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An electric generator driven by a roof ventilator

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Abstract

This paper develops the roof ventilator by adding three phase synchronous generator for voltage generating. The construction contains low flux density permanent magnet in rotational part and the three phase winding stator install at the ventilator base. When the ventilator rotate, the flux of the permanent magnet rotor part is moving across the air gap and induced the ac. voltage in the three phase stator winding. After that, the a.c. voltage is rectified to d.c. voltage and finally charged to the 12V 5A lead-acid battery. The results of the generator performance are at the no-load speed 100 rpm, the generator voltage could be induced 52.3 V. At on-load, the generator could be supplied the load with the real power 1.15W. For the results after install the generator in the ventilator on the roof of a building to charge the 12V battery, and the minimum wind speed for enough charging to battery is at 20 rpm. Additional to the efficiency of hot air ventilation after install the ac synchronous generator, the ventilation is just only reduced 0.13 m^3/min or about 5.78% from the normally ventilation before installation generator 2.25 m^3/min.
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Keywords— Ventilator; Synchronous Generator; Hot air ventilation; Generator winding design

1. Introduction

Thailand is the country in the tropical zone [1]. There are high humidity and warm weather all of year. Especially in Summer on April and May, Day time temperature may be increasing to 45 ^{O}C or 39-41 ^{O}C for the average temperature at noon all of the year. It effects to decreasing work efficiency of worker or damage product for some business. So, air-conditioner in Thailand is the best seller for residence but not for industrial because it must pay a lot of cost as such as electric charge and maintenance cost.

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The concept of natural ventilation without using electric energy is lead to be the roof ventilator. This technology is popular using by install on the roof in warehouse, workshop, industrial building and including to residence as fig. 1.

Fig. 1. Roof Ventilator on the Building.

Nomenclature

a.c.	Alternating current
d.c.	Direct current
p.f.	Power Factor
V	Voltage: unit measurement of electric potential
A	Ampere: unit measurement of current
Nm	Newton-metre: unit measurement of torque
W	Watt: unit measurement of electric power
Wb	Weber: unit measurement of magnetic flux
min	Minute
sec	Second
m	Unit measurement of length in metre
mm.	Unit measurement of length in millimetre
m^2	Unit measurement of cross sectional area in square metre
m^3	Un it measurement of volume in cubic metre
rpm	Speed measurement in revolutions per minute

2. Roof Ventilation

Roof ventilators are divided in 2 types:

- Roof Ventilator with motor driven
- Roof Ventilator with natural air driven

For this paper is interesting to the second type that comprise of stationary part and rotational part. Stationary part is composed of base and fixed shaft. Rotational part is composed of fan blades and bush that put on the fixed shaft on stationary part. For the principle of roof ventilator, when the air flow on the top of roof or the heat air that lifting to under the roof, it turns the roof ventilator. Ventilation rate is up to the speed and the size of roof ventilator. Figure 2 shows the construction of roof ventilator.

Figure 3 shows the heat and humidity in building before installation the roof ventilator are only circulate inside the building and it effort to more temperature and humidity, after installation the roof ventilator, it suction the heat air in the building and thrown to outside of the building, then the inside building temperature and humidity are not too high.

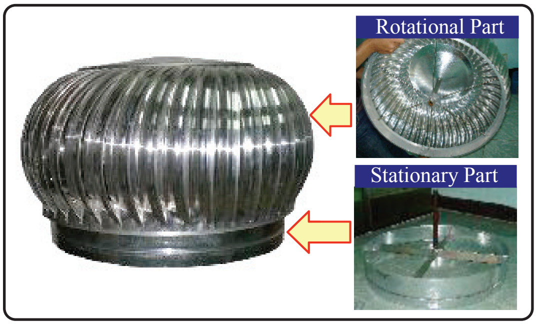

Fig. 2. Construction of Roof Ventilator.

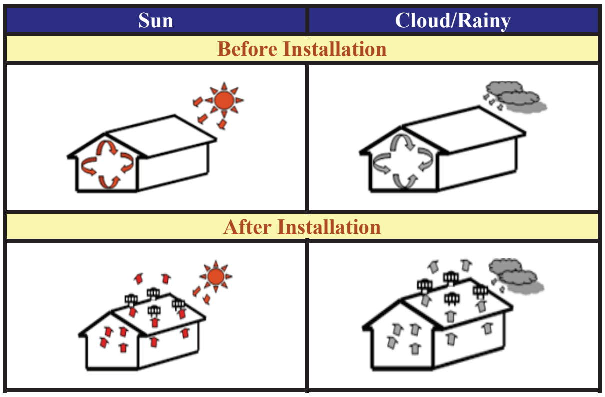

Fig. 3. Construction of Roof Ventilator.

With consideration to the heat inside of the building on day time have 2 sources:

- **Heat from machine**. It is up to type of machine in building, heat production such as radiation or heat transfer to air. In this case, the roof ventilator could effectively flow these heat to outside.
- **Heat from sun**. This heat is transferred via the roof to inside of building. This sun heat has too much and effort to increasing of heat in building that more than 80% coming from radiation, the others coming from transfer to air. Roof ventilator could serve the heat from transfer to air that not more than 20% but not against the heat from the radiation.

As above, the roof ventilator could reduce the heat mass under roof only 20%. So many installations of roof ventilator may not always mean that more decreasing the heat in building. But before installation must be first consider to sources of heat and characteristics of roof ventilator for ventilation.

The table 1 shows the characteristics of roof ventilator about base size diameter, number of blade, weight, impeller size diameter and the efficiency of ventilation. For the roof ventilator which driving the prototype generator is using 22" size because it is donated from Arthit Chakkol Company Ltd. for graduation.

3. AC Synchronous Generator

Figure 4 shows stator and rotor of synchronous generator. Stator part is installed armature winding. Rotor part is installed field winding or using instead permanent magnet. When rotor part is driven by prime mover, field winding must be connected to d.c. supply to build magnetic flux but might be not if using permanent magnet. Magnetic flux across the air gap and cut to armature winding to induced voltage in armature winding.

a b

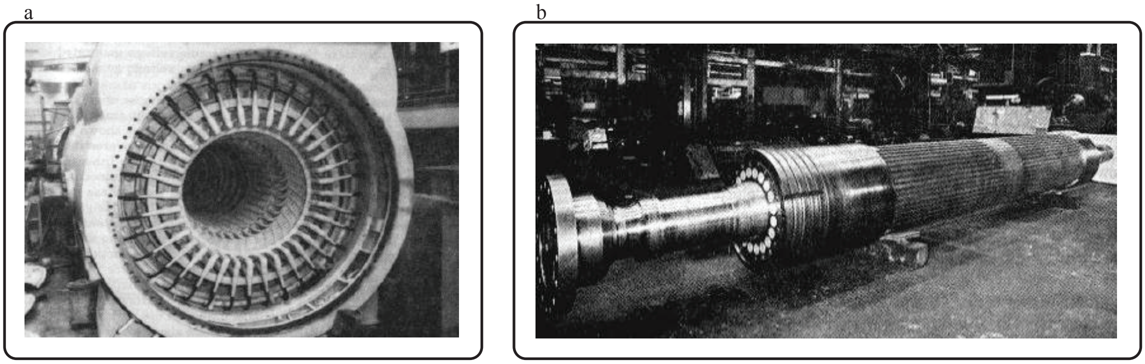

Fig. 4. parts of synchronous generator (a) Stator; (b) Rotor [2].

Table 1. Specifications of Roof Ventilator.

Size (inches) ϕ(A)	Number of Blades	Diameter (Impeller) ϕ(B)	Weight (kg)	The Efficiency of the ventilation (Average speed 6 miles/Hour)
14"	24	19"	2.8	72,000 CFH
18"	30	22.5"	3.4	92,000 CFH
22"	36	28"	7.2	170,000 CFH
25"	42	30"	8.2	190,000 CFH
30"	42	41"	15.8	240,000 CFH
39"	54	46"	19.2	350,000 CFH

4. Design concept of generator

For the concept of generator design is following to these steps:

4.1 Coil turns calculation

This section is determined number of coil turns for armature winding.

$$f = NP/120 \quad (1)$$

$$B_{max} = B_r \times \left[\frac{L_m}{L_m + \delta}\right] \quad (2)$$

$$\phi_{max} = B_{max} \times A_{magnet} \quad (3)$$

$$N_C = \frac{E_A}{4.44 f \phi_{max}} \quad (4)$$

When N is generator speed (rpm), f is generator frequency (Hz) and P is numbers of pole (poles), B_{max} is the maximum magnetic density in air gap per pole (Wb/m^2), B_r is the magnetic density per pole (Wb/m^2), ϕ_{max} is the maximum flux in air gap (Wb), L_m is the thickness of permanent magnet (m.), δ is the air gap between stator and rotor (m.), A_{magnet} is the cross sectional area of pole (m^2) that can find by using the product of width and length of permanent magnet, E_A is induced voltage (V) or requirement voltage from generator, N_C is coil turns (turns).

Table 2 shows the generator parameters for calculation that following to step 4.1

4.2 Wire size calculation

This section is determined the effects of wind force to the roof ventilator and [3] shows the concept for the calculation of the forces from each blade, finally, lead to determine the wire size for coil turn.

$$F = \frac{1}{2}\rho v^2 A \quad (5)$$

$$\tau = F(r \sin\theta_f) \quad (6)$$

$$P = \tau . N_{max} / 9.55 \quad (7)$$

$$I_L = P / (\sqrt{3} E_A \cos\theta) \quad (8)$$

Table 2. Generator parameters design in step 4.1.

Name	Symbol	Design
Output Voltage	E_A	24 V
Roof Ventilator average Speed	N	30 rpm
Poles	P	36 poles
Air gap	δ	3 mm.
Permanent Magnet size	$WxLxT$	(10x15x5) mm.
Permanent Magnet Magnetic density	B_r	0.05 Wb/m2
Turns per coil	N_C	223 turns

When F is wind force that against to roof ventilator (N), ρ is air density that equal 1.024, v is wind speed (m/sec), A is cross sectional area of roof ventilator (m^2), τ is torque of roof ventilator (Nm), N_{max} is maximum speed of roof ventilator (rpm), r is radius of roof ventilator (m), θ_f is the angle of against force (degree), P is power (W), $\cos\theta$ is power factor and I_L is line current (A).

Table 3 shows the generator parameters for calculation that following to step 4.2

4.3 Coil span calculation

This section is determined the coil span for all installation winding on stator core.

$$Coil\ Group = \frac{Total\ Slot}{Pole \times Phase} \tag{9}$$

$$\gamma = \frac{360^{o}}{Total\ Slot} \times \frac{P}{2} \tag{10}$$

$$Coil\ Span = 1 + \frac{Angle}{\gamma} \tag{11}$$

When *Coil Span* is the range between first coil-side and end coil-side that count from first coil-side in first slot to the end coil-side in the other slot (unit measurement maybe use slot or degree), *Coil group* is number of sub coil that distributed in coil span of a big coil, *Total Slot* is total numbers of slot on stator core (slots), *Pole* or *P* is magnetic pole (poles), *Phase* is number of phase system, γ is slot angle in each slot, (electrical degree), *Angle* is the angles for installation coil at each slot that use 2 angles as

- Pole Pitch is 180^{O}
- Phase Initial, Phase A is 0^{O}, Phase B is 120^{O} and Phase C is 240^{O}

Table 4 shows the coil span calculation that following to step 4.3 and Fig. 5 shows winding diagram.

4.4 Stator core design

Stator core is made from laminated sheet steel. And then, bring each sheet to compress to be a toroid core with the 10 mm. thickness.

For the shape of slot is semi closed slot and it has 108 slots for the 223 turns per coils with wire size No. #37. So the stator core must be the shape like this:

- Outer radius is 140 mm.
- Radius to the bottom of slot is 134 mm.
- Slot diameter is 6 mm.
- Air inner radius is 114 mm.

Fig. 6. (a) shows the detail of stator core design and prototype shows in Fig. 6. (b). When winding all coils and installation on stator core, it must be as Fig. 6. (c).

4.5 Rotor part design

This part is used 36 permanent magnets to hold on rotor core. With the size of permanent magnet is 10x15x3 mm. Rotor part must be support with 140mm stator radius, 3 mm. thicknesses of permanent magnet and 5 mm. air-gaps. So, rotor part radius is 148 mm. and magnet span is 10 degree per pole. Fig. 7 shows the detail of rotor part

Table 3. Parameters generator design in step 4.2.

Name	Symbol	Design
Wind speed	v	5 m/sec
Cross sectional area of roof ventilator	A	0.38x0.4 m^2
Radius of Roof Ventilator	r	0.38 m
Roof Ventilator max. Speed	N_{max}	100 rpm
Power	P	5.1 W
Line current	I_L	0.26 A
Maximum line current (125%)	I_L	0.33A
Wire size number	-	#37

Table 4. Coil span of generator winding in step 4.3.

Name	Symbol	Design
Magnetic Pole	Pole/P	36 poles
Phase	-	3 phase
Total Slot	-	108 slots
Slot angle	γ	60^O
Coil Group	-	1
Phase A Initial Slot	-	Slot 1
Phase B Initial Slot	-	Slot 3
Phase C Initial Slot	-	Slot 5
First Coil Span of Phase A	-	Slot 1-4
First Coil Span of Phase B	-	Slot 3-6
First Coil Span of Phase C	-	Slot 5-8
Second Coil Span of Phase A	-	Slot 4-7
Second Coil Span of Phase B	-	Slot 6-9
Second Coil Span of Phase C	-	Slot 8-11

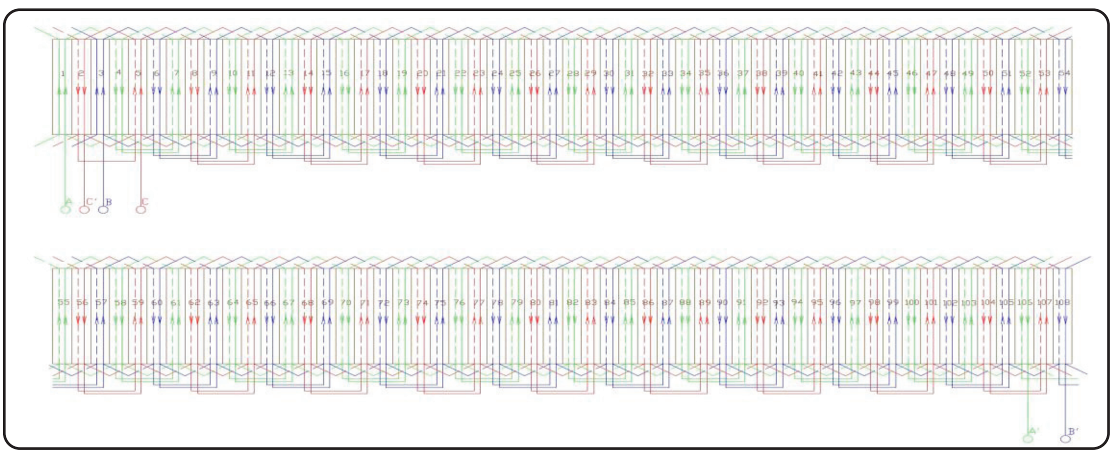

Fig. 5. Winding Diagram.

Finally, all parts could do as Fig. 8. by bring the rotor part put on the stator core. As Fig. 8 (b), with the small size of generator is not obstructed flow rate of heat mass.

5. Experimental

Generator testing could be divided in 3 parts:

5.1 Generator test

This test is operating in electrical machines laboratory and essentially test to determine the characteristics of the prototype generator as shown in Fig. 9 (a).

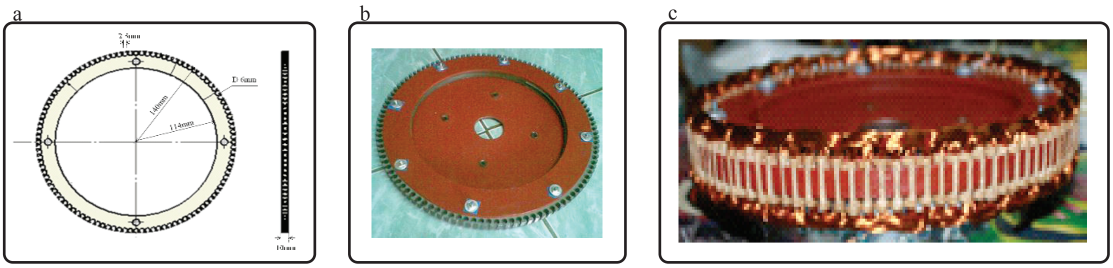

Fig. 6. (a) Design of stator; (b) Prototype of stator; (c) Armature Winding.

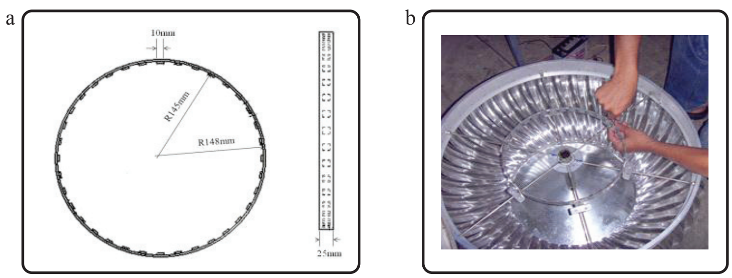

Fig. 7. (a) Design of rotor; (b) Prototype of rotor.

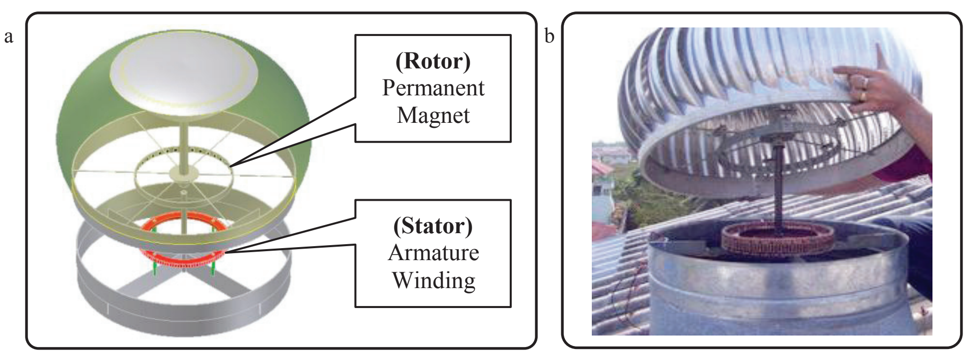

Fig. 8. All parts installation (a) Design; (b) Prototype.

Figure 9(b) shows 3 phase voltage waveform that product from generator. With no-load speed, generator could be induced the voltage that relative to speed as Fig. 9(c).

When generator is distributed power to 1.8 kΩ load with star-connected or star connected, it could be operating as Fig. 10. Notice at 100 rpm, the power is 1.15 W but from design at table 3 is 5.1 W. After that, Fig. 11 shows when testing with delta-connected 1.8 kΩ load.

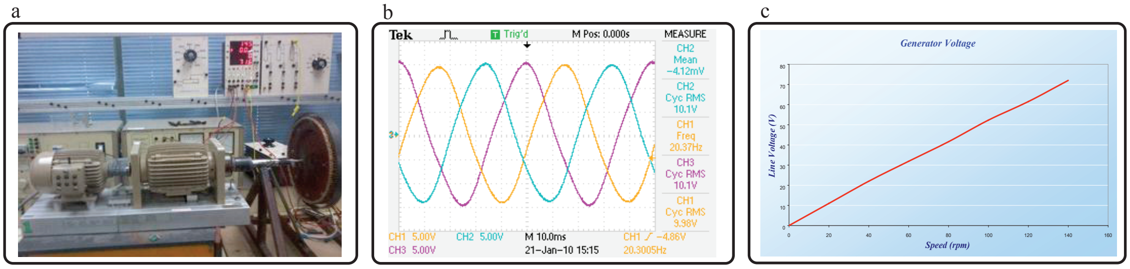

Fig. 9. No-load test results (a) Generator testing; (b) 3 Phase Voltage Waveform; (b) Plot Curve between Speed and Line Voltage.

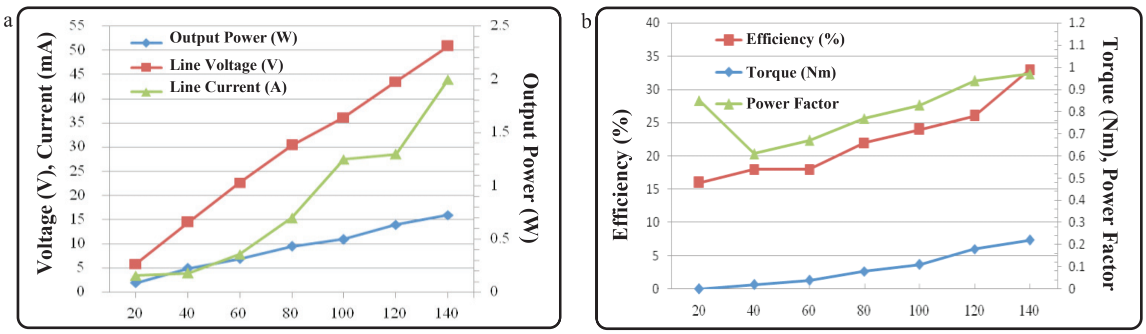

Fig. 10. Generator testing with star-connected 1.8kΩ load (a) Speed comparison with voltage, current and power; (b) Speed comparison with torque, efficiency and p.f.

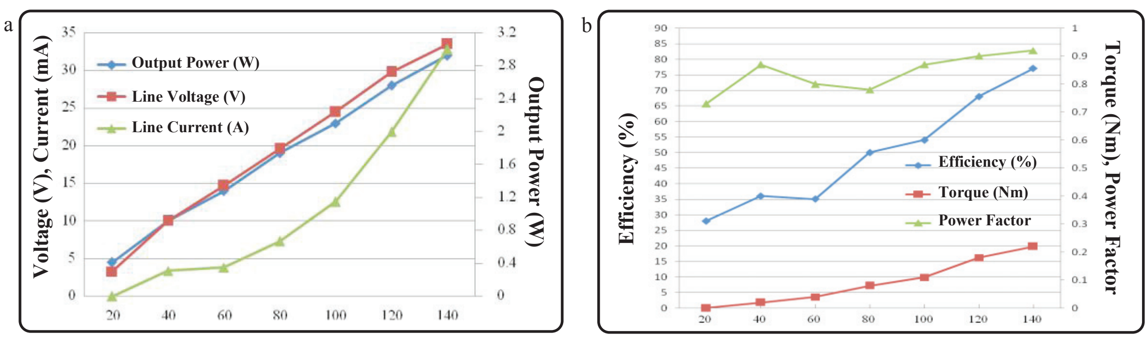

Fig. 11. Generator testing with delta-connected 1.8kΩ load (a) Speed comparison with voltage, current and power; (b) Speed comparison with torque, efficiency and p.f.

5.2 Generator test with roof ventilator

This test is essentially tested to determine the performance of the prototype generator when driven with roof ventilator but still test in laboratory, as shown in Fig. 12 (a)

Fig. 12 (b) shows the ventilation when roof generator driven generator with no-load and on-load that decreasing but not too much. With the operating standard of roof ventilation, the speed of roof ventilator or no-load generator must be at least 4 m/sec wind speed or at 85 rpm from roof ventilator speed in Fig. 12 (b) and then, ventilation rate could be 135 m^3/hr or 2.25 m^3/min. after on-load generator, roof ventilator is reduced the speed down to 80 rpm with the same wind speed 4 m/sec. Then, ventilation efficiency is reduced to 2.12 m^3/min or 0.13 m^3/min of different ventilation rate.

When test generator to distributed power to load, it could be test and recorded in table 5. This test is divided in 2 circuits, Star and delta connected. The results are delta connected is better because it can supply to load more than star connected and droop speed is lower too.

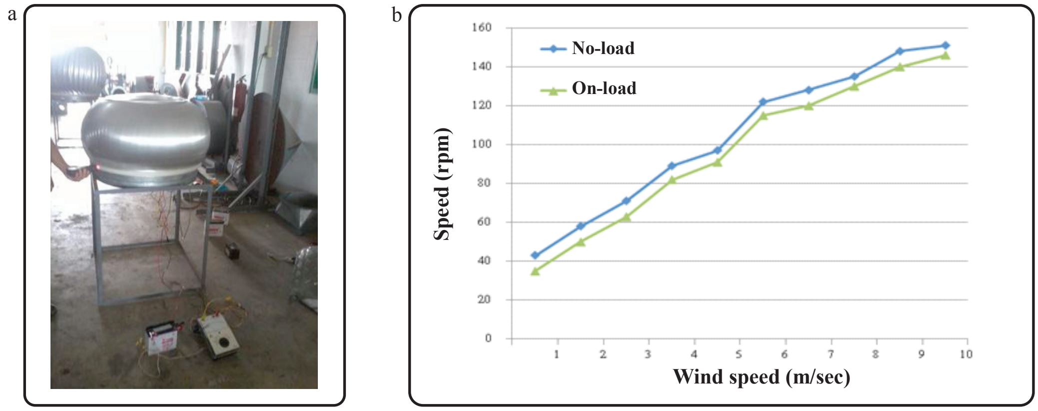

Fig. 12. (a) Generator testing with roof ventilator; (b) Comparison roof ventilator when no-load and on-load test that effect to speed.

Table 5. On-load 1 kΩ comparison with star & delta connected.

No load Speed (rpm)	Star-connected		Delta-connected	
	Speed (rpm)	Power (W)	Speed (rpm)	Power (W)
35	13	0.012	17	0.016
50	23	0.054	35	0.086
63	35	0.095	43	0.130
82	48	0.182	53	0.255
91	51	0.248	61	0.355
115	66	0.511	82	0.552
120	79	0.588	97	0.734
130	87	0.825	105	1.033
140	96	1.007	114	1.138
146	105	1.201	122	1.277

5.3 Generator test with roof ventilator on roof building

This test installs the prototype generator with roof ventilator on the roof of Arthit Chakkol Company Ltd., as shown in Fig. 13.

For this test, generator is tested by charging 12 V 5 AHr battery that has 6 V initial voltage before charging. The charging voltage is recorded every 10 minutes for about 48 times. Then, the result can plot as curve on Figs. 14 (a) and (b).

Figure 14 (a) shows voltage and speed at no-load. At 77 rpm speed, voltage has increased to 30 V.

Figure 14 (b) shows voltage, current and speed while charging to battery. The maximum voltage is occurred at 49 rpm speed with 28mA and 8V Charging. It could be calculate the power 0.224 W.

6. Conclusion

Induced voltage from generator is directly proportional to the speed of roof ventilator. In case of practical installation on the roof, voltage is induced lower than the measurement in laboratory because of wind changing.

Errors of prototype generator is come from calculation and especially stator construction because of no magnetization data of laminated sheet and accuracy of tools for slot making.

a b c

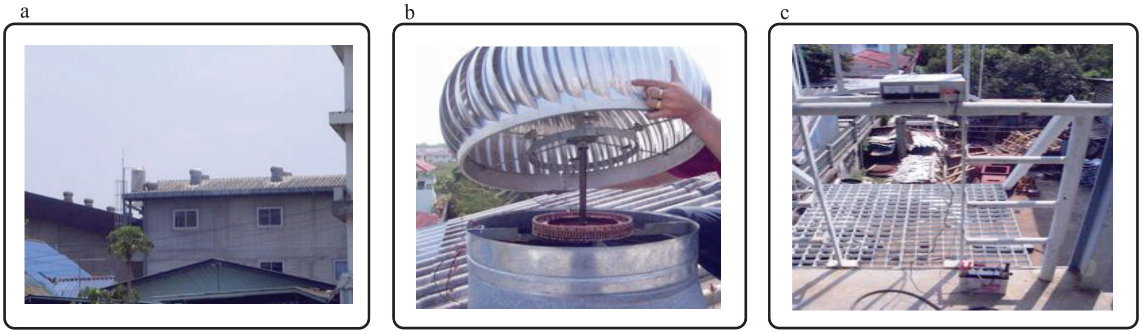

Fig 13. Real installation at Arthit Chakkol Building (a) building; (b) installation; (c) data logging.

a b

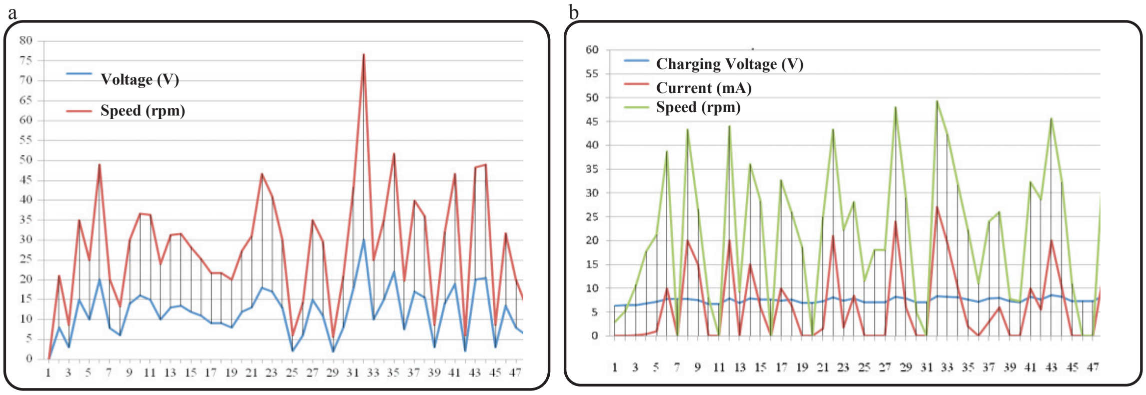

Fig. 14. (a) Voltage and Speed at no-load; (b) Charging voltage, current and speed.

Acknowledgements

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