Hydropower Potential on Agricultural Dam: An Evaluation for Pedu Dam

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Abstract: In line with its continuous GDP increase, the growth in electricity demand has shown a similar trend of annual increment for Malaysia. With the projected continuous increase of electricity demand, more fossil fuel-based power plants are committed to be built in the near future. To mitigate the resulting greenhouse gas emission from increasing demand, exploiting existing agricultural dam initially built for agricultural purposes for energy can be considered as an option. This study shows the potential of generating electricity from Pedu dam located in Kedah, initially built with the objective to harvest paddy twice annually. The study shows that there is a potential of 156,072MWh to be generated from the dam water release, with the power of 33,155kW and a capacity factor of 53.7%, using Kaplan type turbine.

Keywords: Agricultural Dam, Hydropower and Potential

I. INTRODUCTION

Malaysia is a country located in the South East Asia region, having a population of 32,566,900 in the fourth quarter of 2018 [1], with a GDP size of MYR322.6 billion and the annual growth of 4.7% in the fourth quarter of 2018 [2]. In line with its continuous GDP increase, the growth in electricity demand has shown a similar trend of increase annually as shown the Figure 1 below [3]. The current electricity mix 42.6% Natural Gas, 28.9% Coal, 18.6% Hydro, 6.3% Diesel or MFO, 2.2% biomass, 0.9% solar, 0.4 others and 0.1% biogas [3].
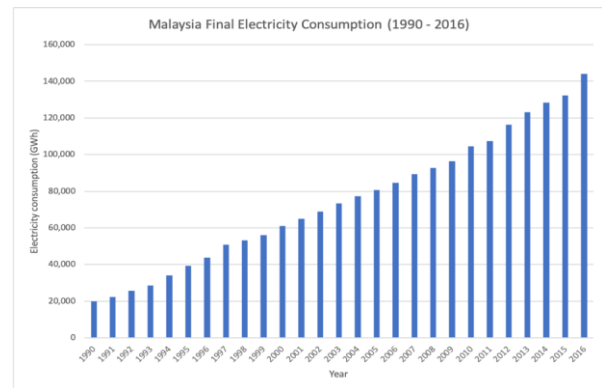
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Fig. 1 Trend for electricity consumption for Malaysia from 1990 to 2016. (Data source: [3])

With the projected continuous increase of electricity demand, more fossil fuel-based power plants are committed to be built as shown in the table below:

Table. 1 Committed new fossil-fuel based power plants [4]

No.	Project	Fuel	Capacity (MW)	Commercial Operation Date
1.	Jimah East Power Sdn. Bhd.	Coal	2000	U1: June 2019 U2: December 2019
2.	SIPP Energy Sdn. Bhd.	Gas	1440	Jan 2020
3.	Edra Energy Sdn. Bhd.	Gas	2242	Jan 2021
4.	Tadmax Resources Sdn. Bhd	Gas	1000	Jan 2023

Albeit the concern of global warming and climate change, Malaysia has committed to build these fossil-fuel based power plants due to the rapid economic growth hence energy demand. They are cheaper and favorable for the stability of the electricity grid. Other than fossil-fuel based power plant, Malaysia has 18.6% share of installed capacity of hydro power plants, totaling 5635.4MW [3]. This comes from 19 stations located across six states, Terengganu, Perak, Pahang, Kelantan in the peninsular and Sabah and Sarawak in Borneo. Other than dams built for power generation, most of the dams in Malaysia are built for either agricultural irrigation or domestic water use.

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Pedu dam was constructed in 1969 under the Muda Irrigation Scheme, alongside with Muda dam with the purpose of agricultural irrigation for 96,000 hectares of paddy farm with the objective of having twice harvesting season annually. It is located in the northern part of Malaysia, in the state of Kedah, close to the border of southern Thailand. Pedu dam has a reservoir storage capacity of 1073 million m^3, with a reservoir area of 53km^2 and a catchment area of 171km^2 with water also coming in from Muda dam, due to the dam having a relatively low storage capacity of 160 million m^3. In addition to agricultural irrigation, it also provides water supply for domestic and industrial in the region Northern Kedah, south Perlis and Pulau Langkawi [5][6]. Figure 2 shows the dam during water release.

Fig. 2 Pedu dam during water release [5]

Retrofitting existing dams with hydroelectric capabilities is one of the options and is not a new idea. The Government of United States in 2007 has done a survey on the potential of hydroelectric development at existing Federal Facilities, involving the Department of the Interior, Department of the Army and the Department of Energy. The survey studied 871 existing federal facilities and estimated 1230MW of potential additional capacity that demonstrate sufficient physical and economic conditions [7]. Although head and flow of existing dams give potential for electricity generation, several issues need to be taken into consideration including structural integrity and safety of the dams, construction costs and complex engineering for integration of new hydropower systems into existing dams [8]. The costs, varying based on location, can include construction, licensing, fish and wildlife mitigation, recreation mitigation, historical and archeological mitigation, water quality monitoring, fish passage mitigation, fixed operation and maintenance, variable operation and maintenance and regulatory related costs [9]. Other than that, sedimentation should also be monitored continuously as it can affect both the operation and safety of the dam, which can be labour intensive and costly [10].

This study investigates the potential of producing electricity from Pedu Dam using existing water release for irrigation purposes.

II. METHODOLOGY

Site study

A general background study was done to understand the characteristics of the dam, including the purpose of its construction, available reservoir, height of dam and nominal flow.

Data collection

Pedu dam water level, dam inflow and dam release were obtained from MADA for the period of 1st January 2017 to 31st December 2018. The mean annual flow gives an idea of a stream's power potential.

Data Processing

The data obtained was converted to metric units. From the daily data obtained, a Flow Duration Curve (FDC) was formed. The FDC shows the quantity of water available for the operation of the hydropower plant at various flow. This curve is defined by the number of days during which the discharge is reached or exceeded in a year.

Below are the steps used to determine of the exceedance probability:-

1. Arrange the daily discharge value in descending order, starting from the highest to the lowest value and calculate the number of the data in total.

2. Put rank next to the data (assign 1 for the largest discharge value)

3. Find the exceedance probability with the equation [11]:

$$P=[mn+1]\times100$$

Simulation

Simulation was done using RETScreen, software developed by the Government of Canada. The software needs the head and flow as inputs and calculates the penstock parameters, power and energy output and capacity factor. The software will also suggest multiple selections of turbine types. The results by the simulation is then validated with analytical calculations.

There are several data that are processed by RETScreen Expert software in order to obtain the characteristics of the plant such as the flow data, turbine efficiency data, design coefficient, hydraulic losses, miscellaneous losses which includes the transformer losses and parasitic losses, also the generator efficiency and constant (density and acceleration due to gravity). The summary of user inputs and simulation outputs is shown in Figure 3 below.
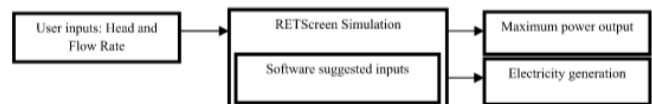

Fig. 3 Simulation input and outputs using RETScreen

The turbine is selected based on the available head and flow by using a turbine application chart, a simple and quick method used for initial turbine selection process. The turbine application chart is shown in Figure 4 below.
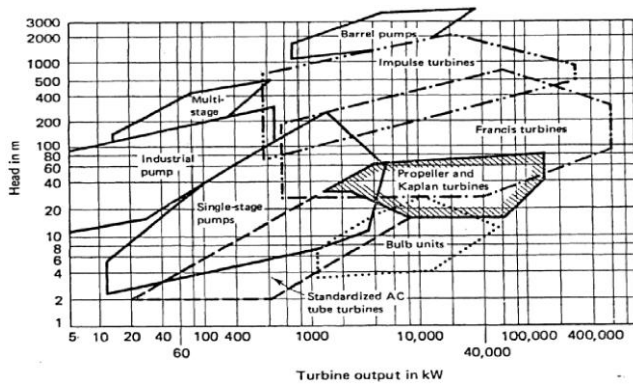
Fig. 4 Turbine Application Chart [12]

The software input for the simulation is shown in Figure 5 below.
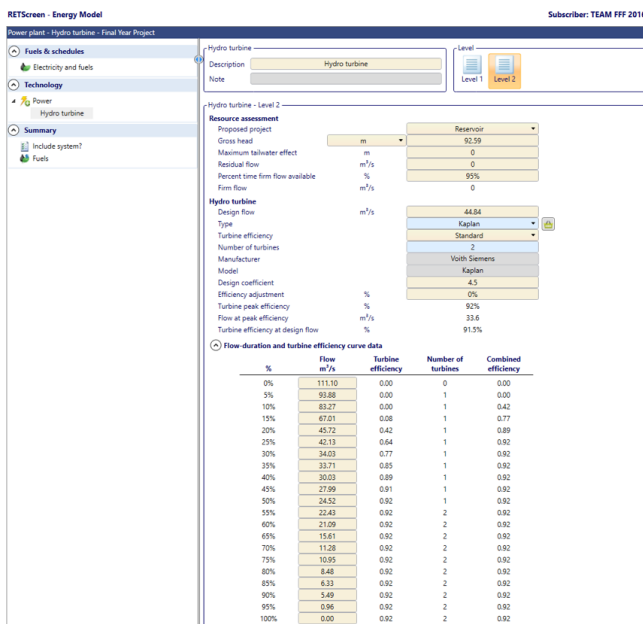

Fig. 5 Input interface of simulation

In addition, maximum hydraulic losses, miscellaneous losses, generator efficiency and availability are also essential parameter in determining the accurate results. The RETScreen software make ease to determine all those values as recommendation are provided [13].

III. RESULTS AND DISCUSSIONS

Results

Table 2 below shows the processed data obtained from MADA, showing the exceedance probability of a given flow rate. The data is ranked from the highest flow rate occurrence throughout the period and the probability that the given flow rate will be exceeded throughout the year. Table 2 below shows the maximum and minimum amount of available stream flow for generation of electricity. For instance, at 0% exceedance probability, noted that the maximum likelihood of the flow is about 111.10 m3/s. This does not mean that the flow rate is 111.10 m3/s for 0% of the time, but the flow is equaled or exceeded for 0% of the time, so basically the flow is at this flow or at a higher flow for 0% of the time. For example, 44.32 m^3/s will be available for 23.196% of the year, or in other word the particular flow rate will be exceeded 23.196% of the year.

This also means that the higher flowrate will always be able to supply 44.32 m^3/s.

Table. 2 Exceedance probability table for Pedu Dam for the year 2017

Flow (m^3/s)	Rank	Exceedance Probability (%)
111.10	1	0.515
99.27	3	1.546
94.55	9	4.639
85.09	12	6.186
73.75	28	14.433
62.41	31	15.979
56.73	33	17.010
51.99	36	18.557
44.32	45	23.196
39.71	54	27.835
33.68	69	35.567
28.36	79	40.722
24.82	96	49.485
21.75	115	59.278
17.02	121	62.371
13.00	133	68.557
8.87	154	79.381
5.68	166	85.567
1.06	184	94.845
0.00	194	100

For this project, the design flow of **44.84 m^3/s** will be used where this value is the average maximum discharge at Pedu dam ranges in between 20% to 25% exceedance probability as stated in Figure 6 below. The available head of **92.59 m** (average maximum water level) will be used as a design input.
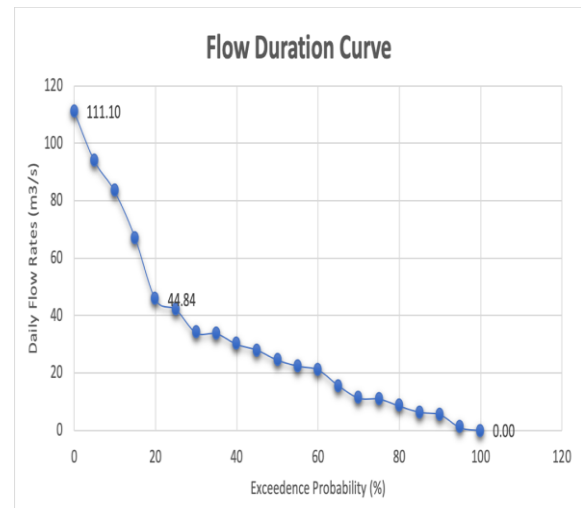

Fig. 6 Flow duration curve for Pedu Dam for 2017

Simulation

RETScreen simulation generates the penstock diameter based on the maximum head of the dam. The penstock diameter and wall thickness generated by RETScreen software. Figure 7 below shows that, for 100 metre length of penstock, the software gives value of 2.3 m for the diameter and 8.9 mm for the average pipe wall thickness.

The length of the penstock are estimated to be 100 metre as the average maximum head for the dam is 92.59 metre.

Fig. 7 Estimated value suggested by the software for penstock dimensions

The value obtained then compared with the equation as follows:

$$D\rho = 2.69 \times (n\rho^2 \times Q^2 \times L\rho/Hg)^{0.1875}$$
$$= 2.69 \times (0.012^2 \times 44.84^2 \times 100/92.59)^{0.1875}$$
$$= 2.163 \ m$$

$$t\rho = D\rho + 508/400 + 1.2$$
$$= 2.163 + 508/400 + 1.2$$
$$= 2.475 \ mm$$

Comparing both values, the penstock diameter from the equation gives the value of 2.163 m which is very close to the value given by the software. For wall thickness, the obtained value is 2.475 mm which is the minimum value required for 100 m length of penstock. Therefore, the output values from the software are valid.

The characteristics of the plant for different turbine types are shown in Table 3 below.

In order to determine the results for power output as well as the amount of electricity exported to the grid, the available head of 92.59 m (average maximum water level) and design flow of 44.84 m³/s (average maximum discharge) are taken into account.

Table. 3 Analysis for turbine selection using 2017 Pedu dam flow data

Type of turbine	Power output, kW	Capacity factor, %	Turbine peak efficiency, %	Turbine efficiency at design flow, %	Electricity exported to grid, MWh
Kaplan	33,155	53.7	92	91.5	156,072
Propeller	33,315	44.2	92	92	129,031
Francis	32,602	53.7	93.7	90	153,327

Figure 8 shows that the propeller turbine type will deliver higher power at its peak efficiency for the flow data (2017) for the Pedu dam which is 33,315 kW, followed by the Kaplan turbine which is 33,155 kW, and the Francis turbine type is observed to have the lowest power capacity among the three turbine types which gives the value of 32,602 kW only. However, the decision on the type of turbine is not only based on power capacity, but also on the annual energy output and the capacity factor.
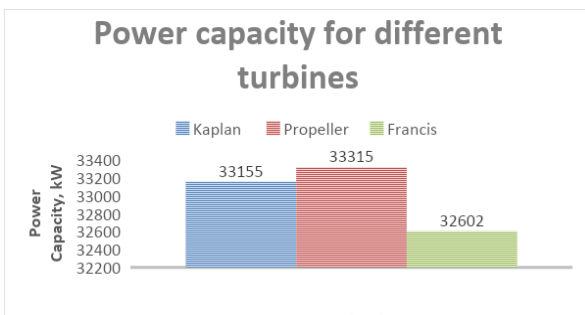

Fig. 8 Plant power capacities for different types of turbine

The annual energy output of the Kaplan turbine based on Figure 9 is the highest of the three types of turbine which is 156,072 MWh. This is followed by turbine types Francis and Propeller which are 153,327 MWh and 129,031 MWh respectively. This is due to the differences in the nature of the three turbine types' efficiency curves.
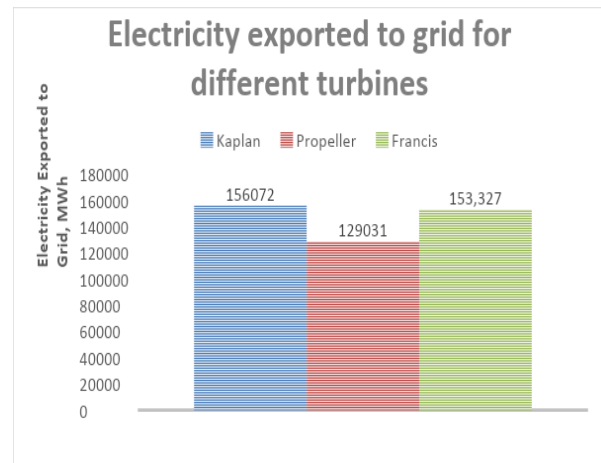

Fig. 9 Plant annual energy output for different types of turbine

On the basis of Figure 10 below, it shows that Kaplan and Francis turbine share the same capacity factor which is the highest compared to propeller. This means that out of all three turbines, the actual annual energy output of the Kaplan turbine is closest to its maximum annual energy output. Although the Propeller turbine has the highest power output, but still Kaplan type has the largest energy produced per year and the capacity factors.
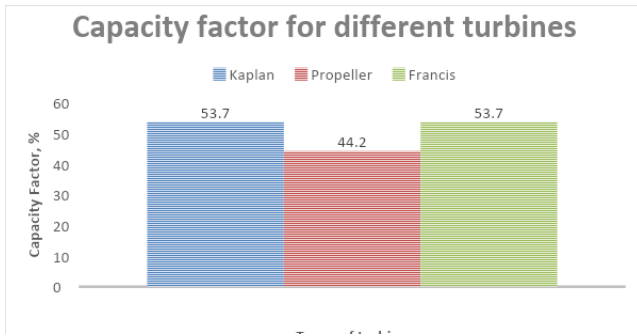
Fig. 10 Plant capacity factors for different types of turbine

However, there is no definite best choice of turbine selection. It depends on the design requirement, for example needing higher power output to supply peak load or to have lower power output but higher capacity factor to supply at more time throughout the year. This is also true when selecting the design flow rate, at which a higher flow rate can be selected but will result in lower capacity factor or selecting lower flow rate which result in higher capacity factor but also lower power.

Based on the selection of Kaplan turbine, it can be concluded that the Pedu dam site will have a capacity of 33,155 kW and will supply 156,072 MWh of energy to the national grid.

The dam power capacity is generated by the RETScreen software and are verified using the equation below:

Given the efficiency of the turbine is 92% (from the software):

$P = \eta_t \times g \times Q_t \times H_n$

$\quad = 0.92 \times 9.81 \times 44.84 \times 92.59$

$\quad = 37{,}470$ kW

It is observed that the value calculated is slightly higher than the value obtained from the software. It is because of the losses are not included in the calculations.

IV. CONCLUSIONS

This study the potential of generating electricity from existing dam initially constructed for agricultural irrigation. The potential power capacity of the dam is 33315kW, with the potential electricity generation up to 156,072MWh. Further study is needed on the design of the agricultural dam to incorporate power generation and a study on the effect of water flow for irrigation is essential to determine if a hydropower installation would affect the agricultural activities.

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