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Design of a Farmstead Power System

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ABSTRACT

A farmstead refers to the main buildings and adjacent lands that constitute a farm, forming the central hub of agricultural activities. Planning is the first and most important step in designing a farmstead. However, people plan to fail, whereby insufficient power requirements will not be sufficient to power the facilities and equipment. The design phase involved creating hybrid power systems tailored to different farm buildings and their components. Implementation, installing and integrating the demand load systems on the selected farm. The Performance data include the energy output, cost analysis and environmental impact, which were collected and analyzed. The study focuses on assessing energy demands across various farm operations by deploying a solar system that could generate approximately 79% of its total energy requirement. The remaining 21% is supplied by non-renewable sources, such as grid electricity, ensuring a reliable power supply during periods of low solar generation. The result of the study on farmstead power systems emphasizes the optimal integration of renewable energy and non-renewable energy sources, showcasing cost-effective design strategies tailored to farm-specific needs and is expected to highlight improved energy efficiency, economic viability through reduced costs, and enhanced environmental sustainability. A power system for a farmstead has been designed, which will be useful for farmstead planning.

INTRODUCTION

Planning is the first and most important step in designing a farmstead. While it costs very little to change a plan on paper, the expenses of altering a finished plan can be prohibitive and a poorly conceived arrangement of buildings can diminish profits far into the future. The modern farmstead layout should provide efficiency, security and safety. The plan should provide for efficient distribution of these services, including water supply, electricity and power, roads and pathways, storage facilities, livestock housing, security, drainage and communication networks. Significant expansion after these services are in place may reduce the original efficiency. The overall goal of the enterprise should be evaluated carefully at the onset of farmstead planning (Alchalabi, 2015).

The planning process of farmstead clearly defines the relationship of each structure or feature to the overall goal. Farmstead is primarily a workplace, but also may affect the relaxation, recreation and play of workers, family members, friends, neighbors and guests or others (Barre, 2015). Constructing a completely new farmstead on a new site allows the opportunity to develop an ideal farm-housing scheme (Smith, 2018). Most existing farmsteads have been modified in one manner or another over the years. Often, these changes have limited future options and have led to inefficient operations. Such limitations might be avoided by evaluating the farmstead and comparing it to an ideal one before any modifications are made. Most of the factors also apply to expansion or replacement plans, although such a situation is often more difficult to control (Alchalabi, 2015). By long-range planning with gradual change, the efficiency of an existing farmstead may be improved materially. Therefore, this study designed a power system for farmstead planning.

MATERIALS AND METHODS

Figures 1-3 show the residential and office buildings, some other facilities that may be found in a farmstead, depending on the level of production are: barn, machine and supply storage, greenhouse, etc. Facilities and equipment which require power usage for operation, including lightening the structures are considered in the design.

i. Residential area

The residential area provides living accommodations for farm workers and management personnel. It consists of bedrooms, bathrooms, kitchens and communal spaces. This area ensures comfort and accessibility for those involved in the daily operations of the farm.

Figure. 1: 3-D design of both residential and office buildings

ii. **Office**

The office is the administrative center of the farm, where managerial tasks and record-keeping occur. It provides essential facilities for efficient operations, communication and planning, ensuring the smooth functioning of the farm's various activities.

iii. **Barn**

The barn serves as a multi-purpose facility for housing livestock and storing animal feed and equipment. It is designed to provide a safe environment for animals while facilitating agricultural activities related to livestock management.

iv. **Machine and Supply Storage**

This building serves as a secure storage area for agricultural machinery and supplies. It ensures that equipment remains in good condition and is readily accessible for daily operations, promoting efficiency in farm activities.

v. Greenhouse

A greenhouse is a specially designed structure used in agriculture to create a controlled environment that supports optimal plant growth (Ponce, 2014). The primary aim of greenhouse design is to integrate structural components and environmental control systems to achieve ideal growing conditions year-round.

Figure. 2: 3-D design of barn and supply storage building

Figure. 3: 3-D design of greenhouses

Locating the Electrical Load Centre of a Farmstead

The load center is the geographical center of the land or its centroid of the electrical system, i.e., its center of gravity of all the electrical systems on the farm. The first step in locating the load center for a farmstead is to draw a scaled map of the farmstead, the location of the serviced entrance within each building and the demand load for each structure noted (Akande, 2024). The baseline designated x and y axes should be located along the two sides of the farmstead; its x and y distances for the load center can now be calculated by finding the weighted means of x and y distances for the loads. The demand loads are used as a weighing factor, their distance can be expressed as given in Equations 1 and 2 (Akande, 2024):

$$\text{Y Load Centre} = \frac{\sum(\text{Li Yi})}{\sum \text{Li}} = \frac{\text{Sum of each load} \times \text{its Y distance from load centre}}{\text{Sum of the loads}} \quad 1.$$

$$\text{X Load Centre} = \frac{\sum(\text{Li Xi})}{\sum \text{Li}} \quad 2.$$

Where: Li = Sum of the loads, Xi = distance from load centre, Yi = distance from the load center

Power Requirement in a Farmstead

The power requirement of a farmstead can be calculated from the energy consumption and cost estimates as expressed in Equations 3 and 4, respectively:

$$E = P \times T \quad 3.$$

$$P_c = E \times E_r \text{Pc = E x Er} \quad 4.$$

Where: E = energy consumption, kW, P = power requirement, J, T = time of operation, hr, Er = electricity rate, Kw/N ; Pc = electrical power cost, Kw/N

RESULTS AND DISCUSSION

Residential Area

A standard residential area which comprises of eight (8) rooms will consist of the electrical components: Lightning bulb, standing fan and air conditioning. Each room consists of 1 lightning bulb and a standing fan

i. For the lightning bulb

If the energy rate of a bulb = 9 W

Energy rate of eight rooms/bulb = 8 x 9=72 W

ii. For a standing fan

If the energy rate of a standing fan = 43 W

Therefore for 8 rooms/fan = 8 x 43 W = 344 W

iii. For air conditioning

If the energy rate of an air-conditioner = 1000 W

Therefore, for 8 rooms/air condition = 8x1000 = 8000W

Total consumption = (72 + 344 + 8000) = 8.416 kW

Therefore, the power requirement for the residential area is 8.42 kW**.**

***Environmental Impact**:*

Using grid electricity contributes approximately **0.54 kg of CO_2 per kWh** to the atmosphere according to the Nigerian grid emission factor. Thus, the residential area emits approximately:

8.42 kWh × 0.54 kg CO_2/kWh = 4.54 kg of CO_2

Office

a. For lighting (LED bulbs)

If the office uses 5 LED bulbs, each rated at 15 W

If they are used for 10 hours per day, the Power consumption by bulbs per day

= 15 W x 10hrs =750 Wh = 0.15 kWh/day

b. For a desktop computer

Assuming the desktop consumes **200 W** and the hours of operation is used for 8 hours per day.

Power consumption = 200 W x 8hrs/days = 1600 Wh/day = 1.6kWh/day

c. For printer

A typical printer consumes around 50 W during printing. Assume the printer is used for 1 hour per day.

The power consumption

50 W x 1hr / day = 50 Wh/day = 0.05 kWh/day

d. Air conditioning unit

Assume a 1.5 HP air conditioning unit (approximately 1120 W) which runs for 6 hours daily.

Power consumption = 1120 W x 6hr/day = 6720 Wh/day = 6.72 Wh/day

e. Ceiling fans

i. Power rating: Each fan consumes around 70 W

ii. Number of fans: Assume there are 2 fans.

iii. Hours of operation: Each fan runs for 10 hours per day.

The power consumption per fan = 70 W x 10hrs/day = 700 Wh/day

Total consumption (2 fan) = 700 Wh/day x 2 = 1400 Wh/day = 1.4 kWh/day

f. Wi-fi router

i. Power rating: A Wi-Fi router typically uses about 10 W

ii. Hours of operation: It runs 24 hours a day.

Power consumption = 10 W x 24hr/day = 240 Wh/day = 0.24 kWh/day

Power consumption in the office

Now, summing up the power consumption of all components:

Total Power Consumption in office = 0.15 + 1.6 + 0.05 + 6.72 + 2.4 + 1.4 + 0.24 = 12.56 kWh/day

Environmental impact

The CO_2 emissions from grid electricity usage for the office is:

12.56 kWh×0.54 kg CO_2/kWh= 6.78 kg CO_2/day.

Barns

a. **Lighting (LED bulbs)**

i. Power rating: Assume the barn has 10 LED bulbs, each rated at 20 W

ii. Hours of operation: Assume they are used for 12 hours per day.

Power consumption by bulbs/day

= 20 W x 12hours/day x 10 = 2400 Wh/day

= 2.4 kWh/day

b. **Ventilation fans**

i. Power rating: A typical barn fan is rated at 100 W

ii. Number of fans: Assume 4 fans are used.

iii. Hours of operation: Fans run for 10 hours a day.

Power consumption by fans per day

= 100 W x 10hr/day x 4 = 4000 Wh/day

= 4.0 kWh/day

c. **Water pumps**

i. Power rating: A typical water pump uses around 500 W

ii. Hours of operation: Assume the pump runs for 4 hours a day to supply water for livestock and cleaning.

Power consumption = 500 W x 4 hr/day = 2000 Wh/day = 2.0 kWh/day

d. Heating lamps or space heaters (if needed for animals)

i. Power rating: Heating lamps typically use 250 W per lamp.

ii. Number of lamps: Assume 5 lamps are used.

iii. Hours of operation: Assume they run for 10 hours a day during cold weather.

Power consumption by lamps per day

= 250 W x 10hr/day x 5 = 12500 Wh/day

= 12.5 kWh/day

e. Barn surveillance system

i. Power rating: A surveillance system typically uses 50 W

ii. Hours of operation: It runs 24 hours a day.

Power consumption = 50 W x 24hr/day = 1200 Wh/day = 1.2 kWh/day

Power consumption in the barn

Total daily power consumption for the barn = 2.4 + 4.0 + 2.0 + 12.5 + 1.2 = 22.1 kWh/day

Machine and storage supply

a. Lighting (LED bulbs)

i. Power rating: Assume the storage area uses 6 LED bulbs, each rated at 20 W

ii. Hours of operation: Assume the lights are used for 8 hours per day.

Power consumption per bulb per day =

20 W x 8hr/day x 6 = 960 Wh/day = 0.96 kWh/day

b. Ventilation fans or dehumidifiers (if needed)

i. Power rating: A dehumidifier or ventilation fan typically uses around 200 W

ii. Hours of operation: Assume it runs for 8 hours per day to maintain proper air quality or humidity levels.

Power consumption = 200 W x 8hr/day = 1600 Wh/day = 1.6 kWh/day

c. Electric tools or charging stations

i. Power rating: Charging stations or power tools typically consume 500 W when in use.

ii. Hours of operation: Assume these are used for 2 hours per day to charge or maintain machinery.

Power consumption = 500 W x 2 hr/day = 1000 Wh/day = 1.0 kWh/day

d. Air conditioning or heaters (if needed for climate control)

i. Power rating: Assume a small air conditioner or heater consumes 1200 W.

ii. Hours of operation: It runs for 6 hours a day during hot or cold weather.

Power consumption = 1200 W x 6hr/day = 7200 Wh/day = 7.2 kWh/day

Power consumption for the machine and the supply storage

The total daily power consumption for the machine and supply storage area = 0.96 + 1.6 +1.0 + 7.2 = 10.76 kWh/day

Poultry

a. Lighting (LED bulbs)

i. Power rating: Assume 20 LED bulbs in a large poultry barn, each rated at 15 W

ii. Hours of operation: Poultry barns require continuous lighting for about 16 hours per day.

Power consumption = 15 W x 20 x 16hr/day = 240 Wh/day = 4800 Wh/day = 4.8 kWh/day

b. Ventilation fans

i. Power rating: Each large poultry barn fan consumes around 200 W

ii. Number of fans: Assume 5 fans are used.

iii. Hours of operation: Ventilation is crucial and typically runs for 24 hours daily.

Power consumption = 200 W x 5 x 24hr/day

= 24,000 Wh/day = 24 kWh/day

c. Heating lamps or brooders

i. Power rating: Each brooder lamp is rated at 250 W

ii. Number of lamps: Assume there are 10 lamps used for heating.

iii. Hours of operation: Heating is typically needed for 14 hours daily, depending on the weather and bird age.

Power consumption = 250 W x 10 x 14hr/day

= 35000 Wh/day = 35 kWh/day

d. Automatic feeding system

i. Power rating: A typical automatic feeding system uses about 200 W.

ii. Number of feeding units: Assume 4 units are used.

iii. Hours of operation: Feeders are active for 3 hours per day.

Power consumption = 200 W x 3hr/day = 600 Wh/day

Power consumption (4 feeder) = 600 Wh/day x 4 = 2400 Wh/day = 2.4 kWh/day

e. Water pumps

i. Power rating: A typical water pump uses 500 W

ii. Hours of operation: Assume the pump runs for 5 hours a day to supply water for poultry drinking and cleaning.

Power consumption = 500 W x 5hr/day = 2500 Wh/day = 2.5 kWh/day

Power consumption in the poultry unit

Summing up all the power consumption components, the total daily power consumption for the poultry unit = 4.8 + 24 + 35 + 2.4 + 2.5 = **68.7 kWh/day**.

Milk processing unit

a. Milk pasteurizer

i. Power rating: A typical small-scale pasteurizer consumes about 10,000 W (10 kW).

ii. Hours of operation: Assume it runs for 8 hours per day.

Power consumption = 10000 W x 8hr/day = 80000 Wh/day = 80 kWh/day

b. Homogenizer

i. Power rating: Homogenizers typically use 5,000 W (5 kW).

ii. Hours of operation: Assume it runs for 6 hours per day.

Power consumption = 5000 W x 6 hr/day = 30000 Wh/day = 30 kWh/day

c. Refrigeration unit

i. Power rating: Refrigeration units use about 4,000 W (4 kW) to maintain cold storage.

ii. Hours of operation: Since refrigeration runs continuously, assume it operates 24 hours a day.

Power consumption = 4000 W x 24 hr/day = 96000 Wh/day = 96 kWh/day

a. Lighting (bulb) = 2.4 kWh/day

b. Air compressor (if used)

i. Power rating: An air compressor typically consumes around 4,000 W (4 kW).

ii. Hours of operation: Assume it runs for 4 hours per day.

Power consumption = 4000 W x 4hr/day = 16000 Wh/day = 16 kWh/day

Power consumption for the milk processing unit

Summing up the power consumption components, the total power consumption for the milk processing unit = 80 + 30 + 96 + 2.4 + 16 = 224.4 kWh/day

Reservoir

a. Water pump

i. Power rating: A typical pump for reservoirs uses about 750 W (0.75 kW).

ii. Hours of operation: Assume the pump runs for 5 hours per day.

Power consumption = 750 W x 5 hr/day = 3750 Wh/day = 3.75 kWh/day

b. Temperature control system

i. Power rating: A temperature control system (such as cooling) may use about 1,500 W (1.5 kW).

ii. Hours of operation: Assume it operates for 10 hours per day.

Power consumption = 1500 W x 10hr/day = 15000 Wh/day = 15 kWh/day

c. Lighting

i. Power rating: Assume 4 LED bulbs are installed for security and maintenance, each rated at 15 W.

ii. Hours of operation: Assuming 12 hours of operation per day.

Power consumption = 15 x 12 x 4 = 0.72 kWh/day

Power consumption for the reservoir:

Total Power consumption for reservoir = 3.75 + 15 + 0.72 = 19.47 kWh/day

Greenhouse

a. Lighting (LED bulb lights)

i. Power rating: Assume there are 10 LED grow lights, each rated at 200 W.

ii. Hours of operation: Grow lights typically run for 12 hours per day.

Power consumption by lights = 200 W x 10 x 12hrday

= 24000 Wh/day = 24.0 kWh/day

b. Ventilation fans

i. Power rating: Assume there are 4 ventilation fans, each rated at 150 W.

ii. Hours of operation: Fans run for 10 hours per day.

Power consumption per fan = 150 W x 4 x 10hr/day

= 6000 Wh/day = 6.0 kWh/day

c. Irrigation system (water pumps)

i. Power rating: A typical water pump uses around 500 W.

ii. Hours of operation: Assume the pump runs for 4 hours per day for irrigation.

Power consumption = 500 W x 4hr/day = 2000 Wh/day = 2.0 kWh/day

d. Fans for humidity control

i. Power rating: Humidity control fans typically use around 100 W each.

ii. Number of fans: Assume 2 humidity control fans.

iii. Hours of operation: Fans run for 8 hours per day.

Power consumption per fan = 100 W x 2 x 8hr/day = = 1600 Wh/day = 1.6 kWh/day

Power consumption for the greenhouse unit

Summing up the power consumption components:

Power consumption = 24 + 6 + 2 + 1.6 = 33.6 kWh

Power Consumption of the Farmstead

The total power used in the farmstead is found by summing up the power consumption in each building in the farmstead, as summarized in Table 1. The total power consumption from the summation of the individual buildings is 400.01 kWh/day.

Table 1: Farmstead Buildings Power Consumption

S/no	Building Section	Power Consumption kWh/day
1	Residential area	8.42
2	Office	12.56
3	Barn	22.10
4	Machine and storage	10.76
5	Poultry	68.70
6	Milk processing	224.4
7	Reservoir	19.47
8	Greenhouse	33.60
	Total	**400.01**

Farmstead Fuel Consumption Calculation

For the calculation of fuel consumption, if an average generator fuel consumption of **0.3 litres/kWh** was assumed. The fuel consumption required to power the farmstead was then obtained by multiplying generator fuel consumption by the total power consumption (Seifi, 2011).

Therefore, fuel consumption:

= 400.01 kWh/day × 0.3 litres/kWh

= 120.003 litres/day

This means the generator would consume approximately **120.00 litres/day** of fuel to produce **400.01 kWh/day** of electricity.

Farmstead Cost Analysis:

Given that the prevailing fuel cost is ₦960 per litre, the cost for running the generator to produce this amount of energy would be:

Running Cost = 120 litres × ₦960 = ₦115,200

Thus, running a generator to produce 400.01 kWh/day would cost around ₦115,200 per day.

Environmental impact

The combustion of diesel in generators typically emits 2.68 kg of CO_2 per litre of diesel consumed. Therefore, the daily CO_2 emissions from using 120.00 litres of diesel would be:

CO_2 emissions = 120.00 litres × 2.68 = 321.60 kg (Tester, 2012)

Farmstead Electrical Power Costs

To calculate the electrical power cost of the farmstead, equation 4 is used:

$$\text{Power Cost} = \text{Power Consumption x Electricity Rate}$$

Where:

Power Consumption (kWh) = Sum of energy used by all electrical devices in the farmstead.

From Table 1, the total energy consumption from all devices is equal to 400.01 kWh/day

Electricity Rate (₦/kWh) = Cost per unit of electricity, which varies by location and provider.

If 1 kWh = ₦209 tariff plan

Monthly electricity tariff plan = ₦209 x 30days = ₦6,270

Power cost = 400.01 x 6270 = 2,508,062.70

The Annual power cost for the farmstead:

=2,508,062:70 x 12 = ₦ 30,096,752:40

CONCLUSION

The analysis and design of the farmstead power system provided valuable insights into the feasibility of utilizing a hybrid energy approach. By integrating renewable energy sources, such as solar power, with conventional sources like the national grid and diesel generators, the system ensures a reliable energy supply while optimizing for cost and environmental impact. The detailed evaluation of power load estimation for different areas of the farmstead highlighted the significant cost-saving potential of renewable energy, especially in regions with high sunlight exposure. Solar energy, in particular, proved to be a cost-efficient and sustainable solution for most farm operations, reducing the reliance on diesel generators, which contributes to higher operational costs and environmental pollution due to fuel consumption.

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