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Low Speed Vertical Axis Current Turbine (LS-VACT): Experimental Results

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Abstract. Depleting of fossil fuels and climate change problem as well as the pollutions arise make the renewable energy one of the best options for long-term usage. In hydropower energy extraction, vertical axis marine current turbine applications; Savonius turbine, which has the ability to operate in low speed current is suitable with the Malaysia's sea conditions. However, due to the drawbacks which are low efficiency and low tip speed ratio, modifications need to be done to harness more power. Low Speed Vertical Axis Current Turbine is appeared to extract energy based on the Savonius rotor. In conjunction to this matter, laboratory work has been done in a way to study the relationship between Power Coefficient (C_p) and Tip Speed Ratio (λ), and also the relationship between Torque Coefficient (C_t) and Tip Speed Ratio (λ) at different current speed which are 0.32 m/s and 0.64 m/s.

1. Introduction

The utilization of electrical energy has become vital role in economic growth and improvement in people's living. But it is overwhelming to know in today's world that 1.4 billion people lack access to electricity, while 85% of them live in rural areas [1]. But the excessive usage of this energy can cause environmental pollution, greenhouse effect, carbon dioxide emission; not to mentioned the fossil fuel depleting. Due to this matter, to replace the fossil fuel-based energy sources with renewable energy is essential and ultimately will benefits global environment. This renewable energy sources includes: bioenergy, direct solar energy, geothermal energy, hydropower and wind energy could progressively help the world to achieve the idea of sustainability. As it is known, the renewable energy sources replenish themselves naturally without being depleted in the earth and become the most outstanding alternative energy sources compared to the fossil fuel-based energy sources.

Among the renewable energy, hydropower generation provide a huge potential resource of energy which can be harnessed from the water flows. The hydropower energy may be generated from the waves, tides, ocean currents, and the natural flow of water in river. Apart from this, the manmade channel, canals, industrial outflow can turn the turbines to produce hydrokinetic electrical energy [1]. And the great things about hydropower generation does not produce greenhouse gases and thus termed as a green source of energy as well as yield to the global warming. Hydropower can be classified into large, medium or small scale [2].

Small scale hydropower is one of the best options in term of technology due to its ease of operation and maintenance compared to all energy generation industries. It also can be adjusted according to the local geographical, environment and socio-economic conditions [2]. Thus, it can contribute significantly improving the economic of the rural population in Malaysia.

Hydropower from the river is one of the best renewable sources of energy and it is more predictable compare to solar or wind energy. For this river sources of energy, the small-scale hydropower is one of the best options in order to generate and supply electricity to off grid and rural or remote electrification. While Malaysia is blessed with adequately of water resources which consist 150 rivers in Peninsular Malaysia and 50 rivers in Sabah and Sarawak and high volume of rain per year can be used to generate the power [2]. Thus, Malaysia has a significant potential for small scale hydropower generation.

2. Hydropower Turbine

To harness energy from marine currents especially river stream, there are mainly two kinds of hydro-turbines, they are horizontal axis turbine and vertical axis turbine [3]. These have been long considered as primary choices for hydrokinetic conversion, and several river turbine prototypes were deployed and operated since late 1970s until 1990s, however these eventually decommissioned [4]. Due to that, currently, both horizontal and vertical axis turbines become the key for further research. However, horizontal axis turbines are more complex system mainly be used for extraction of the ocean energy and for large plant where high maintenance costs are balance by large energy produced. Thus, these turbines are expensive for small scale power application. While the vertical axis turbines are relatively simple and represent a promising technology to exploit marine currents due to their small plants in remote areas [4].

The ideal marine current speed to make the turbine work at least 2m/s [5,6]. However, for Malaysia’s sea and river the average current speed is 1 m/s, which is half of the speed for turbines have been developed [6]. Due to Malaysia sea conditions, which are low depth and current speed, it creates limitation for the extraction of energy[7]. Hence, the use of conventional current turbine is no longer feasible. In conjunction to that matters, some modification must be made to enable the turbine to work in low speed current, thus, it is vital to focus on the design and development of turbines to increase the efficiency therefore can generate more electricity.

These days, turbines are under progressive development to increase torque and efficiency so they are usable for low speed velocity and as a result can increase the output power [8, 9]. Previously, a Savonius vertical axis turbine has been proposed to harness current energy, but unfortunately there are two main drawbacks which are low efficiency and low tip speed ratio (TSR) [10]. Therefore, modifications of turbine system are needed to harness the maximum power, especially for remote area. Hence, a Low Speed Vertical Axis Current Turbine (LS-VACT) is appeared to extract this marine energy from low speed current based on the Savonius rotor [11].

3. Performance of LS-VACT

Tip Speed Ratio (λ) or TSR is the ratio between the rotational speed of the tip blade and the actual velocity of the water. Tip Speed Ratio, TSR is defined in equation (1).

Equation 1:

$$\lambda = \frac{\omega D}{2U} \qquad (1)$$

The torque of the turbine is defined in (Nm) as in the equation (2).

Equation 2:

$$T = F\,r \tag{2}$$

The torque and turbine RPM was measured by using a load cell and infrared optical tachometer respectively. The turbine was loaded by adding weights (masses) to the loading system and again the torque and turbine RPM was measured as illustrated in figure 1. The load cell is to measure brake load and then the load times by the moment arm (lever) gave the turbine torque.
Water of incoming velocity U represents mechanical power P and mechanical torque T respectively by swept area of the turbine A_s consists of turbine diameter D represent in the equation (3) and (4).

Equation 3:

$$C_p = \frac{P}{\frac{1}{2}\rho A_s U^3} \tag{3}$$

Equation 4:

$$C_t = \frac{T}{\frac{1}{4}\rho A_s U^3} \tag{4}$$

The efficiency of the turbine will be measured by using this coefficient of power and coefficient of torque accordingly.

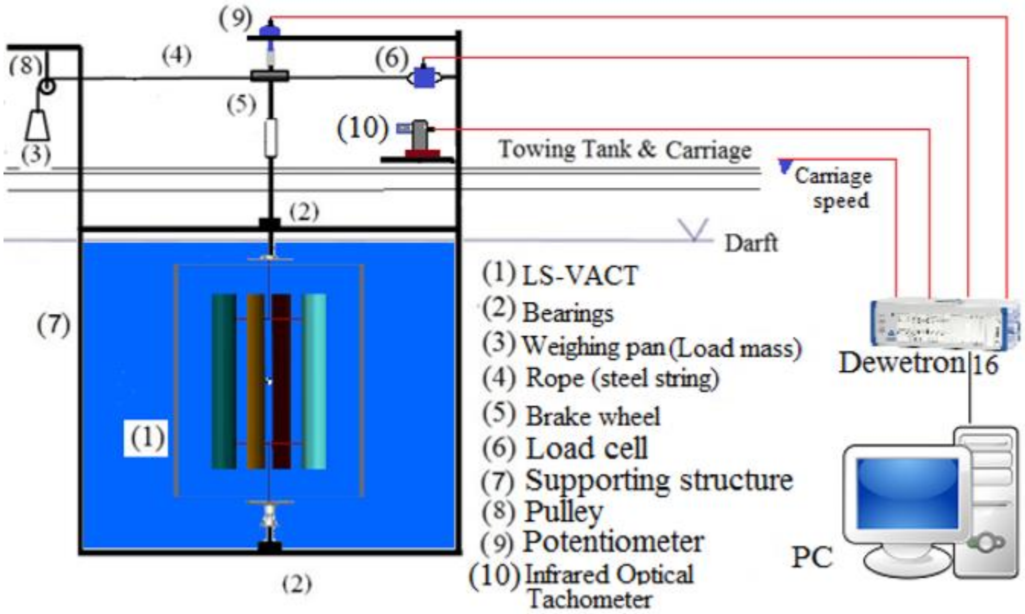

Figure 1. Schematic diagram of the experiment setup

4. Results and Discussions

The LS-VACT is a vertical axis current turbine like conventional Savonius turbine. This conventional Savonius turbine is suitable for Malaysian's water condition which are low speed current and low depth [12]. Therefore, the LS-VACT is a design consists of four bucket blades and arms to overcome the low speed problem as well as can increase the performance. The particular parameters and sketch as shown in table 1 and figure 2. The experiment was conducted at Marine Technology Centre (MTC) of Universiti Teknologi Malaysia. The summary of experimental as shown in table 3 and figure 3 to 6.

Table 1. The particular parameter of the LS-VACT

No	Specification	Parameters
1	Height of Rotor, H (m)	1.5
2	Diameter of the bucket, d (m)	0.35
3	Blade Area, A_s (m2)	0.525
4	Diameter of turbine, D_p (m)	1
5	Arm length, r` (m)	0.15
6	Current speed, U_∞ (m/s)	0.32 – 0.64

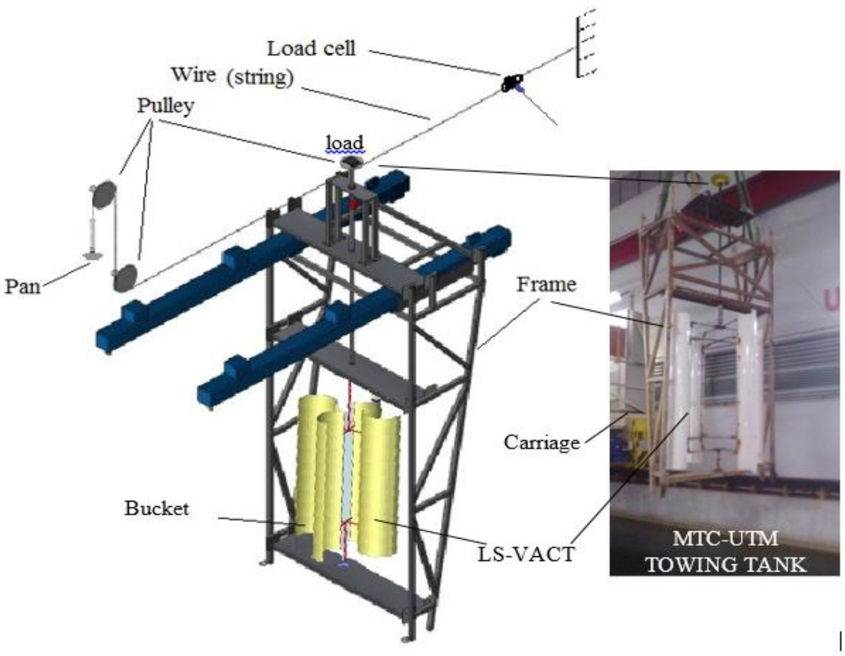

Figure 2. Test rig of the LS-VACT coefficient.

Table 2. LS-VACT at different load (kg) for current speed 0.32 m/s and 0.64 m/s.

No	Load (kg)	Current Speed (m/s)	RPM	Angular velocity (rad)	TBR (λ)	Exp-Torque of the LSVACT	Exp-Mechanical Power of the LSVACT	Cp	Ct
1	0.00	0.319	3.71	0.39	0.57	0.00	0.00	0.00	0.00
2	1.15	0.318	3.41	0.36	0.53	0.89	0.32	0.04	0.07
3	2.15	0.317	3.28	0.34	0.51	1.61	0.55	0.06	0.12
4	3.15	0.317	3.03	0.32	0.47	2.23	0.71	0.08	0.17
5	4.15	0.317	2.74	0.29	0.43	2.85	0.82	0.09	0.21
6	5.15	0.317	2.49	0.26	0.39	3.45	0.90	0.10	0.26
7	6.15	0.318	2.43	0.25	0.38	3.98	1.01	0.11	0.30
8	7.15	0.317	2.42	0.25	0.38	5.01	1.27	0.14	0.38
9	8.15	0.317	2.22	0.23	0.34	4.94	1.15	0.13	0.37
10	9.15	0.317	1.87	0.20	0.29	6.97	1.75	0.19	0.52
11	10.15	0.316	0.00	0.00	0.00	10.11	0.00	0.00	0.76

No	Load (kg)	Current Speed (m/s)	RPM	Angular velocity (rad)	TBR (λ)	Exp-Torque of the LSVACT	Exp-Mechanical Power of the LSVACT	Cp	Ct
1	4.15	0.637	7.72	0.81	0.69	2.68	2.17	0.030	0.050
2	6.15	0.637	7.56	0.79	0.67	3.86	3.06	0.042	0.072
3	8.00	0.637	7.54	0.79	0.67	4.99	3.94	0.054	0.093
4	10.00	0.637	7.35	0.77	0.65	6.07	4.67	0.064	0.114
5	12.00	0.637	7.14	0.75	0.63	7.35	5.50	0.076	0.138
6	14.00	0.637	7.09	0.74	0.63	8.78	6.52	0.090	0.164
7	16.00	0.637	6.96	0.73	0.62	10.31	7.52	0.104	0.193
8	18.00	0.637	6.79	0.71	0.60	11.91	8.47	0.117	0.223
9	19.50	0.636	6.26	0.66	0.56	12.68	8.31	0.115	0.237
10	19.75	0.636	6.15	0.64	0.55	13.34	8.60	0.119	0.250
11	20.20	0.637	0.00	0.00	0.00	19.40	0.00	0.000	0.363

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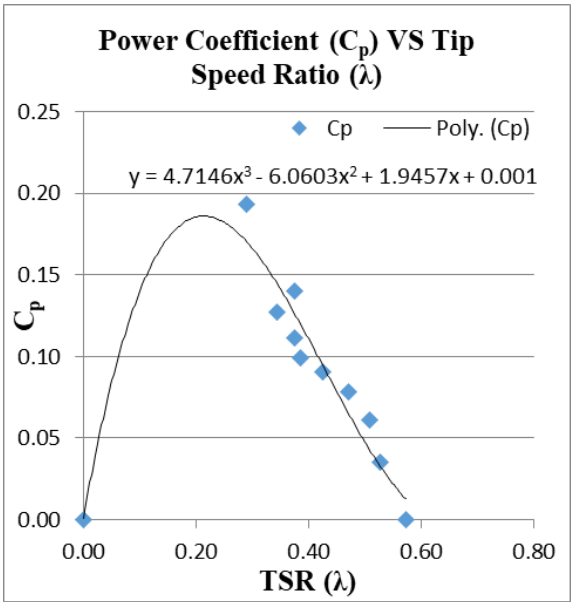

Figure 3. LS-VACT power coefficient Vs TSR at current speed = 0.32 m/s.

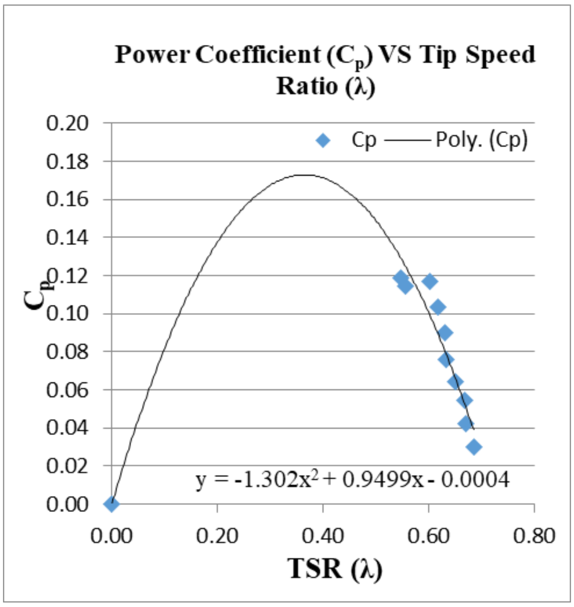

Figure 5. LS-VACT power coefficient Vs TSR at current speed = 0.64m/s.

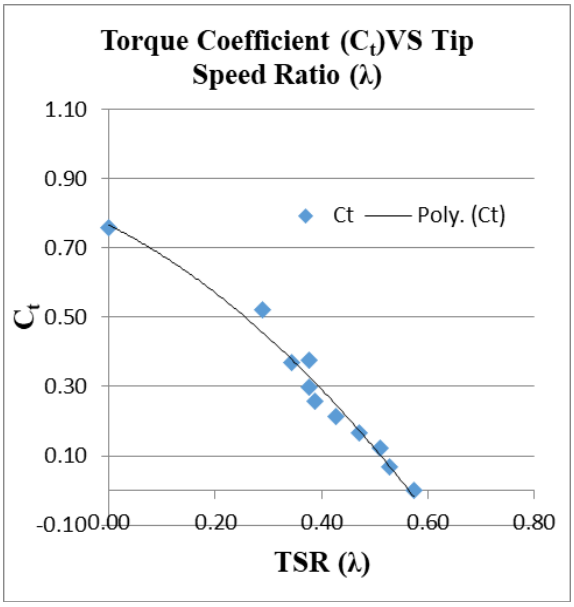

Figure 4. LS-VACT torque coefficient Vs TSR at current speed = 0.32m/s.

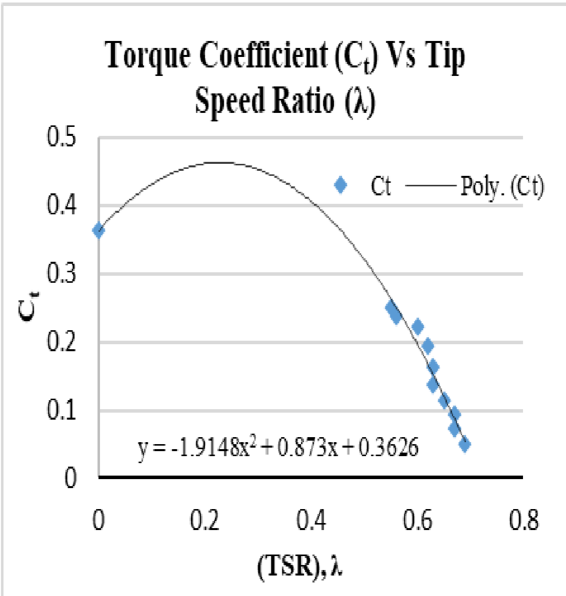

Figure 6. LS-VACT torque coefficient Vs TSR at current speed = 0.64m/s

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Table 3. Performance Results of LS-VACT at current speed 0.32 m/s and 0.64 m/s.

Current speed, U_∞ (m/s)	Tip Speed Ratio (TSR), λ	Torque Coefficient, C_t	Power Coefficient, C_p
0.32	0.29	0.520	0.190
0.64	0.60	0.223	0.117

The graphs show the variation of coefficient of power and coefficient of torque corresponding to the tip speed ratio for LS-VACT. The maximum coefficient of power and coefficient of torque at the tip speed ratio of 0.29 is observed. The test results present on the right half of the C_p-TSR and C_t-TSR curve because the experimental process includes the increasing the load on the turbine gradually from no load condition for fixed-stream velocity in the water channel. During no load condition, the rotational speed of turbine could be maximum and as the load increased, the rotational speed of the turbine decreases. Therefore, the tip speed ratio decreases. While for a certain load, the turbine cannot continue the rotation because it cannot generate torque and that is the reason there are few data point or no data on the other half part of the curve.

5. Conclusion

The experimental was conducted in the towing tank at Marine Technology Centre (MTC) Universiti Teknologi Malaysia (UTM) to study the relationship between Power Coefficient (Cp) and Tip Speed Ratio (λ), and also the relationship between Torque Coefficient (Ct) and Tip Speed Ratio (λ) based on the different current speed; 0.32 m/s and 0.64 m/s. By using the towing tank equipment in MTC as shown in figure 2, the summary of the results obtained presented in table 3 and figure 3-6. Different load has been used to study the effect of LS-VACT torque force.

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