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Permanent magnet motors used for optimum electric generating from small windmill

(Conference Paper)

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Abstract

Small scale wind mill as wind energy converter system (WECS) with permanent magnet generator has great opportunity to develop for the islands of eastern area of Indonesia. Application of this appropriate technology will increase electrification ratio. Experiment and simulation studies of electric machines used for electric generating from small multi blades windmill were carried out. Diameter of the wind mill is 3 meters. The electric machines are 350 Watt brushless direct current (BLDC) motor with permanent magnet at rotors. The machine is used as electric generator by simple electric circuit addition for lamps to get its characteristics and for charging of 12 V and 24 V batteries. Wind speeds were 4 up to 9 m/s covered annual wind speed at Indonesia and rest of islands of eastern Indonesia. Results showed that the generators efficiency decreased when loads increased, 65.3% and 77.6% for 12 V and 24 V batteries charging. Two generators with a controller charged both batteries optimum. Transmission ratio of gearbox is 1-4 for primary generator and 1-5 for secondary generator. Maximum wind speed of primary generator for 12 V batteries charging is 7 m/s and switch to secondary generator for 24 V batteries charging. Minimum wind speed for 24 V batteries charging is 6 m/s and switch to primary generator. © 2015 IEEE.

Author keywords

battery charging; multi blades windmill; optimum load; permanent magnet generator; permanent magnet motor

Indexed keywords

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Appropriate technologies; Brushless direct current motor; multi blades windmill; Optimum loads; Permanent magnet generator; Permanent magnet motor; Transmission ratios; Wind energy converters

Engineering main heading: Electric generators

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PROCEEDING

2015 International Conference on Sustainable Energy Engineering and Application (ICSEEA)

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5-7 October 2015
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Foreword from the Chairman of ICSEEA 2015

On behalf of the Organizing Committee of the 3rd International Conference on Sustainable Energy Engineering and Application (ICSEEA 2015), I would like to welcome you all to Bandung to attend this scientific conference. I hope this conference can provide an interesting program and serve as an excellent forum for innovative and technical discussion.

Starting from this year, the deputyship of engineering sciences in Indonesian Institute of Sciences (LIPI) supports a conjunction of several existing conferences in Indonesia, and publishing the proceedings at the globally indexed publishers. As such, The ICSEEA 2015 is to be held from 5 to 7 October 2015 in Bandung, West Java, Indonesia, together with five other conferences, as part of Science and Technology Festival 2015 organized by LIPI. The technical co-sponsor of ICSEEA 2015 is IEEE Indonesian Section and this conference is organized by Research Center for Electrical Power and Mechatronics (RCEPM-LIPI). It is an event where international scientist, technologists, researchers, academicians, government officials, practitioners and private sectors interact and promote networking as well as expand their science and technology cooperation.

Under the theme “Sustainable Energy for Greater Development,” the conference will showcase new frontiers of sustainable energy engineering and application as a means for improving, developing and enriching human life. ICSEEA 2015 received 47 papers from 9 countries, out of which, 21 were accepted for oral presentation (only 17 of them will finally be submitted to IEEE for various reasons).

We are very honored with the presence of two very distinguished keynote speakers with extensive experiences in their respective fields: Dr. rer. nat. Günther Scherer, a senior investigator from TUM CREATE (Singapore) and Associate Professor John Young, Ph.D from University of New South Wales (Australia). They will share their knowledge on the field of sustainable energy engineering.

I would like to express my sincere gratitude to all distinguished keynote speakers, presenters, participants and scientific reviewers for their invaluable contributions to ICSEEA 2015. The success of ICSEEA 2015 is also indebted to the efforts and goodwill of all those who were involved in organizing the conference.

I sincerely hope that you will find this conference interesting and beneficial. And I wish you could spend some time to enjoy the beauty of the city.

Sincerely yours,

Kadek Heri Sanjaya
Chairman of ICSEEA 2015

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***Abstract*—Small scale wind mill as wind energy converter system (WECS) with permanent magnet generator has great opportunity to develop for the islands of eastern area of Indonesia. Application of this appropriate technology will increase electrification ratio. Experiment and simulation studies of electric machines used for electric generating from small multi blades windmill were carried out. Diameter of the wind mill is 3 meters. The electric machines are 350 Watt brushless direct current (BLDC) motor with permanent magnet at rotors. The machine is used as electric generator by simple electric circuit addition for lamps to get its characteristics and for charging of 12 V and 24 V batteries. Wind speeds were 4 up to 9 m/s covered annual wind speed at Indonesia and rest of islands of eastern Indonesia. Results showed that the generators efficiency decreased when loads increased, 65.3% and 77.6% for 12 V and 24 V batteries charging. Two generators with a controller charged both batteries optimum. Transmission ratio of gearbox is 1:4 for primary generator and 1:5 for secondary generator. Maximum wind speed of primary generator for 12 V batteries charging is 7 m/s and switch to secondary generator for 24 V batteries charging. Minimum wind speed for 24 V batteries charging is 6 m/s and switch to primary generator.**

Keywords*—permanent magnet motor; permanent magnet generator; multi blades windmill; optimum load; battery charging

I. INTRODUCTION

At the end of 2004, the power produced from wind worldwide reached 48 GW or 0.57% of the total world electricity supply. Although not impressive, but wind power is the most promising renewable energy when compared to other renewable energy technologies. [1]. Wind energy is one of the most prospective renewable energy sources for water pumping and electric generating application, especially for rural/restricted area. Thus, wind power generation has gained a high level attention of attention and acceptability compared to other renewable energy resources [2,3,4].

Indonesia electrification ratio was 75.2% at the end 2013 and electric demand is projected 272.34 TeraWh on 2020 [5]. Wind power resource at Indonesia is 9.29 GW with installed wind mill capacity 0.5 MW so that the utilization of wind energy has opportunity for development. KNRT was designing wind energy utilization up to 125 MW on-grid and 25 MW off-grid installed wind mill capacity until 2025 [6]. Especially for the islands of eastern Indonesia with annual wind speed of 8 m / s, off-grid wind energy converter system (WECS) are the biggest opportunity to develop and to increase the electrification ratio [7]. In the road map of wind energy development, one of area concentrations for development is permanent magnet generator and its applications [6].

Apart of farmers in north of Java island used windmill mainly for irrigation or for pumping sea water into drying pans for sea salt production. Therefore any wind pump developed for irrigation has to be low in cost and this requirement tends to overide most other considerations. Wind mill designs are often improvized or built by the farmers to easy maintenance as a method of low-cost mechanization [8]. In other hands, electric bicycles are popular vehicles as green transportation. The simple technology on it make users can maintain the bicycle when trouble. Since the simple technology generally involves the bicycle users and/or other workers being present, it is not so critical to have a machine capable of running unattended.

This article present both experiment and simulation study to investigate the used of bicycle BLDC permanent magnet motors as an electric generator on small multi blades windmill as a WECS. Lamps and batteries will be used as generator's load for lighting and charging. Switch controller regulate generators to produce optimum electric power optimal as the shaft speed and thus wind speed. The electric generating system is designed for multi blades windmill on 4 up to 9 m/s wind speed. The wind speed is covered annual wind speed at Indonesia (4.5 – 5.0 m/s) and also potential wind energy area at eastern of Indonesia (8 m/s).

II. EXPERIMENT METHODS

The electric generators used for experiment were bicycle BLDC motor. The motor specification were 350 W, 48 V, brushless, 3 phase, permanent magnet. For electric generating, BLDC machines output were modified by electric components diodes (3 x 75 A) addition. An arm was attached on electric generator's rotor for torque measurement and shaft power input. The driver of electric generator was an 1,500 Watts 3 phase electric motor with 2,000 Watts inverter as a speed controller (Fig. 1).

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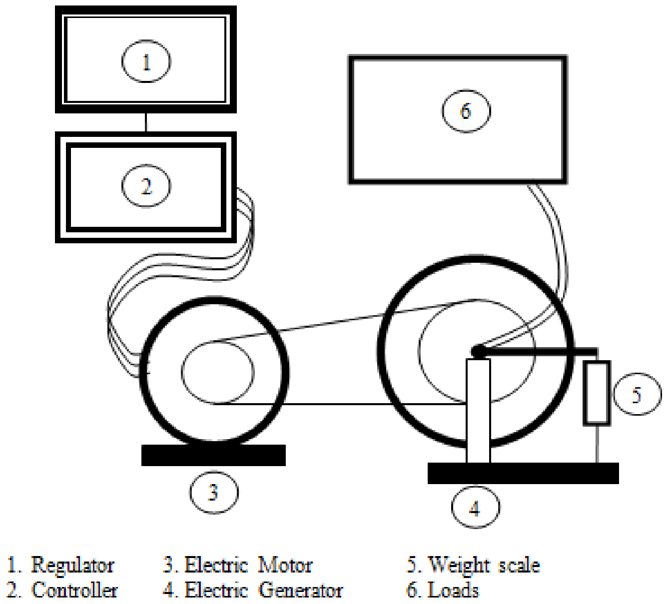

Fig. 1. Schematic of experiment apparatus.

Shaft power input to the electric generator :

$$P_{ing} = 2\pi\, n_g \left(\frac{1}{60}\right) F\, L \left(\frac{1\,J}{1\,N\,m}\right) \tag{1}$$

where n_g is shaft speed of generator (rpm); L is torque arm lenght (= 0.24 m); F is force (N).
Electric power output from electric generator :

$$P_{outg} = V_o\ I \tag{2}$$

where V_o is voltage (volt); I is electric current (ampere).

Three independent loads for generator were variable lamps (Fig. 2), 12 V battery with inverter and 40 W lamp and 24 V battery with inverter and 40 W lamp (Fig. 3).

Coefficient of power (Cp) and tip speed ratio (tsr) of American multi blades windmill [9] were used as the reference for simulation.

$$Cp = \frac{P_{outw}}{P_{inw}} \tag{3}$$

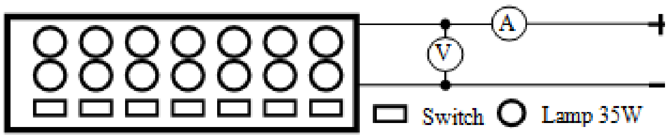

Fig. 2. Load circuit system with 14 lamps.

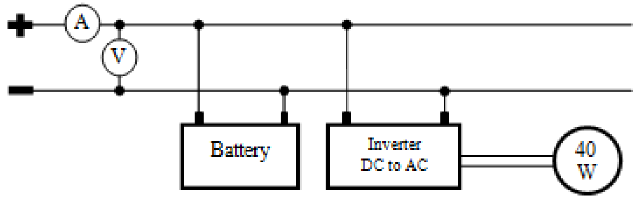

Fig. 3. Battery with inverter and lamp.

$$Cp = \frac{P_{outw}}{P_{inw}} \tag{3}$$

Wind power input of wind mill:

$$P_{inw} = 0.6\ A\ V^3 \tag{4}$$

where A is swept area of wind mill (m^2); V is wind speed (m/s).
Tip speed ratio (TSR):

$$tsr = \frac{V_{Tip}}{V} \tag{5}$$

$$V_{Tip} = \frac{\pi\, D\, n_w}{60} \tag{6}$$

where V_{Tip} is speed of blade tips (m/s); D is diameter of windmill (3 m); n_w is shaft speed of windmill (rpm).

III. Result and Discussion

Based on the lamp load experiment result, electric generators had higher efficiency for lower lamp load and higher shaft speed (Fig. 4). Maximum speed for L2 was limited by ability of lamps. The wolfram wire of lamps was broken-off due to overloaded. Maximum speed for others higher load (L10, L12, L14) was limited by characteristics of electric machines. The experiment was limited by 300 Watts as maximum electric power output.

Based on the battery and lamp load experiment result, electric generator had higher efficiency for battery 24 Volt load, similar shaft speed range (Fig. 5). The electric generator shaft speed range, electric power output and shaft power input for battery 12 Volt and battery 24 Volt loads were 107.1 - 214.8 rpm, 23.2 - 293.7 Watts, 35.1 - 477.6 Watts and 171.3 - 273.7 rpm, 19.8 - 298.6 Watts, 28.3 - 385.3 Watts. The electric generator efficiency range for battery 12 Volt and battery 24 Volt loads were 61.5% - 69.6% and 70.0% - 79.6%.

Performance of multi blades windmill [3] was extracted and presented on shaft power output and shaft speed with wind speed. The wind speeds was V = 4 up to 9 m/s. Equation

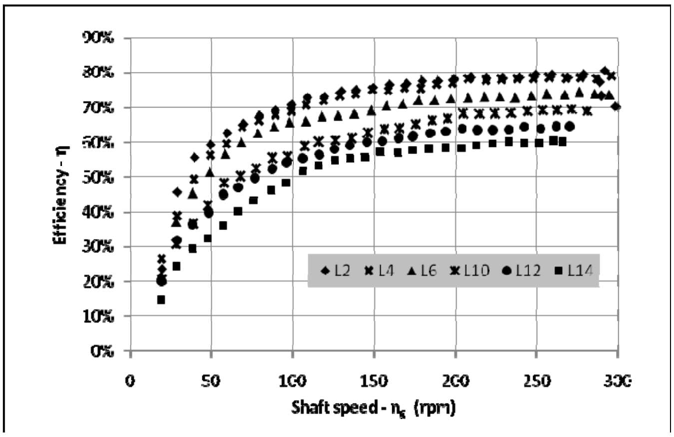

Fig. 4. Performance of generators with lamps load.

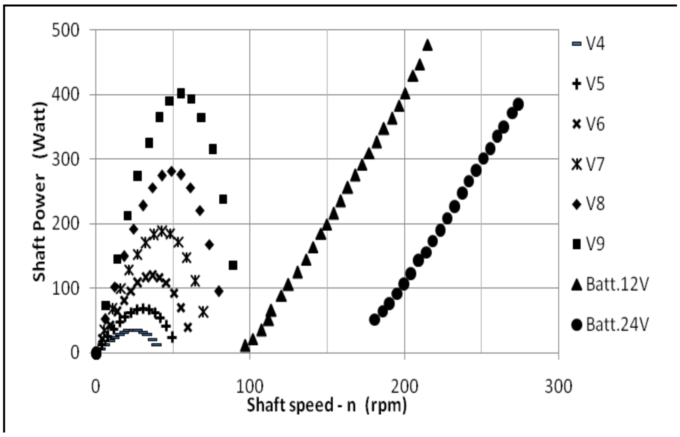

Fig. 6. Wind speed and generator speed lines

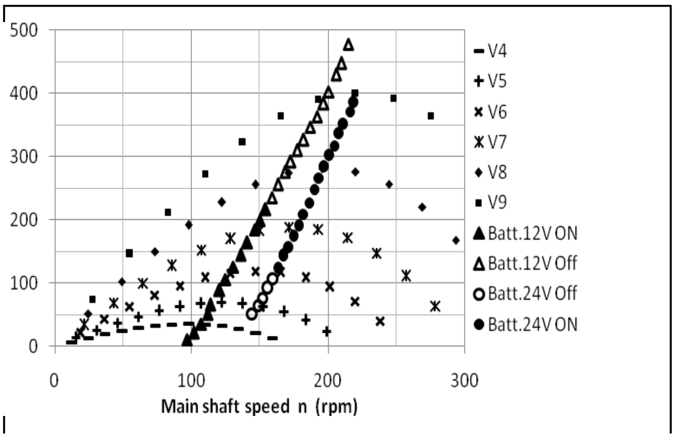

Fig. 7. WECS power output and speed lines

3 to Equation 6 were used for simulation to find shaft power output (P_{outw}) and shaft speed (n_w). Based on simulation and experiment resulted that shaft speed of the windmill was not matched with generator's shaft speed (Fig. 6). Ideally, generator's line was laid on peak power of each wind speed that will give maximum efficiency of WECS.

Batteries 12Volt and 24 Volt, the common equipments for cars, were used as simulation for electric charging in this WECS. Each battery was coupled with one electric generator. Thus WECS produced electric on two different DC voltages. Each of electric generator produced specified voltage as the battery. It was simulated 12 V electric generator charged the 12 V batteries on 4-7 m/s wind speed and 24 V electric generator charged the 24 V batteries on 6-9 m/s wind speed. At 7 m/s wind speed, the controller switched off 12 V electric generator and switched on 24 V generator which called high switching (HS). Simulation experiment resulted gearbox transmission ratio (i) of windmill shaft speed to 12 V electric generator generator shaft speed i1 = 1:4 and 12 V generator shaft speed to 24 V electric generator shaft speed i2 = 1:5 (Fig. 7). The main speed used for reference was 12 V generator shaft speed.

At 6 m/s wind speed, the controller switched-off 24 V electric generator and switched-on 12 V electric generator which called low switching (LS). Voltages and amperes of electric generators also could be used as input parameter for switch controller. HS parameters were 14.9 V and 9.3 A. LS parameters were 25.0 V and 4.3 A.

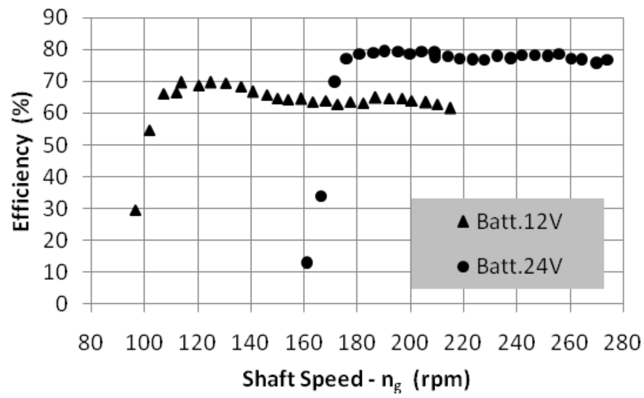

Fig. 5. Performance of generators for battery charging

In a case wind speed over than 9 m/s, two solutions proposed for the main electric generator and windmill protection. Other 24 V generators with i=1:5 were attached and operated with switching controlled. The secondary electric generators operated parallel with main 24 V electric generator and gave extra power electric power output. Second solution was switched the 24 V electric generator off and breaking system on. The windmill stopped and was not be additional power output.

IV. CONCLUSION

Investigation of bicycle BLDC motors as an electric generator on WECS was carried out. Two lamps of 35 watts, 24 volts as load of electric generator result highest maximum efficiency (around 80%). Higher electric generator's load reduce efficiency until 60%. Increasing electric generator's shaft speed will increase efficiency in any loads. As a battery charger, 12 volt battery load result average efficiency of 65.3% on the shaft speed range 107.1 - 214.8 rpm and 24 volt battery load result average efficiency of 77.6% on the shaft speed range 171.3 - 273.7 rpm. Two electric generators with switching controllers is sufficient load for 3 meters diameter multi blades windmill in wind speed range 4 m/s up to 9 m/s. Transmission ratio of 1:4 for generator of 12 V batteries and 1:5 for generator of 24 V batteries give optimum efficiency due to loads lied around peak power for any wind speeds.

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