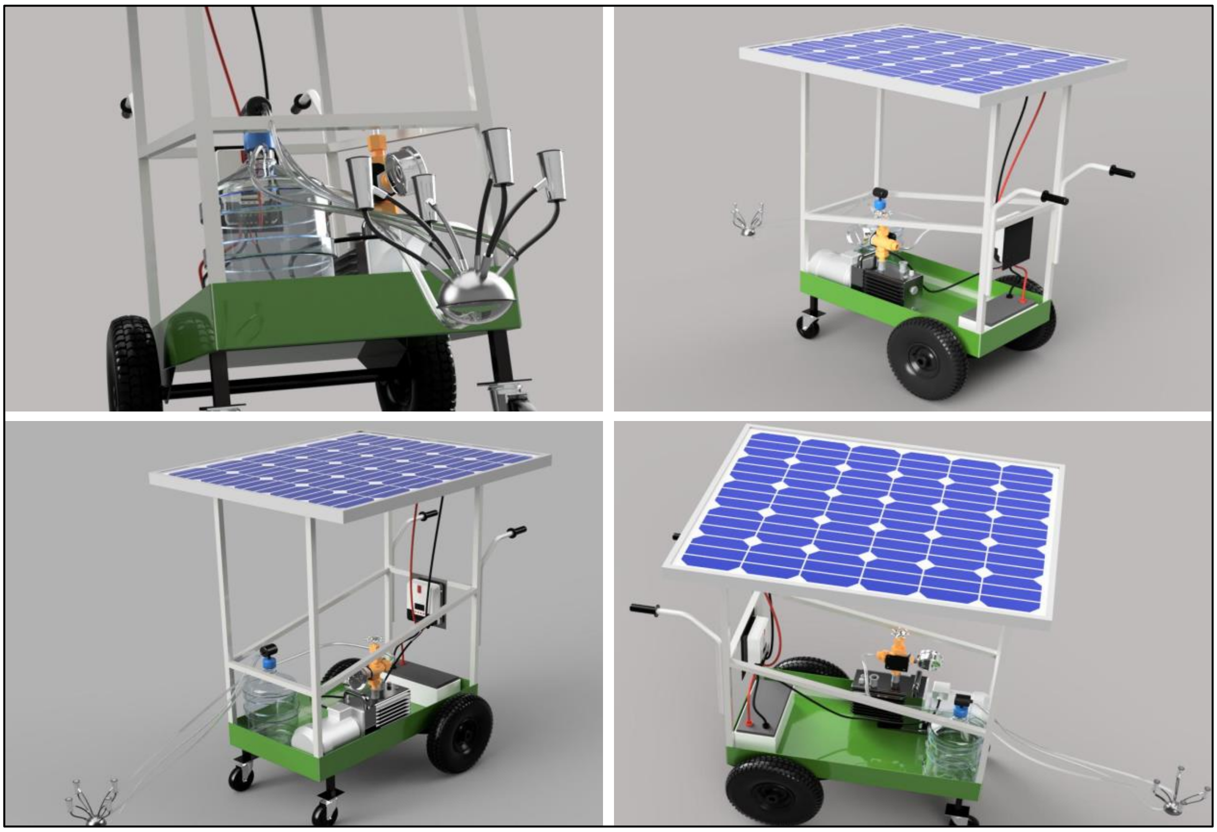


Plate 3 3-D Model of the Solar Powered Milking Machine Design

- *Constructed Solar-Powered DC Milking Machine*

We began the construction of the solar-powered milking machine by assembling the DC which was directly connected to the suction pump. The short milk tube was connected to the teat cups while the long milk tube was connected to the milk bucket and then to the milk claw. The milk liners were then attached to the teat cups to ensure gentle massage of the teat. The constructed solar-powered DC milking machine can be seen in Plate 4.

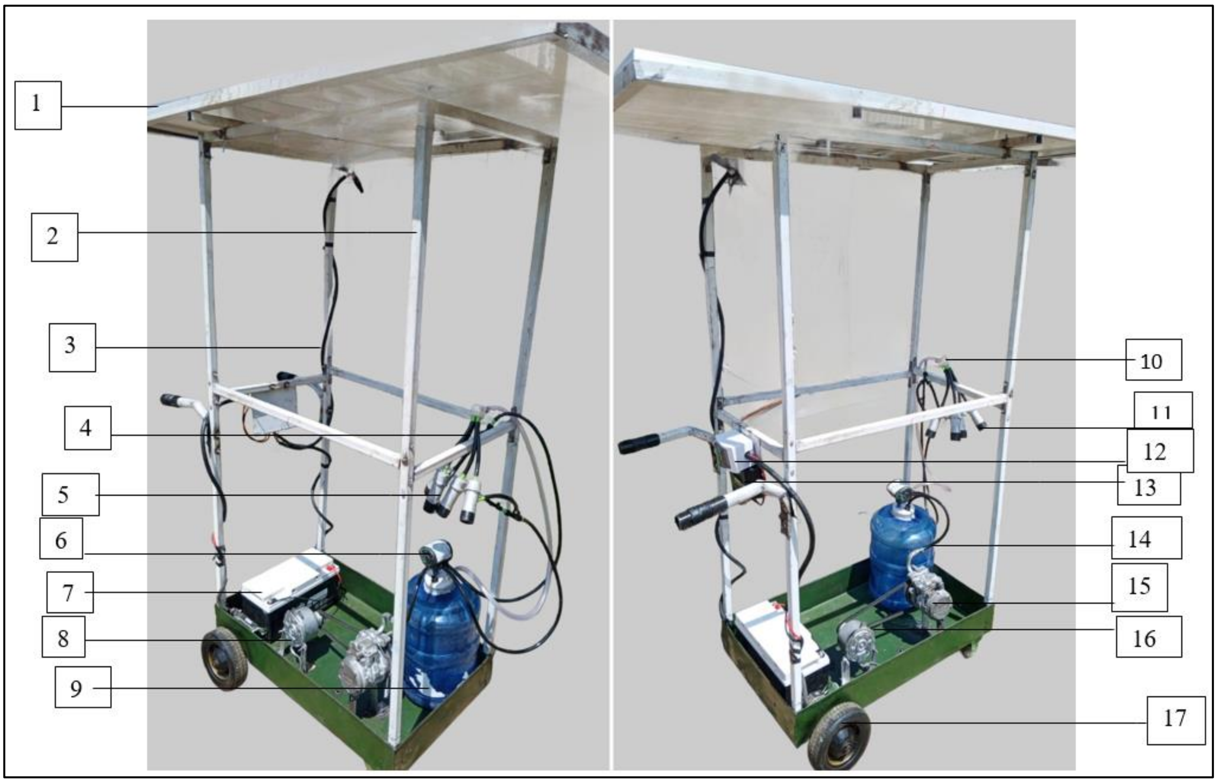
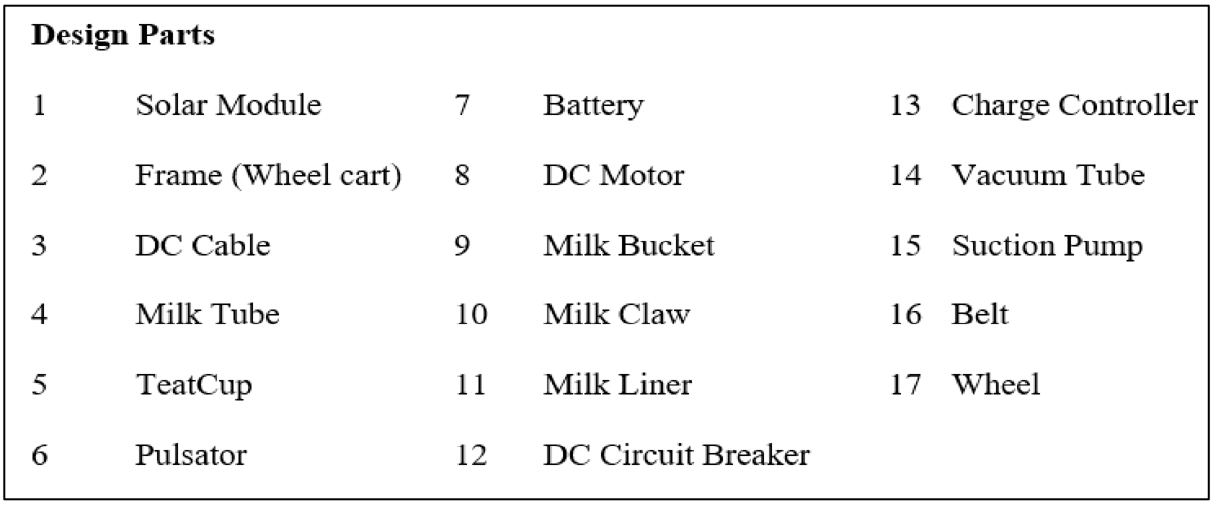


Plate 4 Constructed Solar-Powered DC Milking Machine for Dairy Cattle



Design Parts

1	Solar Module	7	Battery	13	Charge Controller
2	Frame (Wheel cart)	8	DC Motor	14	Vacuum Tube
3	DC Cable	9	Milk Bucket	15	Suction Pump
4	Milk Tube	10	Milk Claw	16	Belt
5	TeatCup	11	Milk Liner	17	Wheel
6	Pulsator	12	DC Circuit Breaker		

Table 7 Specifications of Design Parts

S/N	Materials	Part name	Dimensions
	Solar Module	Man-Tech (Monocrystalline) Solar Module	Length 1485mm
			Breadth 690mm
			Thickness 30mm
2	Deep cycle Battery	Solar plus (Deep cycle gel)	Length 340mm
			Breadth 181mm
			Height 265
3	Charge Controller	PWM Solar charge controller	Length 167mm
			Breadth 90mm
			Thickness 40mm
4	DC Motor	Radiator fan motor	Length 90mm
			Breadth 100mm
5	Suction Pump	Mechanical Compressor	Length 140mm
			Breadth 145mm
6	Teat cup	32mm PVC	140mm
7	Claw	Thermoplastic	Top 50mm
			Base 47mm
			Length 47mm
8	Short milk tube	Multipurpose Garden hose	120mm
9	Long milk tube	Multipurpose Garden hose	820mm
10	Short pulse tube	Multipurpose Garden hose	130mm
11	Long pulse tube	Multipurpose Garden hose	820mm
12	Milk bucket	Dispenser bottle	19.8L
			Length 450mm
13	Vacuum tube	Multipurpose Garden hose	690mm
14	Milk Liner	Rubber tube	150mm
15	Belt	Mechanical belt	340mm

IV. CONCLUSION

Design spark mechanical and RETScreen software were used to design and simulate the feasibility of the milking machine based on the available materials and energy requirement for the system. The 3D model of milking machine was meticulously designed based on the need of the end users using various shapes and specifications, while the electrical part was designed based on the climatic data of the host location using data gotten from the National Aeronautics and Space Administration (NASA). The solar-powered DC milking machine was constructed from locally available materials to reduce the cost of production and suit the need of both small and large scale dairy farmers.

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