

The Dairy Farm Model With Low Cost Alternative Energy

N. Kaewprathum¹, K. Taweeyanyongkul², S. Pangchuntherk¹, S. Choengthong³, K. Boonyanuwat⁴,
G. Podjanaaree⁵, and A. Saraboon⁶

¹Dairy Farming Promotion Organization of Thailand
160 M 1 Mittraphap Road, Muaklek, Saraburi, Thailand
Nattaphorn.k@dpo.go.th

²Asia-Pacific International University
Muaklek, Saraburi, Thailand

³Prince of Songkla University
Surattani Campus, Surattani, Thailand

⁴Livestock Department
Bangkok, Thailand

⁵G. Dairy Farm
Muaklek, Saraburi, Thailand

⁶Energy Office of Saraburi Province
Saraburi, Thailand

Abstract - Thailand has a capacity of 1,067,452 tons of raw milk production per year. This level of production by the dairy industry requires millions of electric energy units annually. The specific demands depend on farm size--small, medium or large. The energy cost for dairy farming is approximately 20-25 percent of total cost. If farmers are able to reduce their energy use, they will be able to increase their profit margins. This study presents a dairy farm model for low-cost alternative energy for a medium-sized farm with 30-50 milking cows. The purpose of this research is 1) to create a low cost alternative energy prototype for medium dairy farms, 2) to determine the value of investment for energy from biogas and solar energy as replacements for fuel and electricity from the main grid, and 3) to discover how to use excess energy to maximize the efficiency of dairy farms. The research was divided into three phases: 1) Electricity generation by a Rooftop Solar Panel on the barn using a 4,500W hybrid inverter for single phase electricity. 2) Electricity generation from biogas for 3-phase appliances, and 3) the use of alternative energy for the barn ventilation to reduce heat stress for dairy cows. The results revealed that the electricity generation by the Rooftop Solar Panel produced a total of 5,855.59 kWh per year or an average 16.07 kWh per day. This reduced the electrical consumption from the main grid by 78-100%. Additionally, the production of biogas from the manure and wastewater, in a modified biogas reactor, produced 61.82 cubic meters of methane and 135.08 kWh of electricity per day. The electricity produced can be used to optimize farm management.

Keywords: Dairy farm, Biogas, Solar energy, Alternative energy, Electricity generation.

1. Introduction

Dairy farms require a lot of electricity particularly during the dry season, when electricity is used to pump groundwater to keep it in the ponds for washing the cow, washing the floor and washing the milking equipment. They also require electric power to boil water for Clean-in-place (CIP) in the milking pipe system. In a dairy farm, many of the loads require high starting currents, such as cooling system; motors; and generators, these heavy loads usually accounting for more than 70% of the total energy consumed. The cooling system/refrigeration needs to be operated 24/7 for preserving products and it is the critical load in a dairy farm.

This research was designed to use alternative energy in dairy farms as a dairy farm model for medium-sized farms (30-50 lactating cows). Integrating a solar roof with a biogas generator, was one of the approaches to develop low-cost dairy farming systems that affect the sustainability of dairy farming. A conceptual of the research was used biogas from a Modified Cover Lagoon Digester (MCLD) with semi-anaerobic digestion technology and generated electricity worked together with electricity from solar cell. The model was an alternative to sustainable dairy waste management and sustainable energy on farms which run on full-scale systems.

Cost-effective measures for the model included low capital costs, low operating costs, low maintenance costs and a short payback period. Biogas was used to generate electricity. The electricity from the biogas was integrated with electricity from solar cells to provide alternative energy integration where farmers can reduce the use of fossil fuels and electricity bills in a way that is economically feasible. On most medium-sized dairy farms, the cost of electricity is the highest production cost. These farms will use electricity for the milking machines, cooling water pump to maintain the quality of raw milk, ventilation fans in dairy houses and also for night-time lighting.

A 4.5 kilowatt solar rooftop installation using a Pure sine Hybrid Inverter, a charger with built-in charge control system was designed. The Hybrid system was a back-up power system using a battery system which saved electricity. It produced electricity in single phase 220 v/ac. The biogas digester was a Modified Covered Lagoon Digester (MCLD) with a capacity of 12 cubic meter of wastewater. The study took place on a medium-sized dairy farm in Saraburi province, located in the central region of Thailand. Modified Cover Lagoon Digesters and rooftop solar systems have many benefits for dairy farmers generating renewable power for dairies that operate in the region. It is also important to support the development of sustainable energy resources. The model farm had 38 milking cows which produced 410 kg of raw milk per day which required 54,000 watt of electricity per day. The electricity current system was single phase 220v./ac and 3 phase 380v./ac. The single phase for lighting, the 1.5 horse-power motor of 2 water pumps and a 0.5 motor of the milking machine was supplied by solar photovoltaic (PV) electricity to replace grid power. The 3 phase current used for the 1.5 hp motor of the cooling tank, the 1 hp motor of ventilation fan and air conditioning 1,000 TBU was supplied by electricity from a biogas generator which also replaced grid power.

This dairy farm model was developed to test the system. The studies alternative energy options were from biogas and solar energy. Wastewater from the milking barn was used to produce biogas. Solar panels are installed to generate electricity according to the demand for electric power on the farm, approximately 4.5 kW, and energy from both sources was used to replace fuel and electricity. The biogas digester and solar cells were designed and modified to suit the conditions of the location. All of the energy requirement of the farm were from sunlight and biogas: For cooking, boiling water to replace LPG. Rooftop solar PV solar cells reserved electricity in a battery and through the operation of an inverter, was used for the milking machines, the pump, the lighting system and ventilation system in dairy barn. A concept was used for the integration of biogas-powered electricity and solar- power electricity. The energy generated by both sources provided for proper management, along with ventilation, in the greenhouse. Optimally temperature is maintained between 25-28° C and 60-68% relative humidity to prevent heat stress in dairy cows. The state of the cows is monitored by observing their breathing. Other behaviours such as feeding and the rate of milk production are also observed.

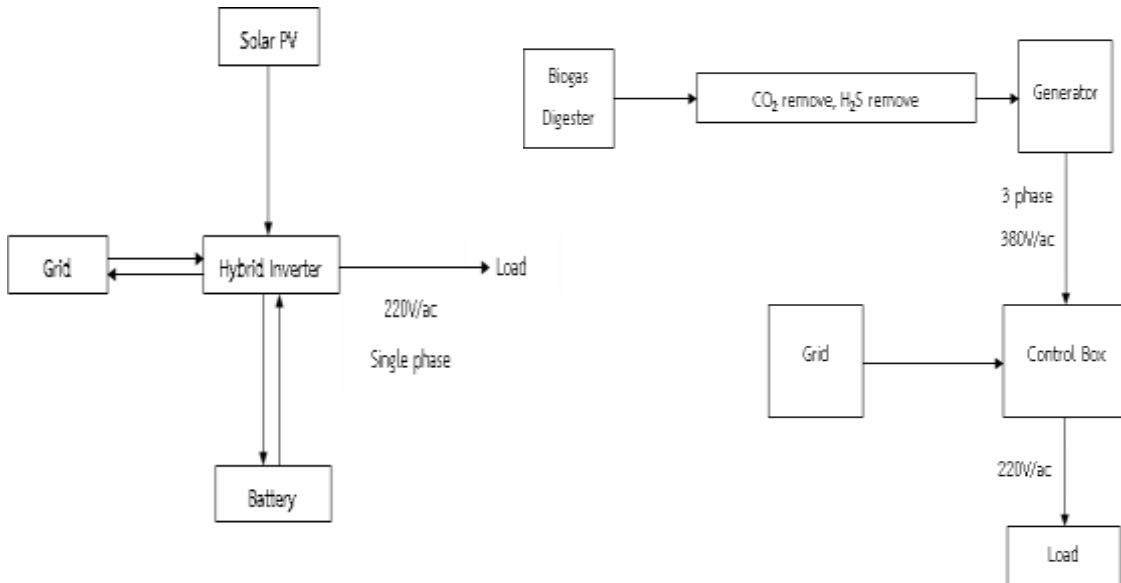


Fig. 1: Diagram of single-phase solar power (left), and three-phase biogas power (right).

2. Materials and Methods

2.1. The Construction of a Modified Covered Lagoon Digester

The lagoon was designed to receive 12m³/day of manure and wastewater from the milking barn by gravity flow through the flushing aqueduct. Gas started to be produced in day 36

The dimensions of the excavated lagoon was 6-meters width, 155.-meter length, 3-meter depth, with sloped sides. It was then covered with 0.5 mm thickness polyethylene (PE) sheet (Figure 3). This gave the lagoon a storage capacity of 232.5 m³.

The modified covered lagoon digester in this study consisted of three main components: A 1.5-mm High Density Polyethylene (HDPE) gas collection cover sheet, a 1-inch diameter steel pipe made into a rectangular frame, and a gas sender polyvinyl chloride (PVC) pipe. The edge of the cover sheet was folded and glued to create a 20cm wide opening through which the rectangular steel pipe was passed. The steel pipe was sufficient to secure the cover in place over the lagoon. A hole was created at the edge of the cover sheet into which the PVC gas sender pipe was inserted and sealed. (Figure 4). This method has a distinctive advantage of being simple and easy to use in rural areas.



Fig. 2: The construction of wastewater lagoon digester.



Fig. 3: Modified Cover Lagoon Digester (MCLD) before (left) and after (right) gas production.

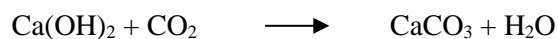
A sample of manure waste water from the housing barn and milking barn before draining into the digester and a sample of water flowing out of the digester were analyzed for parameters shown in Table 1, using the standard methods.

Table 1: The Methods for Wastewater Parameters Testing.

Parameters	Methods
pH (25°C)	APHA-4500-H+B.
BOD, 5 days (mg/l)	APHA-5220 C.
COD (mg/l)	APHA-5210 B. & 4500
TSS (mg/l)	O G. APHA-2540 D.

2. 2. Raw Biogas Production and Purification

The process of biogas production started with 12,045 litres of manure and wastewater from the milking barn that was drained into the digester every day for 196 days. During this period, the biogas digester converted the animal manure waste and flush water into a natural biogas by semi-anaerobic digestion. The gas produced was stored under the gas collection cover before flowing through the pipe to a biogas purification system in which carbon dioxide (CO₂) and hydrogen sulphide (H₂S) were removed. Biogas, theoretically, should be composed of 55-70% methane, 30-45% carbon dioxide, <1% hydrogen sulphide, and some trace water vapour (Res. J., 2016). Several researchers have used different techniques to remove carbon dioxide from biogas (Ghatak & Mahanta, 2016). Some widely used techniques are water scrubbing, membrane separation (Magomnang & Villanueva, 2015) and cryogenic separation under varying conditions (Siripornakarachai & Sucharitakul, 2008). In this study, the biogas was purified by two processes as shown in Figure 5. Firstly, carbon dioxide was removed from the raw biogas using a limestone solution chemical absorption method: A ratios of 40:60 limestone to water solution was prepared in a cement chamber and after the heat that was generated from the exothermic reaction had completely cooled, the raw biogas was passed through the solution. This method was able to reduce the carbon dioxide present in the biogas as shown in the following reaction:



Secondly, the sulphur was removed from the raw biogas. The process used was also able to remove moisture. Iron oxide (regenerated steel wool) was used to eliminate hydrogen sulfide with more than 95% efficiency as shown in the reaction below:

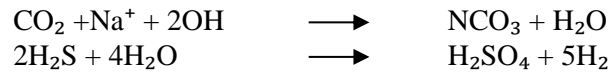


Fig. 4: Biogas Purification with Limestone Solution (left) and Steel Wool (right) before Going into the Generator.

The adsorption of oxidized hydrogen sulfide in the biogas to elemental sulfur and sulfate, using steel wool, helped to minimize any damage that might have occurred to the power generator and to eliminate unpleasant odor that might have affected the environment and the health of the workers. The raw biogas produced from the digester and a purified biogas were quantified using standard methods shown in Table 2.

Table 2: Methods Used For Quantification of Biogas Produced and Purified Biogas.

Parameters	Methods
Methane	Sampling Bag/Total Hydrocarbon Analyzer
Carbon Dioxide	NIOSH Method 6603
Hydrogen Sulfide	Method P&CAM 126

2. 3. Electricity Generated Using Biogas

In theory, biogas can be used as fuel in nearly all types of combustion engines, such as gas engines, diesel engines, gas turbines and Stirling motors etc. (Siripornakarachai & Sucharitakul, 2008). Biogas can also be converted directly into electricity by using a generator (purified biogas is required). The generator produced 3-phase AC electricity. In this study, a Toyota 1JZ-G A/T Model 6 cylinder 2,990 cc 6-valves engine, (Toyota, Japan) turbocharged with an intercooler, was modified and tuned to enable the use of biogas instead of gasohol. It was coupled to an induction motor to work as a 3-phase 4-pole 22 kW generator to produce electricity at 50 Hz capacity.



Fig. 5: A Modified Generator for Three-Phase AC Electricity Using Biogas Fuel.

2. 4. Solar Photovoltaic Installation and Hybrid Inverter

A rooftop solar photovoltaic (PV) system, with 4.5 kilowatt capacity was designed and the 15 panels of 300 watt polycrystalline solar panels were placed, south-facing, on the roof of the housing barn. A hybrid inverter (a relatively new tool for solar PV installations), with 3,000 watts plus and 8-deep cycle batteries with 12 v.250 Ah was used for electricity storage. The solar PV panels, panels, main grids and the batteries were connected to this hybrid inverter. Hybrid inverters enable the selection between renewable energy, energy from the grid and energy storage based on consumption. Unlike conventional inverters, rather than systematically storing energy in batteries, hybrid inverters store energy only when necessary, when there is more production than consumption (Neto, Carvalho, Carioca, & Canafistula, 2010). These systems allow choice between consumption and storage of electricity from PV panels through an internal intelligent apparatus control unit. The technology adds different energy sources--phase coupling: on-grid or grid-tie techniques and the management of stored electricity in the battery--off-grid technology. Hybrid inverters operate on-grid as well as off-grid, and in 'hybrid', both on-grid and off-grid at the same time. Hybrid inverters are PV solar panel installations dedicated to energy auto-consumption of energy (Tiwari, Priyadarshni, & Chaudhary, 2015). A hybrid inverter that, when paired with a charger, by default automatically directs the flow of energy where it is needed most at the time. Electricity from the solar panel array is used first to power any appliances that are on, then to charge the system's battery bank, which can be drawn upon at a later point in time when the sun is not shining. If the battery bank is fully charged, electricity will then be exported to the grid. In this study's design when the battery was discharged to its minimum allowable level, the biogas generator, as a backup source, was switched on (Sahu, 2013).



Fig. 6: Rooftop Solar Photovoltaic Panels on the Dairy Barn (left) and the Hybrid Inverter Connecting to the Grid and Batteries.

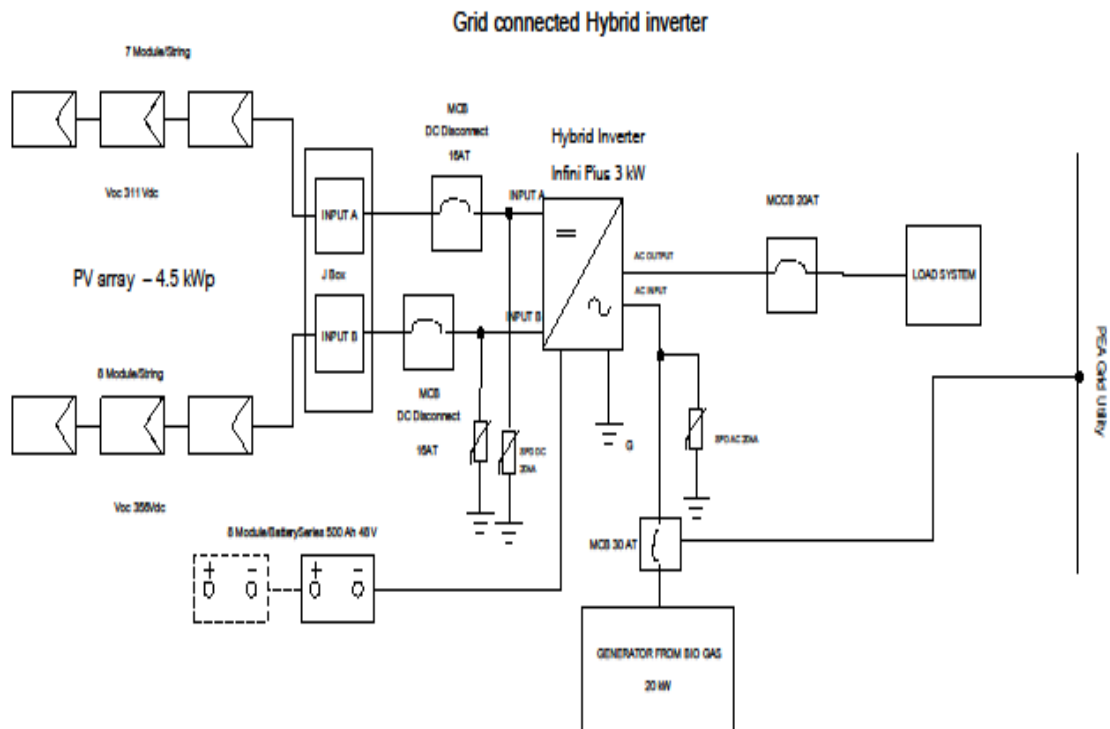


Fig. 7: Electrical circuit of a 4.5 Kw Solar Photovoltaic Rooftop System with a Hybrid Inverter.

3. Results

3. 1. The Modified Covered Lagoon Digester (MCLD) Operation

The wastewater, raw manure from 38 milking cows mixed with flush water, used in this study was about 15-25 percent manure to water. The volume of the liquid in the digester was controlled by the volume of flow into and out of the digester. This was to avoid the hydraulic washout of bacteria. The temperature of MCLD was monitored to not exceed 50° C in order to facilitate mesophilic bacteria growth .

Table 3: Operation Data of the Modified Covered Lagoon Digester.

Description	April, 2017
Number of cows	38 milking cows
Cow feeding	Total mixed Ration (TMR) 39 kg/cow/day The ratio of Napia grass 65%
Quantity of cows manure	648 kg/day
Average influent daily flow	12,045 litres/day
Sources of wastewater; Housing Barn and Milking Barn	100 %
Wastewater way into digester	Flushing
BOD	1,822.0 mg/l

COD	9,240.4 mg/l
TSS	5,053 mg/l
pH	7.4
Temperature in digester	41-46°C
Digester Volume	232.5 m ³
Size of lagoon, width x length x dept.	6*15.5*3 m
Trend free space	10 cm each side
Biogas collection volume(balloon)	232 m ³ with HDPE 1.5 mm.
Weather	37 - 39°C
Time operation	Summer
Digestion system	Integrating with the anaerobic and aerobic digestion
Aerobic digestion	7 days
Study period of the covered lagoon	Day 196 to the end of the study period
Covered space, width x length x high	8.0* 17.5*1.70 m
Free space of wastewater surface in lagoon	10 cm each side
Transfer gas with/ long	PVC pipe 2" diameter, 20 m long from biogas digester to the generator

Table 4: The Results of Organic Removal Rate.

Parameters	Influent	Effluent	Removal%
pH (25°C)	7.4	7.0	5.41
BOD , 5 days (mg/l)	1,822.0	37.9	97.92
COD (mg/l)	9,240.4	115.5	98.75
TSS (mg/l)	5,053	80	98.42

3. 2. Biogas and Methane Production

The results of this study were compared to the theoretical gas production for gas quantity, and the composition was related to the chemical composition of the influent. For the pure substrates, the quantity of gas and its composition were calculated. In theory, “one mole of glucose can produce 6 moles of gas. That means 1 kg of glucose, or any organic matter can produce a maximum of 0.35 m³ of gas. Therefore, maximum gas production is 0.75 m³ gas/kg of carbohydrate. Lipids can yield 1.42 m³/kg of lipids destroyed” (Sahu, 2013). For this study, the 232.5 m³ liquid in the digester was fermented within a semi anaerobic system. The intention was to start the digester at a low loading rate, with 196 days detention time. Sunlight was 10 -12 hours per day at the site. The biogas was analysed after the gas was produced constantly at the maximum rate. Methane at 90.46% was produced as shown in Table 5.

Table 5: Biogas Production.

Biogas	Composition (ppm)	%
Methane	838,800	90.46
Carbon Dioxide	88,400	9.53
Hydrogen Sulfide	33	0.004

The total biogas production was 55.64 m³/d calculated from 9,240.4 mg/l COD of influent revealing 98.75 % of removal. Theoretically, 1 kg of COD loaded converts to 0.35 m³ of biogas (at biogas temperature 0°C). The biogas yielded at biogas temperature 44.3 °C was calculated by the equation below:

$$0.44/273 = V_2 / 308 ; T_1 = 0^\circ\text{C} = 273^\circ\text{K}$$

Where :

$$T_2 = 44.3^\circ\text{C} = 273 + 44.3 = 317.3 \text{ }^\circ\text{K}$$

$$V_2 = 317.3 * 0.40 / 273$$

$$V_2 = 0.511 \text{ Little}$$

When the biogas temperature increase was 44.3 °C (with the stable gas pressure) = 0.511 Little
Biogas yielded Calculation

$$\text{BGG.} = Q * \text{COD} / 1000 * \text{Eff. COD removed} * \text{Gas Yield}$$

Where :

$$Q = 12.045 \text{ m}^3/\text{d}$$

$$\text{COD} = 9,240.4 \text{ mg/l}$$

$$\text{Eff. COD removed} = 98.75 \%$$

$$\text{BGG.} = 12.045 * 9240.4 / 1000 * 98 * 0.51 = 55.46 \text{ m}^3/\text{day}$$

$$\text{Methen (CH}_4\text{) production } 90.46\% = 55.64 / 90 = 61.82 \text{ m}^3/\text{day}$$

Biogas can generate into electricity: Theoretically, 1 m³ of methane produces 2.185 kWh of electricity = 61.82 * 2.185 = 135.08 kWh/day.

3. 3. Total Biogas Heat

Determination of biogas heat by total combustion of 100% methane was 37.6317 MJ / m³ on a dry gas base (Department of Industrial Works, n.d.). This research found 90.46% methane and 9.53 % carbon dioxide which can be calculated for the total heat. The total heat of biogas (dry gas) produced in this study at 44.3 °C, 9.82 pa, was equal to 33.6300 MJ / cm³.

3. 4. Solar Photovoltaic Operation

The ability of the solar PV system to generate electricity in this study was approximately 15.88±1.52 kWh/day between August 2016 and July 2017 as shown in Figure 9. Each panel produced 1.06 kWh/m²/day. Oy Not LLC (2009) found a 5.04 kWh/m²/day average, annually, in Thailand.

Table 6: The Results of Annual Electricity Production from the Solar Photovoltaic System.

Statistic of Electricity Production	
N	12
Mean	15.96
Std. Error of Mean	0.44
Std. Deviation	1.58
Variance	2.49
Minimum	13.34
Maximum	19.10

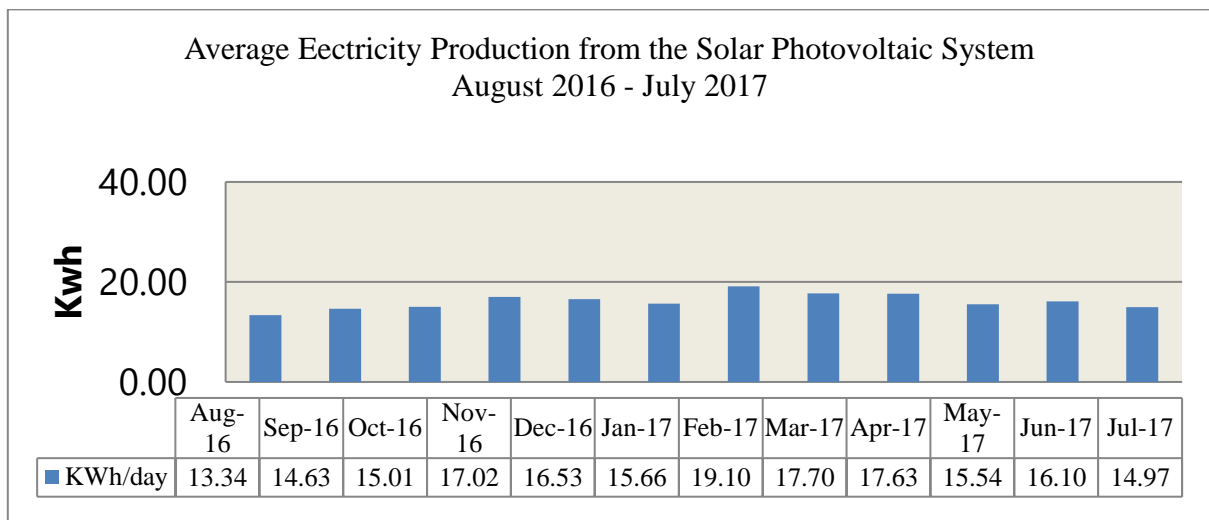


Fig. 8: Average Electricity Production from the Solar Photovoltaic System (kWh/day) between August 2016 and July 2017.

There was fluctuation of electricity production in the month of October, 2016 as shown in Figure 10. During October, 2016 there was quite a lot of rain, the ambient temperature ranged from 36-38°C in the day time, and there was about 2-5 hours of sunlight per day. The electricity produced per day really depended on the hours of sunlight. Within a day, the highest point when electricity was produced was around 11.00 am followed by a slow decline thereafter as shown in Figure 11.

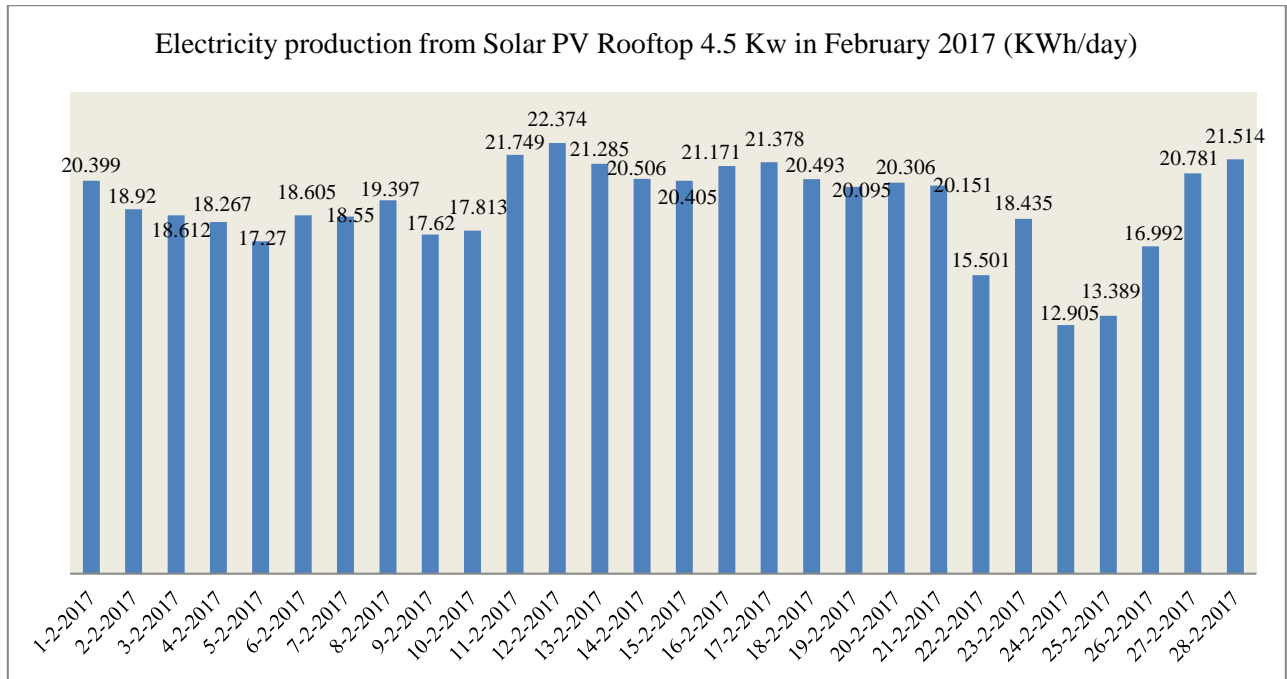


Fig. 9: The Daily Electricity Production from the Rooftop Solar Photovoltaic, 4.5 Kw, Panels in February 2017.

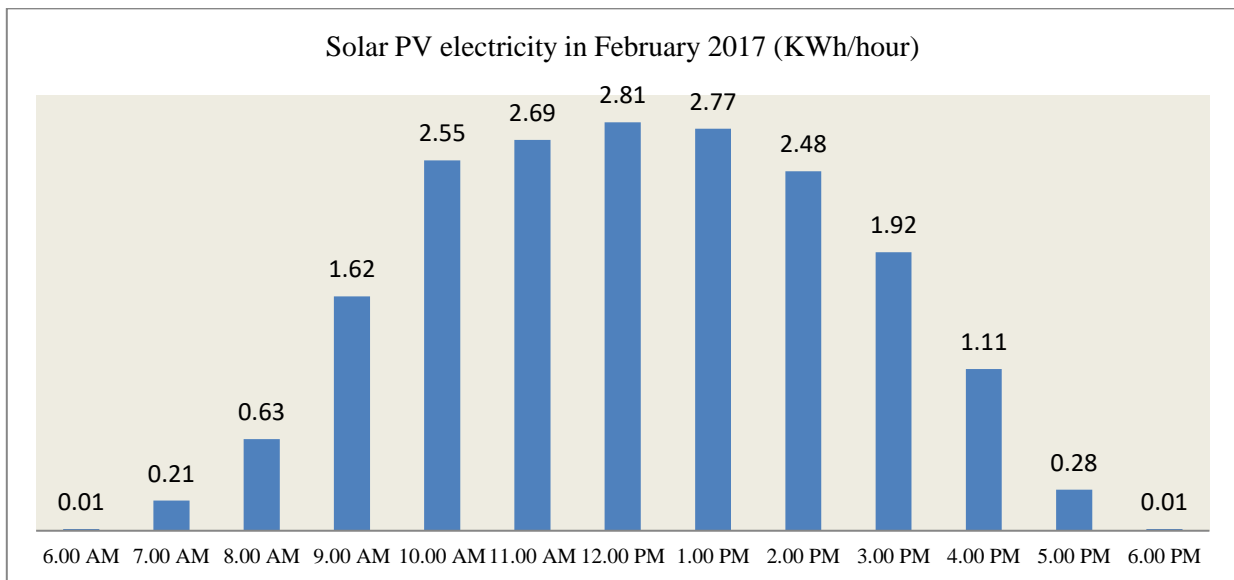


Fig. 10: The Hourly Electricity Production from the Rooftop Solar Photovoltaic, 4.5 Kw, Panels in February 2017.

4. Conclusion

For a low cost alternative energy prototype for medium dairy farms with 38 milking cows, this research designed a solar PV 4.5 KW power system and using 30 m² rooftop array which generated an average of 15.88±1.52 kWh/day of electricity between August 2016 and July 2017. A Modified Covered Lagoon Digester (MCLD) was also designed which received 100% of the liquid manure from the housing barn and milking barn, 12,045 litres/day. Biogas production was 61.82 cubic

meters of methane and 135.08 kWh of electricity per day. Biogas composition was 90.46 % of methane in day 196 of retention time during summer season. The electricity produced can be used to optimize farm management. These two sources of renewable energy replaced electricity from grid by more than 78%. This prototype of a low cost alternative energy can be applied to both on or off grid facilities. It can be the ideal pilot farm for farmers in rural areas as it is simple, low cost, easy to construct, and high efficiency results.

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