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บทความวิจัย

การศึกษาเชิงเทคนิคและเศรษฐศาสตร์ระบบสูบน้ำพลังงานแสงอาทิตย์ระหว่างไฟฟ้ากระแสตรงและกระแสสลับสำหรับพื้นที่เกษตรกรรม

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บทคัดย่อ

งานวิจัยนี้นำเสนอการศึกษาเครื่องสูบน้ำพลังงานแสงอาทิตย์แบบไฟฟ้ากระแสตรง (DC) และไฟฟ้ากระแสสลับ (AC) สำหรับพื้นที่เกษตรกรรม งานวิจัยได้ทำการวิเคราะห์ทั้งทางด้านเทคนิคและด้านเศรษฐศาสตร์ หรือความคุ้มค่าในการลงทุน ซึ่งจะทำให้ได้แนวทางที่เหมาะสมในการนำไปใช้งานในสถานการณ์อื่นได้ ระบบเครื่องสูบน้ำพลังงานแสงอาทิตย์แบบไฟฟ้ากระแสตรง ประกอบไปด้วยแผงเซลล์แสงอาทิตย์ 40 โวลต์ 325 วัตต์ จำนวน 5 แผง ต่ออนุกรมกันเป็นชุดเพื่อจ่ายแรงดันไฟฟ้ากระแสตรงให้กับมอเตอร์ไฟฟ้ากระแสตรง 50–200 โวลต์ และระบบเครื่องสูบน้ำพลังงานแสงอาทิตย์แบบไฟฟ้ากระแสสลับ ประกอบไปด้วยแผงเซลล์แสงอาทิตย์ 325 วัตต์ ต่ออนุกรมจำนวน 10 แผง โดยจ่ายแรงดันไฟฟ้ากระแสตรงผ่านอินเวอร์เตอร์เชิงพาณิชย์ขนาด 3.0 กิโลวัตต์ เพื่อจ่ายแรงดันไฟฟ้ากระแสสลับให้กับมอเตอร์ไฟฟ้ากระแสสลับชนิดเหนี่ยวนำ 3 เฟส 2.2 กิโลวัตต์ (3 แรงม้า) ซึ่งได้เชื่อมต่อโดยตรงกับปั๊มชนิดหอยโข่ง ปัจจัยเปรียบเทียบ ได้แก่ ต้นทุน การลงทุน การก่อสร้าง รูปแบบการจ่ายน้ำและปริมาณน้ำ จากผลการวิจัยพบว่า ระบบเครื่องสูบน้ำแบบกระแสตรงมีต้นทุนการลงทุนต่ำกว่าระบบเครื่องสูบน้ำแบบกระแสสลับเปรียบเทียบในปริมาณน้ำเท่ากัน หากเปรียบเทียบในเชิงเศรษฐศาสตร์ระหว่างระบบเครื่องสูบน้ำพลังงานแสงอาทิตย์ชนิดแบบไฟฟ้ากระแสตรงประเมินผลตอบแทนการลงทุน และระยะเวลาคุ้มค่าการลงทุน เมื่อเทียบกับเครื่องสูบน้ำชนิดเครื่องยนต์เบนซิน จะได้ผลตอบแทนการลงทุนประมาณร้อยละ 27.48 ต่อปี หรือคิดเป็นระยะเวลาคุ้มค่าการลงทุนประมาณ 3.64 ต่อปี ทั้งนี้ ขึ้นอยู่กับประมาณการชั่วโมงการทำงานต่อปี นอกจากนี้ระบบกระแสสลับยังสามารถพัฒนาเป็นระบบไฮบริด กล่าวอีกนัยหนึ่งคือสามารถนำไฟฟ้ากระแสสลับจากการไฟฟ้าจ่ายเพิ่มเข้าโดยตรงที่ชุดอินเวอร์เตอร์โดยไม่จำเป็นต้องมีอุปกรณ์เพิ่มเติม แต่ในทางกลับกันระบบเครื่องสูบน้ำแบบกระแสตรง นั้นมีความซับซ้อนน้อย และง่ายกว่า กล่าวโดยสรุประบบเครื่องสูบน้ำแบบกระแสตรงขนาดเล็ก เหมาะสำหรับพื้นที่เกษตรกรรมขนาดพื้นที่ไม่ห่างไกลจากแหล่งน้ำมากนัก และในขณะที่ระบบเครื่องสูบน้ำกระแสสลับนั้นเหมาะสำหรับความต้องการอัตราการไหลสูงและแรงดันสูง สามารถออกแบบให้เหมาะกับพื้นที่เกษตรกรรมขนาดใหญ่ หรือขึ้นเนิน หรือระยะทางไกลจากแหล่งน้ำได้

คำสำคัญ: อินเวอร์เตอร์ ระบบสูบน้ำพลังงานแสงอาทิตย์ การวิเคราะห์ทางเศรษฐศาสตร์ ผลตอบแทนการลงทุน

การอ้างอิงบทความ: พิรพงศ์ ลิ้มประสิทธิ์วงศ์ และ ชัยยพล ธงชัยสุรัชต์กูล, "การศึกษาเชิงเทคนิคและเศรษฐศาสตร์ระบบสูบน้ำพลังงานแสงอาทิตย์ระหว่างไฟฟ้ากระแสตรงและกระแสสลับสำหรับพื้นที่เกษตรกรรม," *วารสารวิชาการพระจอมเกล้าพระนครเหนือ*, ปีที่ 30, ฉบับที่ 2, หน้า 248–258, เม.ย.–มิ.ย. 2563.

Research Article

A Technical and Economic Study between DC and AC Solar Pump Systems for Agriculture Plant

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Abstract

This research presents the study of DC and AC solar pumps for the agricultural plant in terms of technical and economic analysis. This brings to get a suitable way of applying them in different situations. For DC solar pump, the system consists of 5 panels of a 40 V 325 W solar panel which they are connected in series, DC motor 50-200 V and pumps. For AC solar pump, the system consists of the 325 W solar panel amount 10 panels, commercial inverter (VSD) 3.0 kW and centrifugal pump direct coupling with motor 3 Phase 2.2 kW (3HP). The comparison factors include investment cost, construction, water distribution pattern and water quantity. From experimental results, the DC solar pump system is lower investment cost than AC solar pump system in term of the equal amount of water volume. Moreover, if DC solar pumps compare with the petrol engine pump in terms of economical, it is found that the return on investment (ROI) approximately 27.48% a year with a Payback period of 3.64 years. However it depends on running hour per year. Furthermore, AC system can be developed to a hybrid system without any additional requirement while DC system cannot. Moreover, the DC system is simpler than another once. In conclusion, several small DC systems is more suitable for small flat agricultural area uncentered reservoir while the AC pump system is more suitable for high flow rate and high pressure or meanwhile AC systems can be designed for the agricultural wide area or uphill or long distance from a water reservoir.

Keywords: Inverter, Agriculture, Solar Pump, Economic Analysis, Return on Investment (ROI)

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1. Introduction

Thailand, there is majority of agricultural area [1]. Many people are farmers. The Thai people about 37% are agriculturists [2]. The 238,400 km^2 or 47% of all area 512,000 km^2 in Thailand is agricultural area meanwhile another is the non-agricultural area [3]. In this century, the technologies about agriculture are developed for example automatic water pump control, monitoring and humidity condition control [4], [5]. These technologies need energy resources, but majority of agricultural area is far from power line [6]. The question is what energy should be used suitable. Thailand is in the place where suitable for solar energy. Particularly, Thailand, solar density of radiation is in central region area [7]. Therefore, an alternative energy resource suitable presently for Thailand is solar energy. Because it is more comfortable and efficient for agriculture area [8].

Nowadays solar cell is more efficient than the past especially efficiency of power per area [11], [12]. The cost is less than the past also [13]. Therefore, solar pump system has be rapidly developed. The types of solar pumps consist of AC and DC solar pump systems. The AC and DC solar systems can used well. But the question is an agriculturist should select what type. The selection of pump type depends on area and usage characteristics. The different option of area is suitable different solar pump system. To used highly efficient, the type of system is considered.

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Therefore, in this paper presents a study of DC and AC solar pumps in terms of technical and economic analysis for agriculture plant. By case study in agricultural area of Chachoengsao Province, Thailand. The area is far from power electrical line longer than 1 km.

2. Experimental Setups

The research aims to compare between AC and DC solar pump systems. The condition is on the same environment of water deep reservoir and water discharge head and water quantity volume. The wanted water quantity is about 70 m^2/day. The height from reservoir to target is about 10–15 m.

2.1 Location

The both of systems were installed on tropical flat area at Bang-Nam-Peaw zone, Chachoengsao Province, Thailand as shown in Figure 1. The area refers to latitude 13°48'22.6"N and longitude 100°58'15.7"E [14]. Average temperature is 15–40°C in range [15]. The location where is central region of Thailand has solar intensity throughout a year. The solar peak density of direct radiation is approximately 1,350 kWh/m^2/year. Amount of running hour per day in proposed area is an average of sunshine 8 hours per day [9].

The investigated area split half area by AC/DC pump systems area was 5,600 m^2 the total area was 11,200 m^2 (2.8 acre) where was flat area. The configuration of area was trapezoid shape. The canal was built around area in "L shape" for DC solar pump system. There is a natural canal on other side of area as shown in Figure 1. An AC solar pump was placed near natural canal while two DC solar pump were placed on another side (L shape side) as shown in Figure 1. The water distribution pipe patterns for both of systems were the same but the sizes of pipe were different. The main suction pipe diameter of AC pump was 60 mm. The main discharge pipe diameter was 50 mm and sub main pipe diameter was 37 mm. The water distribute pipe serves to plant diameter was 25 mm. On the other hand, the main suction pipe diameter of DC system was 50 mm the discharge main pipe diameter was 38 mm and the pipe which sever water to plant was 25 mm of diameter.

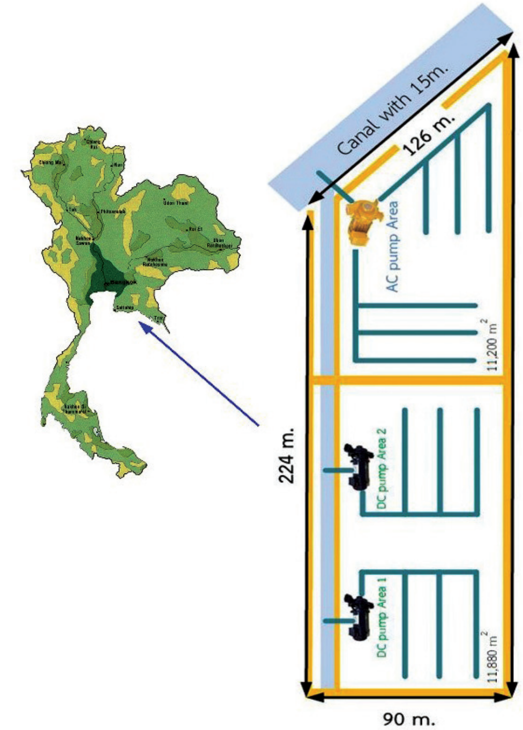

Figure 1: The Experimental Area.

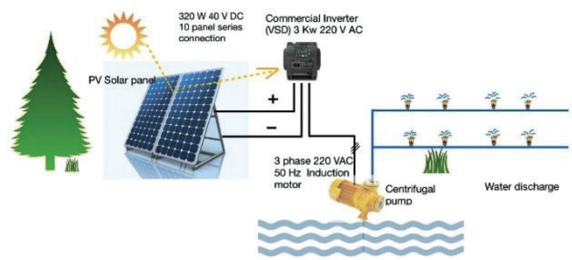

Figure 2: The Diagram of AC solar pump systems.

2.2 Specification of device

For AC solar pump system, the 2.2 kW (3 HP) motor and pump in this study was centrifugal pump total head 15.5 m at Maximum flow rated 30 m^3/h (500 L/min) as refer to technical data in [16] were installed. PV Solar panel "GCL-P6" Maximum power (Pmax) 320 W Maximum voltage (Vmp) 37.6 V Maximum current (Imp) 8.64 A as technical data in [17] 10 panels connected in series were used. The output voltage was about 330–400 V. The 3 kW commercial inverter was applied [18]. The devices in this research were commercial, suitable for economical and endurance. The AC solar pump diagram is shown in Figure 2.

The DC solar pump consists of DC motor brushless type 1.5 kW (2HP) with centrifugal pump was connected direct to solar panel without battery backup. The system diagram is shown in Figure 3. The total generated power and voltage are measured at output solar panel group. The maximum voltage

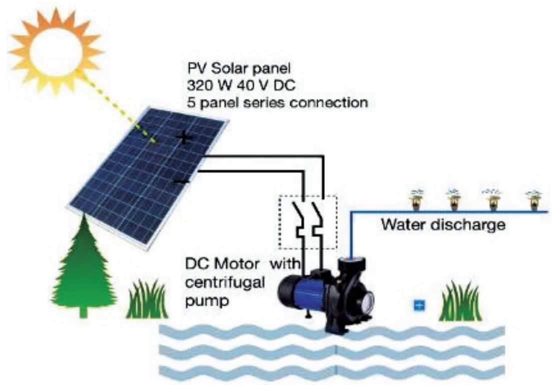

Figure 3: The diagram of DC solar pump systems.

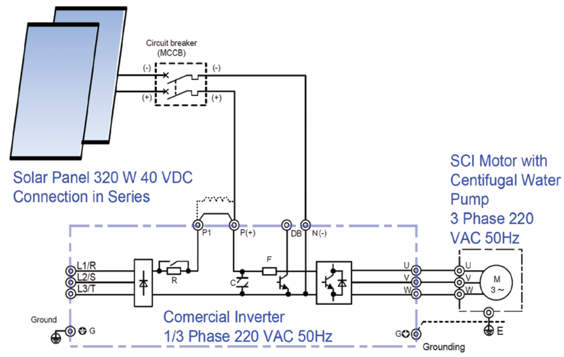

Figure 4: The circuit diagram of AC solar pump system.

is 240 V. The output power and running hour is recorded by data logger.

For DC solar pump system, the set of system consists of 5 solar panels 325 W series connection with 320 W 40 V brushless DC motor is installed. The four poles were used for supporting the panels. The pump type for DC system is centrifugal pump.

2.3 System diagram

The AC solar pump consists of 3-phase 220 V squirrel cage induction motor with centrifugal pump. The solar panels were connected direct from VSD (inverter) without battery backup. The 10 PV solar panels group was connected to DC bus terminals of inverter. The circuit diagram is shown in Figure 4. The total generated power and voltage are measured at DC link voltage which is in internal software of inverter. The maximum voltage capability of inverter is 480 V. The power output and running hour are recorded by VSD software as well.

2.4 The procedure

The research aims to compare between AC solar pump and DC solar pumps. The independent variables are AC and DC solar pump systems. The dependent variables are investment cost, pressure and flow rate. Therefore, the experimental testing process was setup with the same area. The both systems were run the same conditions; area, amount of hour and time. The both systems were running at 7:00 am–5:30 pm. The flow rate was measured a day by turbine meter. The implement was done to find the average value for 7 days.

3. Experimental Results

3.1 Economic analysis

In the same requirements; area and water quantity, the AC solar pump is used just only one set while DC pump is used two sets. The total cost of DC system is a little bit cheaper than AC system. Although construction and motor pump cost of DC is more than another once but DC system has no inverter.

In case of the farmer using petrol engine pump power 3.6 kW (4.8 HP), fuel consumption 1.4 L/h and cost of new unit 700 USD [19]. The total cost of AC, DC and petrol engine pump systems it is shown in Table 1.

Table 1 Comparison between cost of AC and DC and Engine pump system

The List	1 set of AC Solar Pump	2 set of DC Solar Pump	Petrol Engine
Solar Panel	1,500 USD	2×750 USD	0 USD
Construction	400 USD	2×280 USD	30 USD
AC Inverter	625 USD	0 USD	0 USD
Motor or Engine with Pump	350 USD	2×250 USD	700 USD
Piping Cost	200 USD	2×150 USD	200 USD
Total Investment Cost	2,975 USD	2,860 USD	930 USD

3.2 Water flow rate

The maximum of overall voltage and power depend on irradiance as shown in Figure 5 [20]. It is investigated that a motor pump will run in a range of generated voltage. For DC solar pump, it is started at lower voltage than AC solar pump. DC solar pump starts running at 18 V/panel while the AC solar pump will start at 20 V/panel. That means DC system needs lower irradiance than AC system. Therefore, in some area where is low irradiance or low amount of hour solar light, the DC system is more suitable than AC system.

For the AC solar pump speed controlling by commercial inverter, the commercial inverter normally not applicable for fluctuated voltage like solar power supply and inverter will be tripped. The control technique program setting is importance and needed for solar power supply such as min-max speed control, ramp up and down, V/f with a quadratic characteristic controller, sleep mode and Flying restart control technique.

The frequency or motor speed is affected by inverter DC-Link voltage. If solar radiation intensity

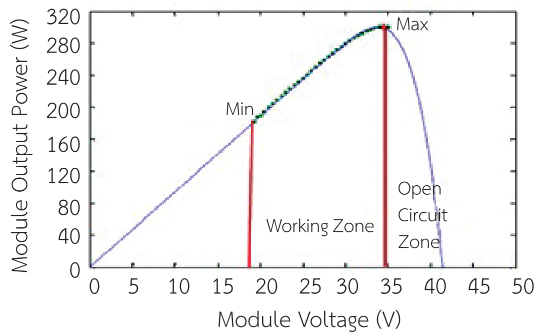

Figure 5: PV operating point of AC solar pump.

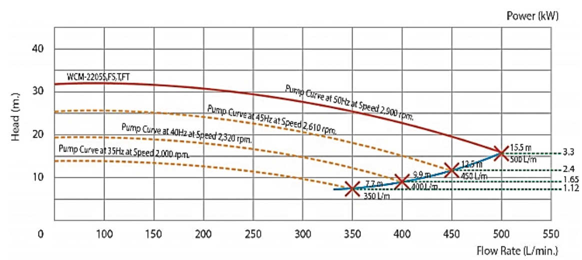

Figure 6: The pump performance curve of AC solar pump with multi frequency.

is high, it is shown that at maximum speed 50 Hz, the curve is the best continuous. So, it effects on the most quantity of water. Sometime solar irradiance is not enough. The inverter will reduce speed following solar irradiance but not lower than limit setting. The result water flow compare to speed is shown in Figure 6 [21].

Table 2 shows flow rate of both systems. It is found that the flow rate of AC solar pump is in range of 77–108 m^3/day. The average is 92 m^3/day. Figure 7. Show comparison of AC and 2 DC solar pumps, flow rate is in range of 107–150 m^3/day. The average is 145 m^3/day.

The two DC solar pumps systems generate water flow higher than AC solar pump systems about 33.60%.

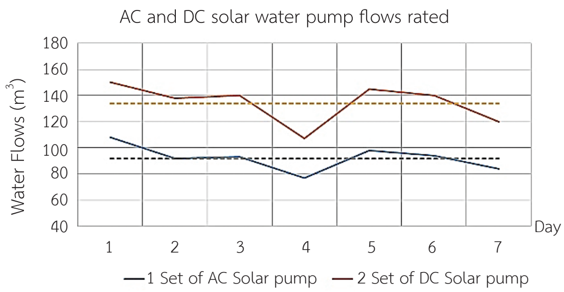

Figure 7: AC and DC solar water pump flows rated.

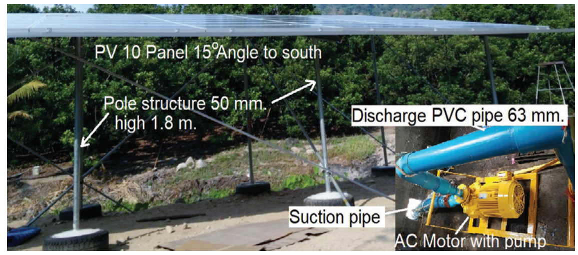

Figure 8: The 10 set of PV Panel construction for AC systems.

Table 2 AC and DC solar water pump flows rated

The List Day	1 Set of AC Solar Pump (m^3/day)	2 set of DC Solar Pump (m^3/day)
1	108	150
2	92	138
3	93	140
4	77	107
5	98	145
6	94	140
7	84	120
Average	92	145

3.3 Construction analysis

The constructions of both solar pump systems are shown in Figure 8.

The poly solar panel type was chosen. The pole structure made of steel pipe 50 mm diameter. For AC system needs 6 poles and DC system needs 2x4 (8) poles. Both of systems, the pole height is approximately 1.8 m the steel beam of C type is used which the angle fixed at 15° in direction of north and south [22]. The maximum flow rate and maximum head (pressure) of pump depending on pump type and pump performance curve such as piston pump or centrifugal pump, in this case selective centrifugal pump flow rated 27 m^3/h with 18 m of head while the flow rated of DC pump is 12 m^3/h with 10 m of head. The piping sizing is depended on pump flow rated which AC system used 63 mm diameter PVC pipe while DC system used 38 mm diameter PVC pipe.

The AC system covered area more than DC system, thus the DC system needs 2 solar pumps to cover the same area. However, AC system needs inverter but DC is not. By this reason, the investment cost of DC system is cheaper than AC system. The detail is shown in Table 3.

Table 3 AC and DC solar pump system comparison

The List	AC Solar Pump	DC Solar Pump
Solar Panel	10 PV poly type panels of 320 W, 40 V series connection	5 PV poly type panels of 320W, 40 V series connection
Solar Structure	6 Poles by 50 mm Steel Piping Pole and C type steel beam	2x4 Poles by 50 mm Steel Piping Pole and C type steel beam
Motor	3 kw 230/400 V SCI Motor	1.5 kw 50–200 V Motor
Pump	Max Flow 27 m^3/h At head max 18 m	Max Flow 12 m^3/h At head max 10 m
Piping	63 mm	38 mm
Covered Area	5,500 m^2	2×2,800 m^2
Inverter	3 kW commercial Inverter	No Need
Accessories	AC. Circuit Breaker and Power cable	DC. Circuit Breaker and power cable
Investment Cost	2,975 USD	2×1,430 USD

3.4 Economic analysis compares with petrol engine pump

The economic analysis is calculated based on the cost of investment and consumption cost of petrol comparison between DC solar pump and engine pump system [19]. The maintenance cost is gotten by lubricant for engine system while for solar is gotten by cleaning and fitting.

The fuel for petrol engine water pump running 1.4 L/h was gotten 7 liter a day base on 5 h per day running and assumption average running by 90 days a year. Total fuel consumption for fixed speed engine pump was 630 liter per year or the cost of fuel approximately 1.1 USD/L the summery cost is shown in Table 4.

Table 4 Comparison between cost of DC solar and engine pump.

The List	DC Solar Pump	Engine Pump
Investment (I)	2,860 USD	930 USD
Maintenance (M)	50 USD/year	100 USD/year
Estimate Working	450 h/year	
Fuel Cost (F)	0 USD/year	693 USD/year

From the table, the average cost per year are gotten by as the Equation (1)–(3)

$$\text{Cost}_{\text{avr}} = \frac{I + ((M + F) \times L)}{L} \tag{1}$$

$$\begin{aligned} \text{Cost}_{\text{av}}\text{Solar} &= \frac{2,860 + ((50 + 0) \times 20)}{20} \\ &= 193 \text{ USD/Year} \end{aligned} \tag{2}$$

$$\begin{aligned} \text{Cost}_{\text{av}}\text{Engine} &= \frac{930 + ((100 + 693) \times 5)}{5} \\ &= 979 \text{ USD/Year} \end{aligned} \tag{3}$$

Table 5 Comparison between Average Cost per Year of DC solar and engine pump systems.

The List	DC Solar Panel	Engine Pump
Systems Life Time (L)	20 years	5 years
Average Cost Per Year	193 USD	979 USD
Return of Investment (ROI) and PB	ROI of Solar pump 27.48% per year or payback period 3.64 Years	

Therefore, the average cost per year both of system are shown in Table 5. It is shown that the average cost per year of DC solar is less than average cost of engine pump system. Moreover, Engine pump systems consumption average cost more than solar. The return of investment (ROI) and Payback Period (PB) are gotten by as the Equation (4), (5)

$$\begin{aligned} \text{ROI} &= \frac{\textit{Average Profit}}{\textit{Investment cost}} \times 100 \\ &= \frac{979 - 193}{2860} \times 100 \\ &= 27.48\% \end{aligned} \tag{4}$$

$$\begin{aligned} \text{PB} &= \frac{\textit{Investment cost}}{\textit{Return on Investment}} \times 100 \\ &= \frac{2860}{(979 - 193)} \times 100 \\ &= 3.64 \text{ Years} \end{aligned} \tag{5}$$

The estimate return of investment (ROI) is 27.48% comparing to DC solar pump gain more than engine pump or on the other hand payback period 3.64 years depending on assumption running hour a year. From the result shows that solar initial cost is higher but in the long term more saving than engine pump systems. Furthermore, solar pump is more convenience to operate and durable than other.

3.5 Agricultural sector

In the term of agriculture, the water supply system is important. In the case of large area or high uphill area which there is just only one water reservoir very far from the water terminal. AC solar pump is more suitable than DC system. Because AC solar pump can be selected high pressure and it can be bought in general commercial market. However, AC system is more expensive and complicated than DC system. By the way, DC solar pump is suitable for flat area where the reservoir is not far from the water terminal. Because its power is smaller than AC system. The DC solar pump has not more various high pressure. However, it is simpler than AC system because it has no inverter so it is cheaper. Another thing about DC solar pump, in case of large flat area is not suitable but the solution is the canal making to reduce distance from reservoir to target.

4. Discussion

Power optimization of AC/DC systems, the requited minimum voltage for AC system is 200 V from solar panel. That means it needs at least 8 panels which generated power about 2.4 kW. Therefore, in this case the motor is selected at 2.2 kW. The AC pump system is suitable for power rate starting from 2.2 kW. By the way, DC motor pump in commercial is available 300-1500 W. Therefore, in this case, 1.5 kW is selected. The advantages of DC are small, low investment, easy to install and suitable for farmer.

Head or pressure requires for AC solar pump is higher than DC solar pump system. However, AC needs maintenance by technician while DC system is simpler than AC system. AC system is more covered area than DC system. For example, at the same area DC system needs two pumps but maybe AC system needs only one pump. If the pump is breakdown, AC solar pump system cannot run while DC system can run by another pump during repair another pump.

Economic sector, the DC solar pump is more economic than AC system. Because investment cost is lower and less maintenance than AC system. The weak point of AC system is life time of inverter. The inverter is electronic device so it is in the condition that low temperature, dry, no humidity and no dust. That place has less in agriculture area.

Normally inverters in commercial market can be used into two connection form; DC bus and AC input of inverter.

Firstly, it can be connected to the DC bus terminals P (+), N (-) according to Figure 4. In this case the pre-charging circuit of the inverter is not used. Therefore, the PV panel was connected to the inverter maximum irradiation should not be over voltage than capacitor rated.

Secondly, it can be connected to the AC supply inputs terminal L and N (-) according to Figure 4. In this case the pre-charging circuit of the inverter is used to limit the initial charging current of the inverter DC link. This can be applied to hybrid with AC power source systems.

5. Conclusions

From experimental results, it can be concluded as following.

1) DC solar pump system is less complicated, and easier to maintenance.

2) DC solar pump systems have more efficient than AC water pump and in term of economics

calculation by estimate compare to petrol engine pump system, The return on investment (ROI) cost is approximate 27.48% a year. The Payback period (PB) is approximate 3.64 years.

3) DC solar pump systems cannot deliver water for long distance but It's suitable for nearby multi distribution spread in a circle. While AC solar pump system can deliver high volume and long distance.

4) The AC water pump can be applied to Hybrid power supply from the public electric supply without addition equipment.

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