Development of solar power system for Sarawak peat water continuous electrocoagulation treatment process

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Abstract. Sarawak state government has established Sarawak Alternative Rural Water Supply (SAWAS) programme in order to serve as a purpose of providing safe and clean water to the rural communities not connected to municipal clean water supply. In the rural areas of Sarawak, particularly on the coastal region where municipal water supply is not available, the villagers are normally resorted to utilize rainwater and peat water for daily usage. Some of these rural areas are even not connected to electricity grid. Subsequently, one of the proposed methods to eradicate these problems in supplying clean water without electricity supply grid is to implement stand-alone water treatment system with solar power system. As such, the main aim of the study is to design a solar power system to support Sarawak peat water electrocoagulation treatment process. The study is divided into two stages. In the first stage, the study designs a solar power system to support the treatment process of peat water for both batch and continuous electrocoagulation systems. This includes designing and fabrication of a small-scale solar power system. The second stage of the study involved experimental studies on both batch and continuous electrocoagulation systems in order to study the effectiveness of solar power system to supply electricity for the electrocoagulation systems. Overall, the study has developed a solar power system for both batch and continuous electrocoagulation of peat water system. From the experiments conducted, the developed systems are capable to reduce 18.8% and 46.15% of peat water turbidity for batch and continuous electrocoagulation systems respectively. However, in order to meet a more stringent drinking water standards, some improvements on the designed systems are indispensable.

1. Introduction
Located in the northwest of Borneo, Sarawak has a population of about 2.6 million [1] in which electricity grid need to be extended through rugged terrain and thick jungle in order to reach isolated communities. However, extending such grid to sparse and remote communities is not always practical in economic terms [2]. Hence, there are still about 30,000 remaining rural households which are not connected to the electricity grid [3]. For villages located more than 30 km from the electricity grid, an off-grid method is preferred [1]. Sarawak is located near the equator line where the climate is hot and
humid throughout the year. The state ambient temperature is approximately from 22 °C to 33 °C with monthly solar radiation of 400–600 MJ/m² [4,5]. Correspondingly, solar energy is one of the promising renewable energy in the state due to the strategic location where solar energy can be harvested throughout the year [4].

Peat water is abundantly found in peatland due to availability of underground water and rainwater. Malaysia has approximately 2.6 Mha of peatland in which over 70% of the total peatland in Malaysia is located in Sarawak [6]. Peat water is commonly used for domestic usage in rural coastal areas households which are yet to receive clean water from the municipal water supply. However, direct consumption of peat water is not advisable, hence, a simple and versatile water treatment system such as electrocoagulation treatment is useful in this case. Electrocoagulation is a water treatment process which is an alternative to chemical coagulation process. The process is capable of reducing the need for chemical coagulants since the electrodes provide the coagulants [7]. Essentially, electrocoagulation process is an environmentally friendly process, and it is significantly less complicated unlike other conventional water treatment methods. Electrocoagulation water treatment had been known for its beneficial advantages including relatively low costs, the possibility of complete automation with high efficiency of particulate removal at a compact treatment facility [8]. This method is characterized by minimum use of chemicals in the process, easy operation and reduced sludge production [9,10]. Moreover, electrocoagulation process have the ability to treat water with low temperature and low turbidity, while it is effective in a wide range of water pH ranging from pH 4 to pH 6 due to its neutralization effect [11]. Additionally, electrocoagulation flocs are large, stable, acid resistant and contains less bound water allowing it to be separated faster by filtration; contains effluent with less total dissolved solids (TDS) that contributed to low water recovery cost; produced gas bubbles to carry pollutant upwards for easy collection and removal; and most importantly convenience for use in rural areas with no access to electricity since solar panel attached to the unit may be sufficient to run the treatment [12]. As 13%, of the Sarawak state's total area is peatland. This imposes the existence of peat water which contains some natural organic matters that causes foul smell, colour, taste and the acidity issues [13]. Consequently, this study is aimed to develop a stand-alone water treatment system which is expected to be able to mitigate this problem. The system should be cheap and could effectively treat peat water. In addition, the technology used for the fabrication process of this water treatment system should be available locally in which easy to maintain and fabricate.

2. Methodology

There are a total of three main tasks performed in this project which includes (i) design and fabrication of solar power system, (ii) experimental studies, and (iii) evaluation of solar system for electrocoagulation treatment system.

2.1. Design and fabrication

The design and fabrication process are divided into two parts, (i) design and fabrication of the solar power system and (ii) design and fabrication for the automation of both batch and continuous electrocoagulation of peat water treatment system. The design of the systems is based on these criteria: (i) Materials used are readily available locally, (ii) Simple fabrication and maintenance process, and (iii) Low fabrication and operating cost.

2.1.1. Solar power system sizing. The solar power system sizing is done by initially determining the initial value of power demand, solar panel arrangement, battery storage capacity sizing, charge controller, inverter, and load management. The sizing calculations are performed for the solar power system as depicted in figure 1.
There are several equations used in solar power system components sizing. First, for Photovoltaic (PV) module sizing, it is crucial to investigate the electrical specification of the PV panel. The formula used for the calculation of PV module sizing is stated by equation (1) and the calculation of the number of PV panels needed is shown in equation (2).

\[ S_p = \left( \frac{Avg_L}{Avg_{\text{sun}}} \right) \eta \]  

\[ N_{\text{max}} = \frac{V_{\text{bat}} \times I_{\text{max oc}}}{P_{\text{np solar}} \times \eta} \]

Where,  
\[ S_p \] = Sizing of Solar Panel  
\[ Avg_L \] = Average daily load  
\[ Avg_{\text{sun}} \] = Average daily peak sun-hours  
\[ \eta \] = Efficiency factor  
\[ N_{\text{max}} \] = Maximum number of PV panel  
\[ V_{\text{bat}} \] = Voltage of the battery  
\[ I_{\text{max oc}} \] = Maximum output current  
\[ P_{\text{np solar}} \] = Nominal power of solar

Second, charge controller is designed in order to prevent battery from overcharging in which it might affects the performance of the battery as well as reducing the battery lifespan. The formula to calculate the size for standard charge controller is stated by equation (3).

\[ SCCR = \sum I_{SC} \times 1.3 \]

Where,  
\[ SCCR \] = Solar charge controller rating  
\[ \Sigma I_{SC} \] = Total short circuit current of PV array

Third, the battery is used as backup storage to overcome uninterruptible power supply (UPS). Equation (4) is used to calculate battery capacity [14] while Equation (5) is used to calculate the required number of batteries.

\[ BC = \frac{TW}{0.85 \times 0.6 \times NBV} \times DOA \]

\[ NBV = \text{Nominal battery voltage} \]  
\[ DOA = \text{Days of autonomy} \]  
\[ BC = \text{Battery capacity (Ah)} \]  
\[ TW = \text{Total watt-hours per day used by appliances} \]
Ah req
bat
CN C
ρ = (5)

Where,

\( N_{\text{bat}} = \frac{C_{\text{Ah, req}}}{C_{\text{bat}}} \) (5)

Fourth, the inverter is used to convert DC voltage to AC voltage. The sizing of the inverter is calculated by using equation (6).

\[ S_i = T_L \times \left( \frac{1 + Af}{Le} \right) \] (6)

Where,

\( S_i \) = Size of inverter
\( T_L \) = Total load
\( Af \) = Additional further load expansion
\( Le \) = Efficiency of inverter

2.1.2. Automation of the water treatment system. The automation of water treatment is done for both batch and continuous system. For batch process, water level sensor and motor stirrer are installed. The water level sensor acts as a switch in which it is able to turn on and off the pump within a range of level limit. The motor stirrer is installed to create turbulence during the electrocoagulation process. This is to provide some comparison studies of mixing and unmixing process [15]. Flow rate sensor and turbidity sensor are installed for the continuous system. Flow rate sensor is installed to measure the flow rate of the liquid entering the system as the flow rate affected the efficiency of the continuous electrocoagulation system. Turbidity sensor is installed to measure the turbidity of the treated water during the electrocoagulation process.

2.2. Experimental studies on the effect of the angle of the solar panel
The experiments are conducted on the effect of solar panel angle at 20°, 25° and 30° while being coupled with mimic loads of continuous electrocoagulation which are 5W Alternating Current (AC) pump, 18W AC bulb, 5W Direct Current (DC) bulb as shown in figure 2. The experiment is conducted for three days in a row on sunny day. The averaged three days’ results obtained are then evaluated in accordance to temperature, irradiance received, power generation, voltage output and current output.

2.3. Evaluation of solar system for electrocoagulation treatment system
There are two different systems for electrocoagulation treatment employed in this study which are the batch and continuous system as shown in figure 3a and figure 3b respectively. The optimum angle as
investigated is used to generate electricity to power up the electrocoagulation treatment system. Table 1 shows the operating parameters for both batch and continuous system.

![Figure 3a. Batch electrocoagulation system.](image1)

![Figure 3b. Continuous electrocoagulation system.](image2)

| Parameter               | Batch                  | Continuous             |
|-------------------------|------------------------|-------------------------|
| Electrode spacing       | 2 cm electrode spacing | 0.7 cm electrode spacing|
| Number of electrodes    | 8 number of electrodes | 20 number of electrodes |
| Treatment time          | 2 hours                | 20 hours               |
| Amount of treated water | 1 litre                | 1 litre                |

### 3. Results and discussion

#### 3.1. Experimental studies on solar power system configurations

The variables affected by the solar panel angle are temperature, irradiance, power generated, voltage output and current output. The results of temperature and irradiance are depicted in figure 4 and figure 5, respectively. On clear weather, the temperature increases in corresponding to the irradiation. However, when the temperature is too high at 65 °C it affects the efficiency of the solar panel operation [16]. Long-time PV panels operation in high temperature can cause irreversible degradation of its electric output power [17]. This is due to the fact that the temperature decreases the value of voltage linearly while the current increases exponentially. From the result obtained, solar panel of 30° angle shows the highest amount in term of temperature (about 75°C) during the peak hours whereas the angle of 25° shows a slightly less value (about 55°C). The maximum average temperature in Sarawak is 34°C to 35°C and the minimum average temperature is 21.8 °C to 22.3 °C [18]. Irradiance, on the other hand, shows that angle of 30° to be quite consistent from 9.00 am to 1.00 pm as compared to the other angle studied. Solar irradiance is one of the factors in determining site location, where location with high solar irradiance is preferable and has high potential in generating maximum output [19].

![Figure 4. Temperature of solar panel.](image3)

![Figure 5. Irradiance received at solar panel.](image4)
Figure 6 shows the power generated by the solar panel in a specified angle of 20°, 25° and 30° while figure 7 and figure 8 show the voltage and current generated by the solar panel, respectively. The power generated for 30° angle of solar panel is the highest as compared to another angle of solar panel. For both voltage and current output, solar panel of 30° angle shows high value as compared to the other angles. However, it is noticeable that at 1200 hour, the temperature of 30° solar panel is higher than 65°C in which causing some reduction is solar panel efficiency as showed by figure 5 at 1200 hour. Despite this problem, the optimum time to harvest solar energy is from 11.00 am to 1.00 pm daily.

![Figure 6. Power generated by solar panel.](image1)

![Figure 7. Voltage output from the solar panel.](image2)

![Figure 8. Current output from the solar panel.](image3)

In this solar power system, all of the power generated by solar panel is in DC form in which are used to charge the battery and from the battery, the current is converted into alternating current (AC) by the inverter before being used for the electrocoagulation system. Figure 9 shows the power output from the battery to the loads. All the loads are using their sources of power from the battery. The highest power output from the battery is at 1.00 pm for 25° instalments solar panel which is 27.657W and the lowest power output is at 4 pm for 30° instalments solar panel which is 23.907W. From the calculation, the total power needed to generate all the loads is 28W. Figure 10 shows the power input to the inverter. Figure 11, figure 12 and figure 13 show the power input to the pump, power input to the DC bulb, and power input to the AC bulb, respectively. Power output to the inverter indicated the power used by the AC loads. The AC loads compromise of the 5W AC pump and 18W AC bulb where the total AC loads is 23W. The highest power output from the inverter is on 2.00 pm for the 20° instalment of solar panel which is 25.54W and the lowest power output recorded from the inverter is at 3.00 pm for 25° instalment of solar panel which is 23.218W. There are 2.322W differences recorded for the highest and lowest power output from the inverter. Power input to the pump and the AC bulb shows a steady-state flow of bar chart where the pump recorded 4.4W power to generate pump while 16.6W is needed to generate the AC bulb. The total power generated by the AC loads is 21W according to the collection of data. Data collection for the DC bulb is still considered as steady-state as there are slight differences recorded for the power to generate the DC bulb which is still within the range of the rated power.
3.2. Suitability of solar power electrocoagulation system

Table 2 shows the comparison of the process with and without solar for both batch and continuous systems. The comparison is done based on the removal efficiency of turbidity of the peat water. Electrocoagulation treatment of peat water by using solar power system is inefficient because the removal efficiency of turbidity for both batch and continuous electrocoagulation is low which is less than 50% as compared to DC converter power grid. This is due to the low current density generated by the solar power system. Low current density leads to lower production of metal coagulant. Metal coagulant production is dependent on current density and time [19]. In addition, batch and continuous electrocoagulation water treatment used a different flow rate of submersible pump thus the power rated for the pumps are not the same. Batch electrocoagulation system uses a faster flow rate which is 6.5 litres/min with a rated power of 13.2W to fill up the storage for treated peat water from raw peat water storage which is 0.44Wh energy. As for continuous electrocoagulation, it uses a slower flow rate which is 0.07 litre/min with a rated power of 4.4W with the amount of energy used of 8.8Wh. For the power usage by the electrodes for both batch and continuous are the same which is 4.949W for operating time of 2 hours. Since the rated power for both batch and continuous electrocoagulation are the same as well as the operating time, accordingly, the electricity usage for electrocoagulation process is the same which is 9.898 Wh. Both batch and continuous electrocoagulation systems are treating the same amount of treated water but the removal efficiency of turbidity are found to be different. The removal efficiency
of turbidity for batch electrocoagulation is from 11 NTU to 9 NTU which is 18.8% while the removal efficiency of turbidity for continuous electrocoagulation is from 13 NTU to 7 NTU which is 46.15%. Both systems did not meet the standard set by the Ministry of Health, the Drinking Water Quality Standard where it specified the maximum allowable level of turbidity is 5 NTU. However, both systems treated water falls into Class II of National Water Quality Standard, which means it is qualified for general washing purposes. In order to improve the system, more solar panels need to be added in order to increase the power generated in which, in turn, provide sufficient electricity for the complete electrocoagulation process to occurs.

| Parameter              | Without Solar | With solar |
|------------------------|---------------|------------|
|                        | Batch System  | Continuous System | Batch system | Continuous System |
| Current                | 5.0 A         | 0.4 A      | 0.4 A       | 0.4 A      |
| Current density        | 25.00 A/m²    | 2.00 A/m²  | 0.50 A/m²  |
| Final turbidity        | 1 NTU         | 9 NTU      | 7 NTU      |
| Removal efficiency     | 93.35 %       | 18.80 %    |

4. Conclusion

The optimum angle for the develop solar power system for peat water electrocoagulation system is found to be 30° where it absorbed the most heat and solar irradiation from the sunlight. However, the efficiency of solar panel dropped at noon due the extreme temperature but the efficiency increases again after the temperature has reduced. The highest generated power by solar panel is at 2.00 pm while it generated the least power at 4 pm. From the experiments conducted, it is observed that the turbidity values of peat water for both batch and continuous electrocoagulation systems have been reduced. The reduction is more prominent for continuous electrocoagulation system process which is 46.15% as compare to batch system at 18.8%. However, the water treatment by mean of solar power system do not meet the Malaysian requirement for drinking water. This is due to significant low current produced by the solar power system. Nevertheless, the study has proven that it is possible to apply solar power system for electrocoagulation treatment of peat water. However, further research on the improvements of the system are needed in order to produce better quality treated water which meet the Malaysian water quality standards.

5. References

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