Transactions of the TSME (2016) Vol. 4, No. 2, 156-165
Journal of Research and Applications in Mechanical Engineering

ISSN 2229-2152 print
DOI: 10.14456/jrame.2016.16

Research Article

EXPERIMENTAL STUDY ON SUITABILITY OF STARTING A WIND TURBINE POWER PLANT BY AN AUXILIARY START SYSTEM

S. Wongtom*
N. Pananda
Department of Mechanical Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna, 50300, Thailand

ABSTRACT:
This research project aims to explore the suitability to start a wind turbine using a commercial alternator known as an Alternating Current Generator (ACG) starter. The ACG starter was used in this project as a wind turbine starter. The study was done experimentally for two cases regarding wind speed. The first experiment, the wind turbine was running for 2 minutes with constant wind speed of 3, 4, 5 and 6 m/s respectively. The second experiment was to operate the wind turbine with varying wind speed in the range of 3-6 m/s for 1, 2 and 3 minutes respectively. The power generating performances for the systems with and without starting system were compared. Using the ACG starter with starting duration of 500 milliseconds was found to extend the power generating duration, regarding the experimental duration. As a result, the greater amount of the total generated electrical power was obtained. The experiment with variable wind speed also found that using the ACG starter provides longer generating period. The maximum power consumption for the ACG starter was found to be about 260 Watts which was much less than the generated power. One can conclude that using the ACG starter to start the wind turbine can increase the amount of generated power. This is especially suitable for the location where wind intermittently flows.

Keywords: *Wind turbine starter, Alternator starter, Low speed wind turbine*

1. INTRODUCTION

The natural power resources are known to be endless. There are plenty and various types of such the resources. The challenging task is how to take benefits from these natural resources. For example, solar energy can be obtained directly from the sun using either solar cells or solar collector. Biogas obtained from animal waste can also be energy resource in form of gas. Hydro energy is another form of natural power resource that its energy can be taken using water turbine etc. In this paper, wind energy is considered. Wind energy is well known as clean energy. It does not cause to any environmental pollution. The most significant issue is that wind energy has never come to an end.

Wind energy can be obtained using wind turbine which transforms wind energy to mechanical energy. Such the energy form can be applied to water pumping or electrical generating, for example. The application of wind turbine for power generation turns wind energy into mechanical energy and then electrical energy. The wind turbine needs to spend some time to start rotating from standstill to the desired speed. This depends on drag force and friction forces of the turbine. Time duration needed for the wind turbine to rotate is not definable. It also depends up on

* Corresponding author: S. Wongtom
E-mail address: ww_sompon@hotmail.com

wind speed. For the areas with low wind speed, for example 3 – 5 m/s, and with discontinuously flowing wind, the wind turbine confronts to start itself. To this point, it concerns the authors to implement such the auxiliary system to increase the performance of the wind turbine. This is to control speed of the wind turbine at start period. Therefore, loosing kinetic energy can be reduced.

Thus the main of this research project is to experimentally compare the capability of power generation efficiency between the power generating wind turbine with and without the auxiliary start system. Reader should be reminded that this research project aims to compare performance of electrical generating capability for the wind turbine with and without the ACG starter system. The performance of the wind turbine and the performance of generator are not considered in the paper.

2. Theoretical Background

2.1 Wind turbine

A certain wind turbine will start rotating for a certain win speed flow through its blades. Figure 1 shows varieties kind of the wind turbine which power coefficient is plotted versus the tip speed ratio [1]. It is seen that a three-blade rotor has the highest power efficiency among the wind turbines given in the figure. The rotor power coefficient for the three-blade rotor is seen to be about 0.48 at the tip-speed ratio of about 7. Thus it is appropriate for this study to use the three-blade wind turbine with horizontal axis. The tip-speed ratio can be determined from

$$\lambda = \frac{\omega R}{v} \tag{1}$$

where v is the actual velocity of the wind, R is the rotor radius in meters and ω is the rotor rotational speed in radians/second. Wind power can then be determined from

$$P_w = \frac{1}{2}\rho_{air} A v^3 C_p \tag{2}$$

where ρ_{air} is density of air which is about 1.255 kg/m^3 at 15°C, A is the area of a circle and C_p is the rotor power coefficient.

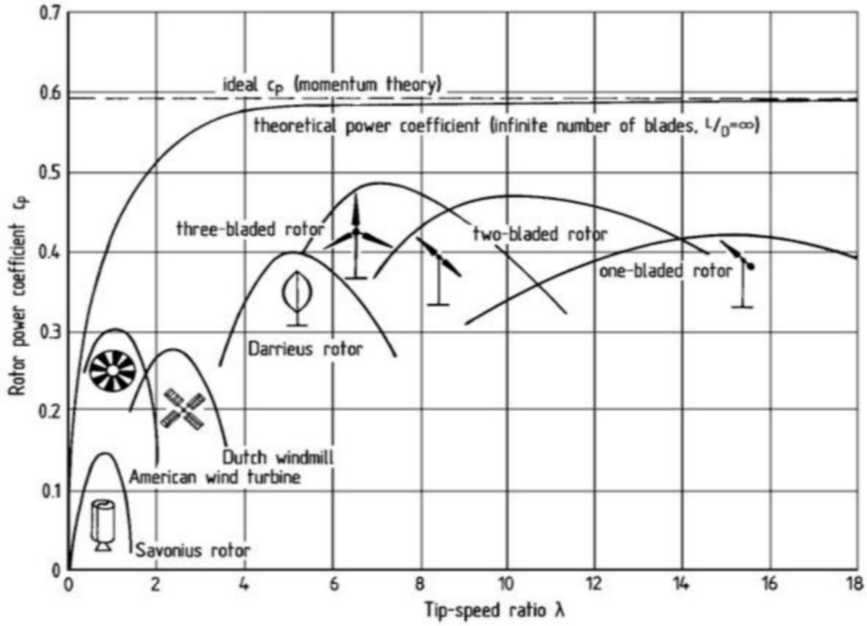


Fig. 1. Power coefficient and tip-speed characteristic for various types of wind turbine.

2.2 Wind speed

In this study, the wind speed chosen was based on the average wind speed reported for the upper north region of Thailand. Major, S. at el. [2] aimed to improve the low wind speed turbine for Thai applications. The average wind speed reported in the paper was about lower than 3 m/s. Chaichana, T. at el. reported that the average wind speed measured at Monlan Royal Project, Chiang Mai, was about 4.86 m/s with standard deviation of 2.11 m/s [3]. The wind potential for the upper north region was also reported to be about 5.73 – 6.24 m/s. It was measured at 40 metres above the ground at the Monlan Royal Project and the Maehae Royal Project [4]. Chaicha, T. and Chaitep, S. also reported the average wind speed which measured at the Chiang Mai International Airport between 2001 – 2006 [5]. The yearly average wind turbine was found to be about 5.7 m/s. Thus, in this study, the wind speed was chosen to range from 3 - 6 m/s. Therefore the tip-speed ratio and the rotor power can be calculated and listed in table 1.

Table 1: Tip-speed ratio and Power coefficient for the wind turbine used in the study

Wind speed (m/s)	Tip-speed ratio	Power coefficient (approximate)
3	10.47	0.4
4	9.42	0.44
5	8.79	0.46
6	7.75	0.48

The calculation of the tip-speed ratio listed in table 1 shows the tip-speed ratio that ranges between 7 to 10. Thus it supports that the suitable wind turbine for this experiment should be a 3 blade-rotor. Therefore the 3 blade-rotor wind turbine with diameter of 2.4 metres and horizontal axis was chosen. The wind turbine used for this study is shown in figure 2.

Fig. 2. The 3 blade-rotor wind turbine with diameter of 2.4 meters.

2.3 Alternator/starter

The alternator was used for this study as a wind turbine starter. It will start the wind turbine at the beginning for 500 milliseconds. The starter will turn to be a generator right after the starting time. This is expected to reduce the starting period and increase the generating duration. The electrical capability for the system with and without the auxiliary system was compared. In addition, the reader should be reminded that this research project does not intend to experiment the starter or the alternator. Only the possibility of using such the device to start the wind turbine was considered.

The alternator used in this study is known as the Alternating Current Generator (ACG) starter. It was invented by Honda to be used in the PCX model by Thai Honda Manufacturing Co., Ltd. [6]. The ACG starter is a DC 12 V. brushless alternator as shown in figure3. Its power generating output is 266 Watts. The operational principle is interpreted for two stages. The first stage, the ACG starter works as a starter motor. The motor begins working when power is applied to the stator cores. As a result, torque is generated and then motor drives the engine as shown in figure 4 (a). Once the start completed, the ACG starter gets into the second stage. At this stage, the ACG starter works as an alternator. The alternator starts working when a charging current in the coil occurred as shown in figure 4 (b). The more information about working principle of the ACG starter can be found in [6].

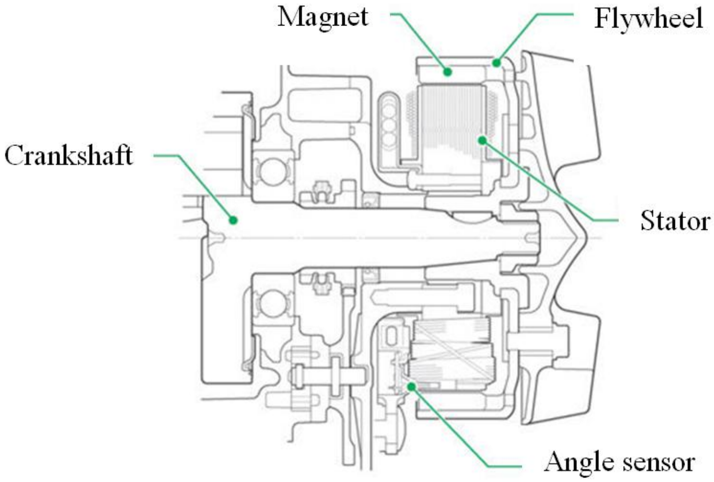
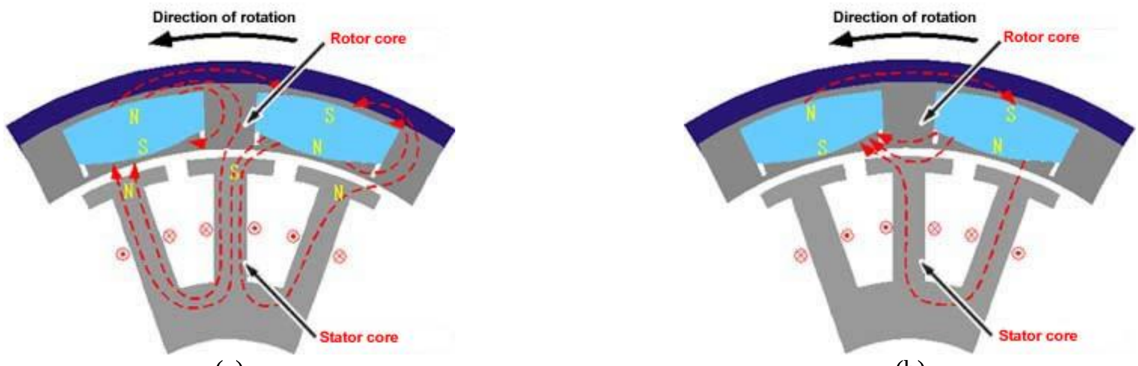


Fig. 3. Cross section view of the brushless ACG starter [6].

The alternator used in this study is known as the ACG starter. It was invented by Honda to be used in the PCX model by Thai Honda Manufacturing Co., Ltd. [6]. The ACG starter is a DC 12 V. brushless alternator as shown in figure3. Its power generating output is 266 Watts. The operational principle is interpreted for two stages. The first stage, the ACG starter works as a starter motor. The motor begins working when power is applied to the stator cores. As a result, torque is generated and then motor drives the engine as shown in figure 4 (a). Once the start completed, the ACG starter gets into the second stage. At this stage, the ACG starter works as an alternator. The alternator starts working when a charging current in the coil occurred as shown in figure 4 (b). The more information about working principle of the ACG starter can be found in [6].

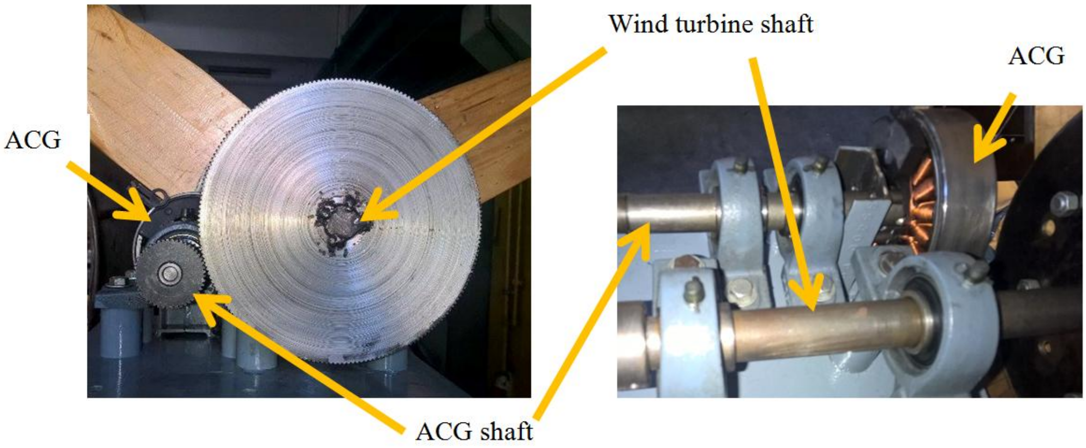


(a) (b)

Fig. 4. Cross section view of the ACG starter.

3. Experimental Setup

The experimentation was setup by connecting the shaft of the 3 blade rotor to the ACG starter via transmission gears as shown in figure 5. The transmission gears were used to increase the revolution speed of the ACG.



(a) Front view (b) Side view

Fig. 5. Transmission gears connecting the shaft of the wind turbine to the ACG starter.

The wind generator as shown in figure 6 was used to produce the wind speeds as mentioned. The wind speed was measured using an anemometer. The electrical load was set up using three automotive light bulbs with the power of 35/35 Watts, 60/55 Watts and 100/90 Watts.

Fig. 6. Wind generator.

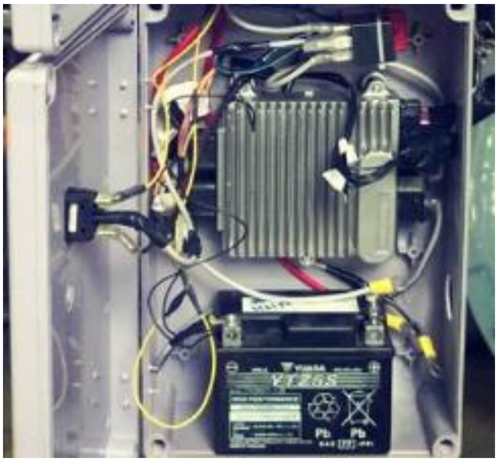


Fig. 7. The Engine Control Module used for controlling the working status of the ACG.

The ACG starter was controlled electronically using the control unit known as the Engine Control Module or ECM which is as shown in figure 7. The generated power from the ACG was captured electronically. The Arduino UNO was used as the controller. The wind speed was measured at three different points as shown in figure 8 and then averaged. The turbine was let rotating when the average wind speed at these points reached the desired values. Then time and record the power being generated for the desired duration.

The experiment was done for two circumstances, i.e., constant wind speed and variable wind speed. For the experiment with constant wind speed, the average wind speed was controlled to be 3 m/s, 4 m/s, 5 m/s and 6 m/s, respectively. The data record duration for these wind speed was 2 minutes. The second experiment was done by varying the wind speed to be at 3 m/s to 6 m/s within the recording duration. The recording duration was varied from 1 minute, 2 minutes and 3 minutes. The experiments for the system with and without the start system were done in the same manner. Then the results can be comparable.

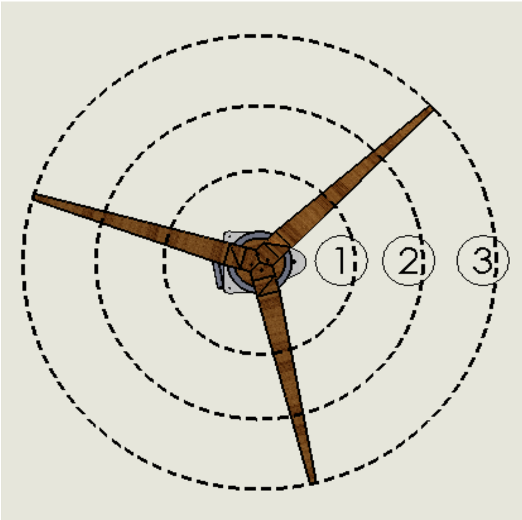


Fig. 8. The locations for measuring wind speed.

Table 2: *Comparison* between the system with and without auxiliary start system

	Without ACG starter	With ACG starter	Generating time increased	
Constant wind speed at 3 m/s for 2 minutes				
Time to start generator (second)	36	10	26	(72%)
Alternator speed (rpm)	540	660	-	-
Time to steady-state (second)	45	20	25	(55%)
Constant wind speed at 4 m/s for 2 minutes				
Time to start generator (second)	24	8	16	(65%)
Alternator speed (rpm)	500	660	-	-
Time to steady-state (second)	34	30	4	(11%)
Constant wind speed at 5 m/s for 2 minutes				
Time to start generator (second)	20	8	12	(60%)
Alternator speed (rpm)	500	700	-	-
Time to steady-state (second)	47	20	27	(57%)
Constant wind speed at 6 m/s for 2 minutes				
Time to start generator (second)	19	7	12	(63%)
Alternator speed (rpm)	580	700	-	-
Time to steady-state (second)	42	28	14	(33%)-
Variable wind speed at 3-6 m/s for 1 minute				
Time to start generator (second)	30	9	-	(70%)
Alternator speed (rpm)	500	700	-	-
Variable wind speed at 3-6 m/s for 2 minutes				
Time to start generator (second)	42	6	-	(85%)
Alternator speed (rpm)	500	450	-	-
Variable wind speed at 3-6 m/s for 3 minutes				
Time to start generator (second)	41	6	-	(85%)
Alternator speed (rpm)	620	450	-	-

4. RESULTS AND DISCUSSIONS

The experimental results for power generating performance obtained from the wind turbine with and without the ACG system are compared as shown in table 2. It is seen in common that time to start generator is shorter when the ACG starter was applied. The power generating time was increased up to 72% for constant wind speed and 85% for variable wind speed. For the case of constant wind speed, the ACG system is found to be the most useful for the lower wind speed, i.e., wind speed of 3 m/s for this instance. However, for the case of variable wind speed, the ACG system is more suitable when wind flow continuously in longer period, i.e., 2-3 minutes for this instance.

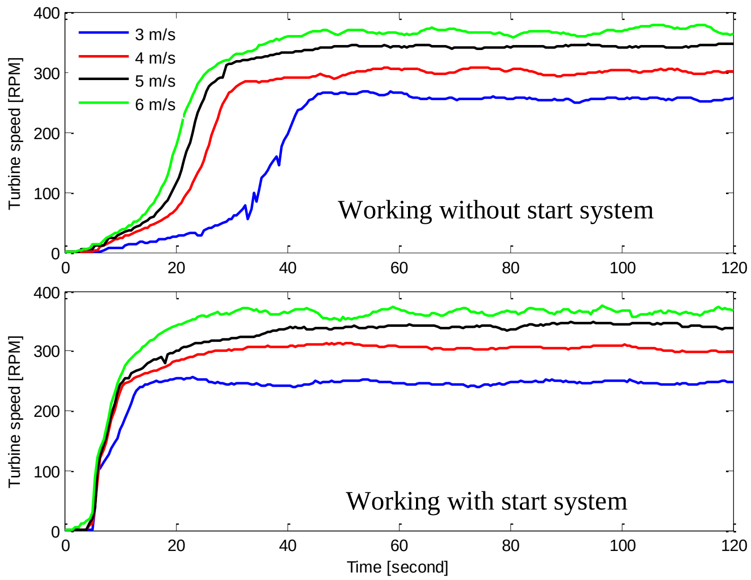


Fig. 9. Turbine revolution speed for constant wind speed.

Figure 9 shows comparison of revolution speed of the wind turbine for constant wind speed. Figure 9 (upper) is seen that the wind turbine took longer duration to reach the steady-state whereas using the start system used shorter time as shown in figure 9 (lower).

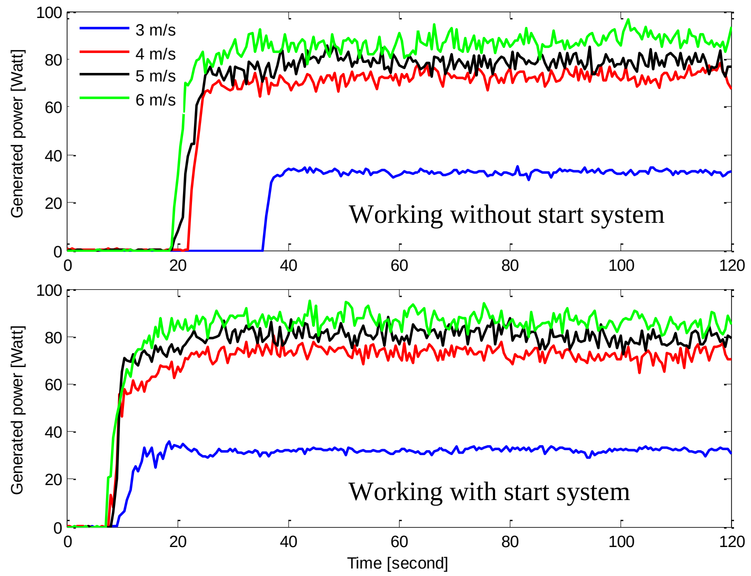


Fig. 10. Power generated for constant wind speed.

Therefore, as shown in figure 10, using the start system resulted in the longer power generating period in comparison to that without the start system. The starting points for power generation are seen to be almost at the same time, i.e. around 10 seconds after start.

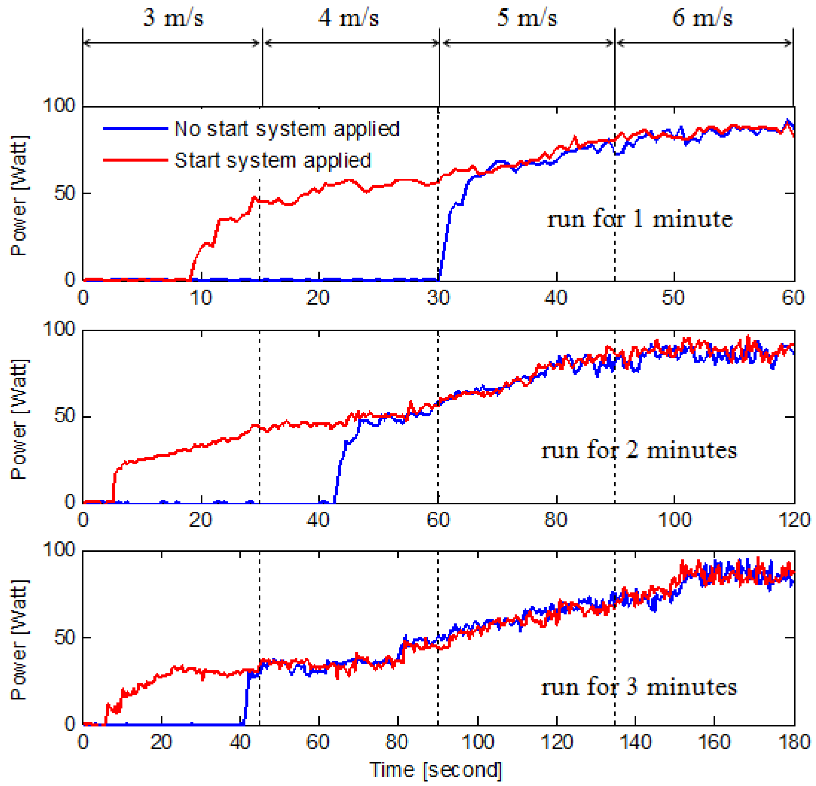


Fig. 11. Power generated for experiment with variable wind speed.

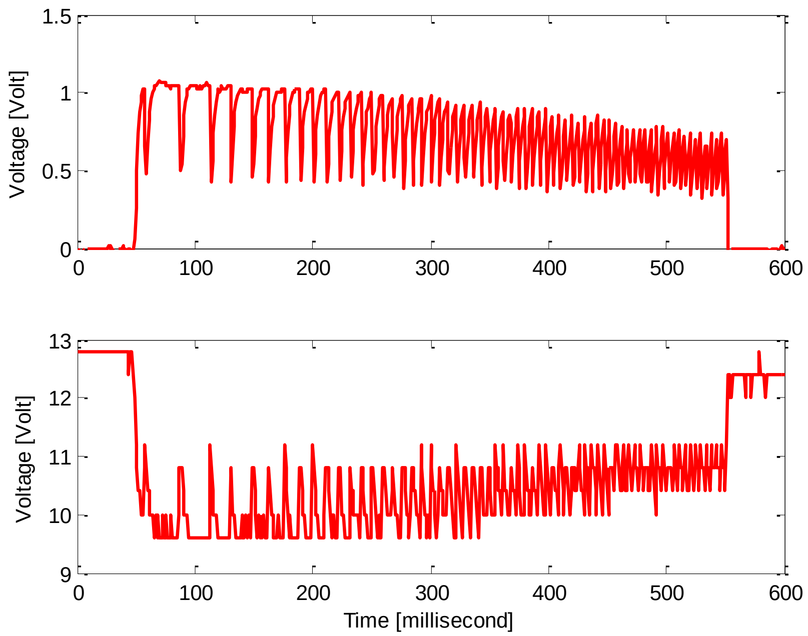


Fig. 12. Voltage measured across a wire (upper) and a battery (lower).

In addition, figure 11 shows the generated power for the experiment with variable wind speed. It is seen that using the start system extends the generating duration. However, it is noticed that, for the longer running time, the use of start system has less important role. Since the extended time is comparatively less than the time that turbine running. From this, it can be implied that the start system is more suitable for the location that wind flow discontinuously in short time.
Furthermore, one may concern the amount of power used to start the wind turbine. As mentioned earlier, the starter was run for only 500 milliseconds right after the wind turbine let rotating. The measured voltage drop across a wire was found to be about less than 1 Volt as a graph shown in figure 12 (upper). The voltage drop reduced as the starting time increased. The voltage drop of the battery was also measured. It was found to be about 10 to 12 Volts during the starting period as shown in figure 12 (lower). The power used during the starting period can then be calculated and listed in table 3.

Table 3: Comparison for power generating between the system without and with the ACG starter

Wind speed (m/s)	No ACG starter Net Power (Watt)	With ACG starter		
		Generated Power (Watt)	Power used for the ACG starter (Watt)	Net Power (Watt)
3	2,744.93	3,482.22	260.60	3,221.62
4	6,813.02	7,956.11	246.00	7,710.11
5	7635.52	8,821.46	229.76	8,591.70
6	8475.16	9,543.92	220.88	9,323.04

The maximum power used for the ACG starter during the start duration is seen to be about 260 Watts to start the wind turbine for the wind speed of 3 m/s. The higher wind speed is seen to require lower level of power to start the wind turbine.

The net generating power performances for the two systems are compared as shown in figure 13. It shows that using start system for either constant wind speed or variable wind speed provides higher generating power for every wind speed. Thus, one can conclude that using start system gains the performance of wind turbine power generating. This is most suitable for the location with low wind speed of about 3 – 6 m/s and flow discontinuously.

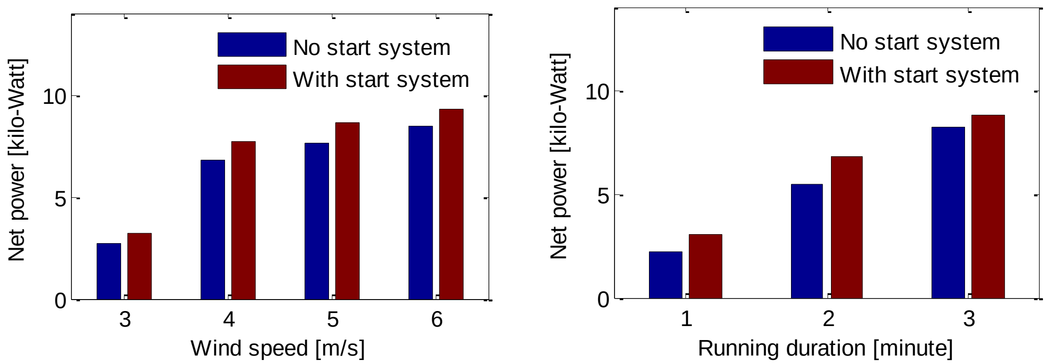


Fig. 13. Net power generated for constant wind speed (left) and variable wind speed (right).

5. Conclusion

This research project aims to study the possibility of using the start system for the wind turbine power generating system. Two cases of wind speed were applied in the experiment, i.e., constant and variable wind speed. The results show that using start system extends the power generating duration. As a result, the total amount of generated power is increased. Although the start system requires some amount of power to operate, the maximum power used is less than 500 Watts at constant wind speed of 3 m/s. It is approximately 15% of the generated power whereas the generating duration is increased for about 72% and the generated power is increased for about 21%. Therefore using start system is considerable suitable for the wind turbine generation. However, it is only suitable for the plant in the area which wind discontinuously flows. This is because the longer duration of wind flow disregards the significant role of the start system.

NOMENCLATURE

A	area of a turbine circle, m^2
C_p	rotor power coefficient
P_w	wind power, Watt
ω	rotor rotational speed, rad/s
R	rotor radius, m
ρ_{air}	air density, kg/m^3
v	wind velocity, m/s

REFERENCES

[1] Phyo, S.P. and Aung, T.H. Wind turbine generation system implemented with a claw pole alternator, International Journal of Scientific Engineering and Technology Research, Vol. 3(16), 2014, pp. 3411-3416.

[2] Major, S. Commins, T. and Noppharatana, A. Potential of wind power for Thailand: an assessment, Maejo International Journal of Science and Technology, Vol. 2(2), 2008, pp. 255-366.

[3] Chaichana, T. Chaithep, S. and Dussadee, N. Wind power potential analysis based on the Weibull and Rayleigh distribution (Case study at Monlan Royal Project, Chaing Mai), Proceedings of the 22nd Conference of Mechanical Engineering Network of Thailand, 2008, Thammasat University, Rangsit campus, Pathumthani, Thailand.

[4] Dussadee, N. Sasujit, K. Chaichana, T. Suwannasit, N. Suankamkong, A. and Kiatsiriroat, T. Estimated potential wind energy in upper north region, Proceedings of the 9th Thai Society of Agricultural Engineering Conference (TSAE), 2008, Chiang Mai, Thailand.

[5] Chaichana, T. and Chaitep, S. Wind power potential and characteristic analysis of Chiang Mai, Thailand, Journal of Mechanical Science and Technology, Vol. 24(7), 2010, pp. 1475-1479.

[6] Honda, Starts the engine quiet and jolt-free, scooter starts moving smoothly, 2016, URL: http://world.honda.com/motorcycle-technology/Engineidlingstop/p3.html (Accessed: March 2016).