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A Design of Electrical Permanent Magnet Generator for Rural Area Wind Power Plant

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ABSTRACT

This paper aims to design and simulate an Electrical Permanent Magnet Generator (EPMG) for rural area wind power plant. The generators available in the market mostly are a kind of high speed induction generator which requires high rotational speed and an electricity to generate a magnetic field. In this project, a radial flux generator is designed to have a low speed rotation using permanent magnet type Neodymium Iron Boron (NdFeB). Software used for designing is Finite Element Method (FEM) Magnet software basis. The model also examined with Simulink/Matlab environment. Extensive modifications are applied to get optimum result by changing generator diameter, number of coils, the copper wire diameter, number of poles, and used slots. The simulation results obtained generator speed 500rpm, the average series voltage is 52.76 Vrms, the generator requires 18cm diameter, number of turn for each coil is 55, diameter of the copper wire used is 0.6mm, and number of poles is 8 pairs and 12 unit slots.

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1. INTRODUCTION

Energy sector is one of the priority areas of Indonesia government now days. It is addressed to national research agenda indicates that renewable and sustainable energy is the most important in national research development, beside food security, information and communication technology, transportation and national defense. During the past few years utilization of wind energy is the most prominent well activities both of research studies and industry communities. According to [1], Indonesia has the most potential wind energy almost 10 Gigs Watt (GW) and approximately 4% are being utilized.

The wind power plant generation has been studied massively in the past few years. Application of wind power station has been successfully carried out previously by the researchers [2], precisely in the southern coastal district of Malang. However the prototype made still using a modified car generator (dynamo), so that the voltage and the current generated is still very limited. One of the important components of wind power plant is the generator, other than wind turbine, and converter. Various generator and control technique was developed using permanent magnet generator for wind turbines [3]. As a result the design captured of a 5MW axial flux permanent magnet generator. However, the detailed of feasibility has not been reviewed. In the other hand, a single phase induction generator has been designed by Dangeam [4]. Using the permanent magnet synchronous generator (PMSG), Glaoui et al [5] has been presented a modeling and simulation a wind turbine for an isolated area. The model proposed was employed with Matlab/Simulink® software-based. Electric generator is the important component of the wind power plant is employed to convert rotation of turbine into an electrical energy. The applicable type of generator mostly is high speed induction generator. The problem is, it needs high speed rotation around 1200–1500 rotation per minute (rpm). It also needs an initial electrical energy to provide a magnetic field. The permanent magnet type used in this study is Neodymium Iron Boron magnets (Nd2Fe14B). The NdFeB permanent magnet is categorized as strong and rare magnet. Characteristics of the magnetic owned NdFeB better when compared with the other permanent magnet, such as Ferrite, Alnico and Samarium Cobalt. The Maximum Energy Product (BHmax) can produce around 30 mega, Gauss Oersteds (MGOe) up to 52 MGOe, which reached 440 KJ/m 3 [6].

G.Dilev and Ose-Zala [7], has designed and built with the induction generator excitation system itself. Magnets used are NdFeB permanent magnets. However, the test has not been shown using certain electrical load, so that it was not known how much the electric power can be generated. The use of NdFeB permanent magnet type generator for low speed has been successfully done by Fiky Alqodri, et al [8] in 2015, with a speed is 500rpm, and the voltage generated is 2V. Thus it is critical to use the gear since it was built through hardware directly without design strategy. The researchers [9] use CAD software to simplify designing of electrical generator. This tool unable to simulate and getting more result. Therefore, the challenges toward designing a high-performance and efficient electrical generator are necessary to examine with wind energy especially in rural area.

In this paper, the design and simulation of low speed permanent magnet generator has been demonstrated. The design of electrical permanent magnet NdFeB in this study referring the work by the researchers [10]. Using Finite Element Method (FEM) software, the design of EPMG in this study examined several steps they are determine the specifications of generator, followed by design of geometry that consists of components of stator and rotor, designing the air gap of stator and rotor, design of permanent magnets and coils used and simulate the model by running and plotting. A complete simulation wind power plant also presented using Matlab-Simulink software base.

2. RESEARCH METHOD

An analytical design method will be described in this section. The permanent magnet type used in this project is NdFeB. The design aimed to determine an initial rotor and stator, coil model, and air gap model. In this study the generator designed based on Finite Element Method (FEM) magnet software. The model also simulate with Matlab/Simulink environment.

The first step to get naming and determine the material used in the generator is initialization and geometry design. It also provides thickness measurement in each part. By these tread, the model can be simulated as well, it covers an important generator components. They are consists of geometry design of stator, rotor, coil, magnet, both air gap of stator and rotor, also air gap and shaft. The initialized geometry design of electric generator can be seen in Figure 1.

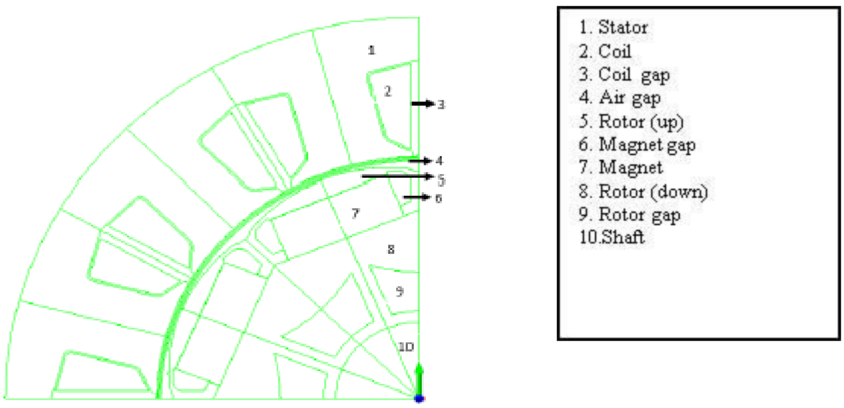

Figure 1. Geometry designed of electric generator

While the finite elements or mesh is set to 2mm for the following parts, they are stator, bottom rotor and magnet. Other than an initial mesh for top rotor and air gap are set to 1mm and 0.5mm respectively.

To determine a mechanical degree and electrical degree of generator can be calculated by equation (1) and (2) respectively. While equation (3) is to calculate frequency.

$$\theta_M = \frac{360}{\text{Stator}} \text{x pole} \quad (1)$$

$$\theta_E = \frac{\text{Pole}}{2} \text{ x } \theta_M \quad (2)$$

$$f = \frac{1}{T} \quad (3)$$

where θ_M, θ_E, F and T are mechanical degree, electrical degree, frequency and amplitude of the generator respectively. In this study, full design rotor rotated every 3 degree with time 1 ms needed, so that to rotate 360 degree it has 0.12 sec. Time rotation, rotation speed and energy coefficient can be formulated by equation (4), (5) and (6) respectively.

$$T_\theta = \frac{\theta_M}{\Sigma \text{ data sampling}} \quad (4)$$

$$T_\theta = \frac{\theta_M}{\Sigma \text{ data sampling}} \quad (5)$$

$$K_E = \frac{V_{dc}}{\omega} \quad (6)$$

The generator model is simulated by employing FEM software basis. Extensive simulation experiments are also carried out for proper wind environment using Matlab/Simulink. Figure 2 shows the Simulink design of EPMG using Matlab/Simulink software captured with full design of permanent magnet electric generator.

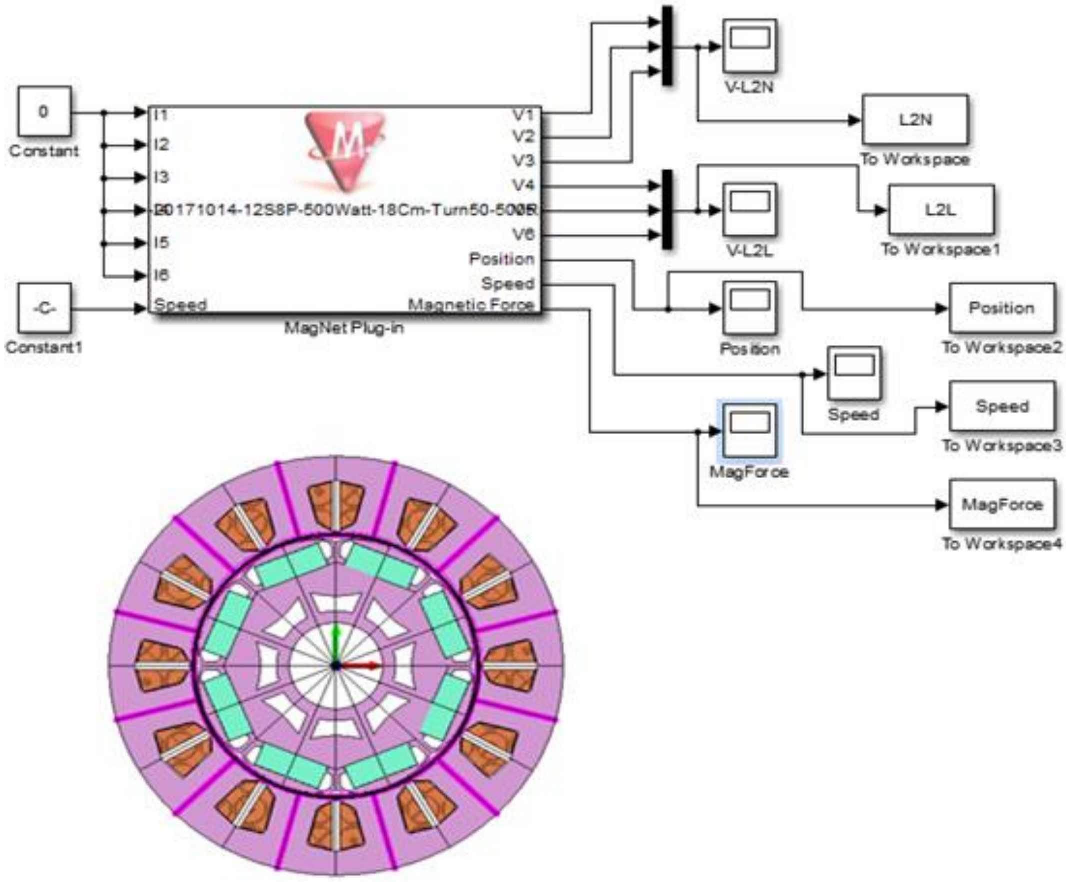

Figure 2. Electrical permanent magnet generator design with Co-Simulation Magnet/Simulink software

In this study, the electric generator has designed with detailed specifications. Table 1 shows the design variables of electrical permanent magnet generator.

Table 1. The Variable Designs of Electrical Permanent Magnet Generator

Design Variable	Initial value
Magnetic poles	8 units
Magnetic type	Neodymium Iron Boron Cylinder
Diameter of generator	18 cm
Copper wire diameter	0.6 mm
Number of turns	25 pcs
Stator and rotor materials	USS Transformers stator 52-29 materials
Air gap (distance stator and rotor)	40 mm
Number of hole rotor	16 units
Number of hole stator	12 units
Stator air gap and rotor air gap	0.5 mm
Coil material	pure copper coil 5.77e7 Siemens/meter
Number of coils	55 units
Number of loops (full model)	660 windings

3. RESULTS AND ANALYSIS

Figure 3 shows the result of flux linkage and voltage based on simulation respectively. Flux linkage is a flux that is connected or flowing from the rotor to the stator or reverse in. Flux linkage value is to determine the voltage produced by the generator. While each coil voltage is the voltage generated by each coil, in other words it is the voltage of each phase. The graph in Figure 3 shows the result of voltage for each coil.

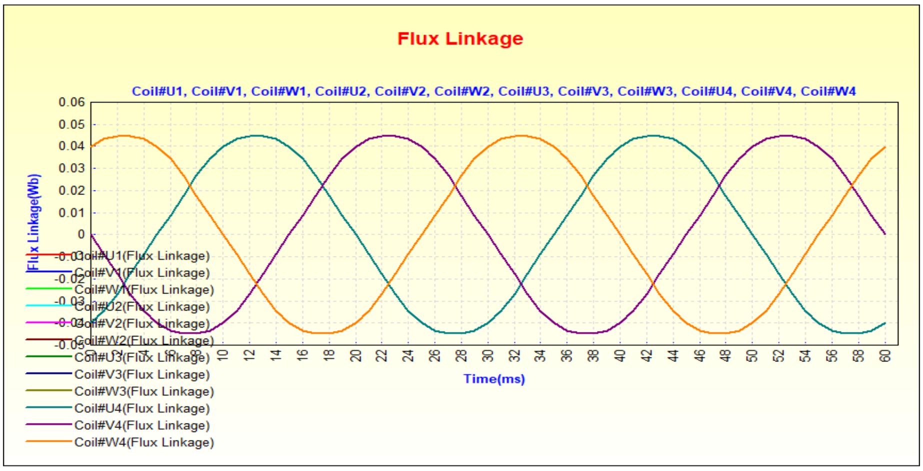

Figure 3. Flux linkage each coil by FEM software method

The V-UV voltage is measured between the U and V phases with the peak voltage is 74.6 V in FEM MagNet and 82.85 V on the MagNet-Matlab/Simulink Co-Simulation. Thus the voltage measured between V and W phases (V-VW) and the voltage measured between the W and U phases (V-WU) have the same peak voltage. Inter coil voltage is obtained with the characteristic of the Y connection [11]. The V-UV voltage is derived from the result of reduction between the U and W phases, the V-VW voltage from the result of the reduction of the V and W phases, followed by the V-WU result from the reduction of the W and U phases. In the simulation of MagNet and Co-Simulation MagNet-Matlab the difference between the simulated tension. The graphs line to line simulation result can be seen in Figure 4 and 5.

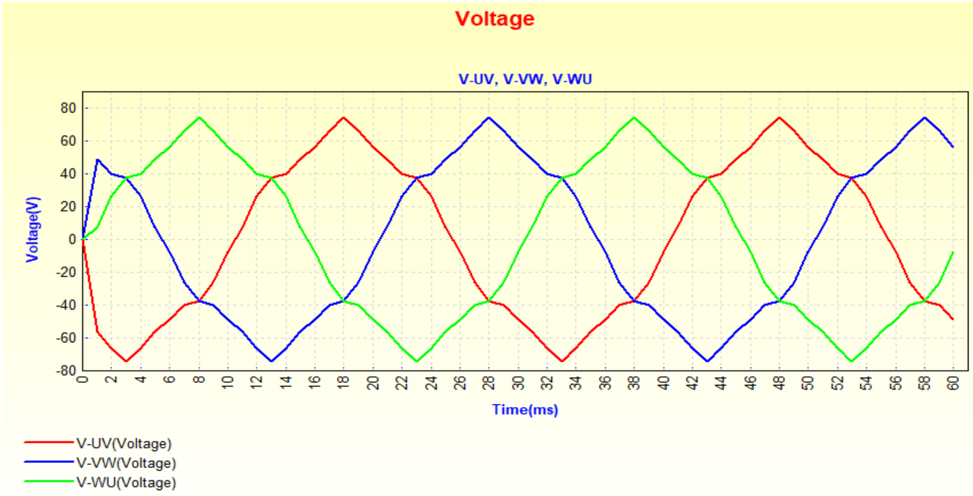

Figure 4. Line to line voltage by FEM software method

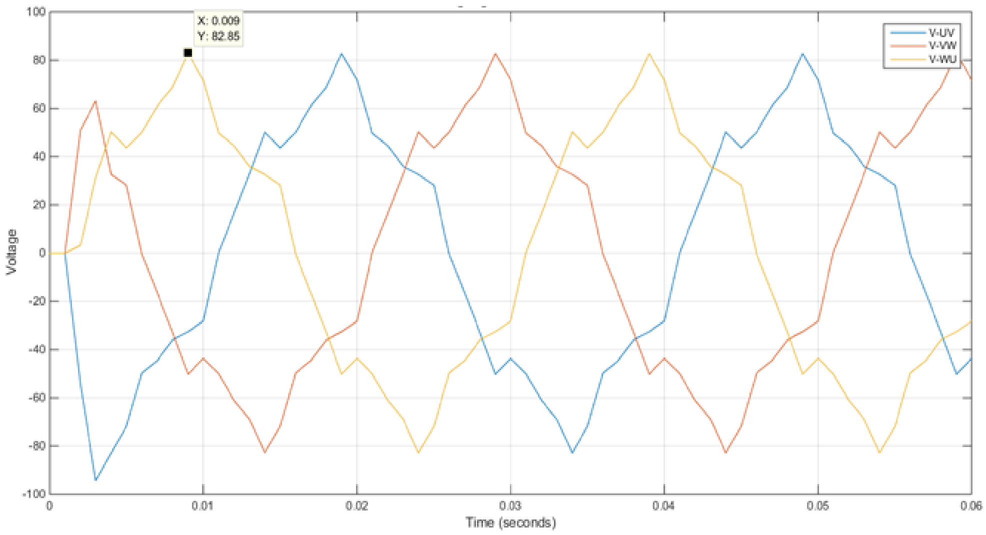

Figure 5. Line to line by Matlab/Simulink software

MagNet Simulation produces Flux Linkage waves that have 120° phase difference. From the waves of the flux linkage can be observed the waves generated according to equation (7) so that the V-U, V-V, and V-W correspond to the Faraday laws [11], as stated in Equation (7) and (8):

$$e_{ind} = \frac{d\lambda}{dt} \tag{7}$$

where

$$\lambda = \sum_{i=1}^{N} \phi_i \tag{8}$$

And ϕ is passed flux through the coil, λ is flux Linkage and e_{ind} is induced voltage. The measurement results of the simulationMagNet is obtained from the peak of Line to Neutral on each of them is 37.3 V. While the Co-SimulationMagNet-Matlab/Simulink peak generated is 44.37 V. The graphs of line to neutral simulation result can be seen in Figure 6 and 7.

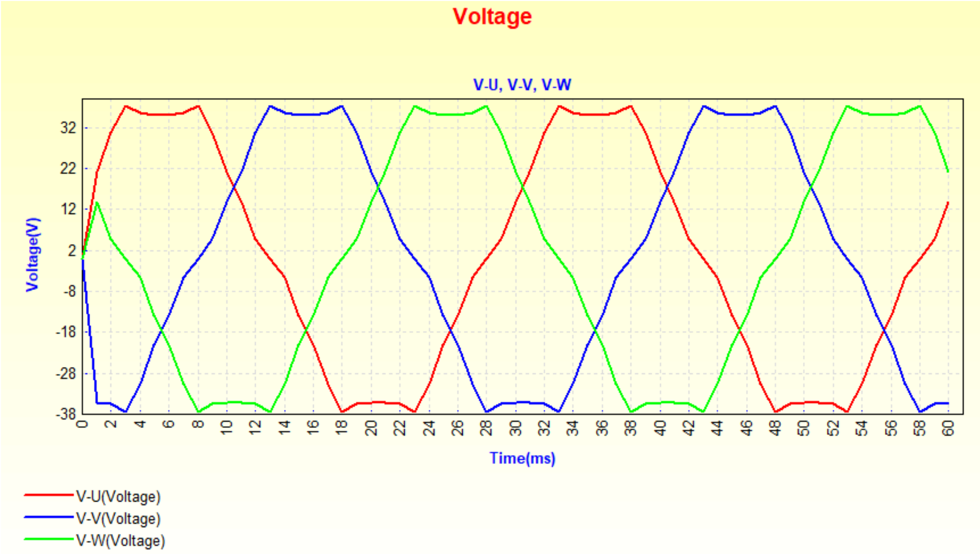

Figure 6. Line to neutral by FEM software method

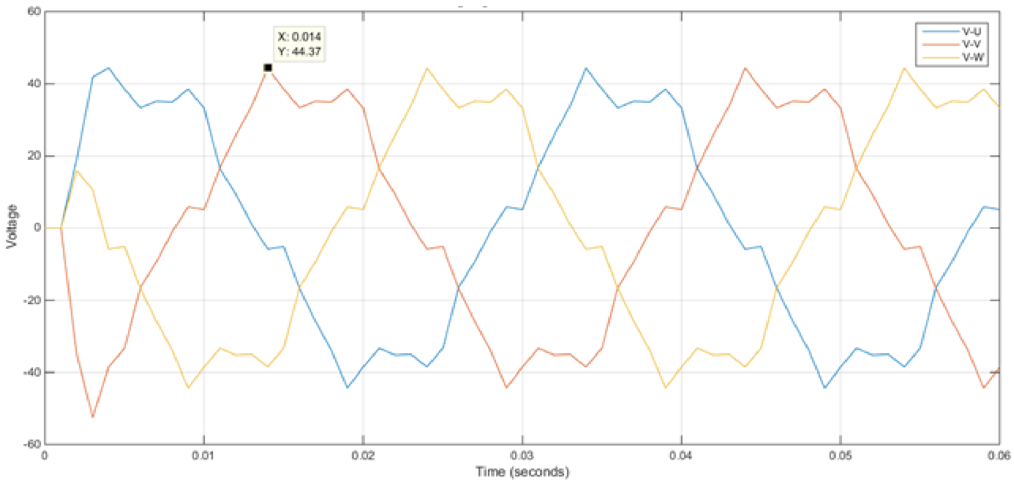

Figure 7. Line to neutral by Matlab/Simulink software

Table 2 indicates load-generator simulation result with an output current 5 Amperes produced. The electric generator simulates with closed-loop circuit, electric current able to flow through the coil windings of generator. If 1 rad/s equal to 9.55rpm, it can be seen that electric generator design with low speed 500rpm. The electric generator design has been simulated to get maximum electric current and time needed when it reach maximum speeds, with customized load electric current.

Table 2. Load Generator Simulation Result

Parameters	Value	Units
Output voltage	52.76	Vrms
Output electric-current	5	Ampere
Rotation speed	52.31	Rad/s
Frequency	8.33	Hz
Time rotation 360^0 design	0.12	Second
Energy coefficient	45.53	Joules
Torque	0.1269	Nm
Mechanical degree	90	degree
Electrical degree	360	degree

4. CONCLUSION

An analytical design and simulation is presented in this study. It has been provided a low speed electric generator that suitable for rural area wind power plant. In terms of accuracy of simulation and generator construction, magnet type Neodymium Iron Boron (NdFeB) and other variables as mentioned (generator diameter, number of turns, poles of magnet) are considered. In this study, flux linkage each coil can also be simulated. These form can generates average voltage Vrms.

The multi input multi output (MIMO) system from both of wind and solar panel can be addressed as future work. Experimental control and optimization technique [12], [13] for MIMO-EPMG is also point of interest. Experimental design of magnet type materials and changing value of variables stated in this work can be as a future work in term of performance for electric generator. The effectiveness of different sample software is also of interest.

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