Prototype Design and Construction of 450 VA Permanent Magnetic Sync Generator for Vertical Axis Wind Power Generator House Scale with Low Wind Speed

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Abstract. Permanent magnet synchronous generator (PMSG) is a mechanical electrical machine that can convert motion energy into electrical energy which has two main parts, namely a rotor using permanent magnets and a stator without an iron core which the machine uses for low and low rotations load torque used as a generator. The driving force for Wind Power Plants (PLTB) which we know is an alternative and renewable power plants, the energy source is wind which continues to exist and is easily available, another reason for the need to develop permanent magnet generators for PLTB is the reduction of petroleum, other fossil energy, subsidies continue to cut materials fuel oil for power generation which increases the price of electricity per KWH as well as a global commitment to reduce greenhouse gas emissions. The need for electricity for the community and the high price of electricity as well as the difficulty of installing electricity with a capacity of 450 VA, this study aims to make a prototype of a laboratory scale permanent magnet generator for wind power plants for residential homes that allows it to be placed close to the ground, no need to be directed towards the wind blowing, can generate electricity with wind speed from 2.5 m/s, easy operation and low cost. The research method in this study is to conduct a literature study, conduct a wind source mapping survey from several sources to obtain wind speed data nationally, design a prototype and design a permanent magnet generator prototype and finally simulation with calculation capacity of the prototype. The design of the permanent magnet generator prototype for the Wind Power Plant has 12 poles with a rotor speed of 500 rpm (revolution per minute) with capacity of 450 VA.

1 Introduction

The meet the electricity needs of the community amid the increasing need for electricity of national around 7.6% per year [1,2] due to the growth of the national population growth which has reached 265 million [3] and the increasing price of electricity per-KWH [4] caused by the reduction of subsidies for fuel oil (BBM) for power plants [5] and the reduction of
inventories of fuel oil and other fossil energy, and the low utilization of renewable energy [6], especially wind energy [7], then it is necessary to create alternative power plants with energy sources that are cheap and abundant sources or new and renewable energy [8], namely residential-scale power plant wind energy with easy and cheap operating costs and can be developed alternative and independent litigation provisions for rural areas that have not yet received electricity with competing local technology and human resources. One of the main components in wind power plants is a generator to convert mechanical energy (rotary) into electrical energy [9]. Wind that flows with a certain speed moves the wind turbine then moves the generator and produces electrical power. One of the main components in wind power plants is a generator to convert mechanical energy (rotary) into electrical energy [9]. The wind flowing with a certain speed moves the wind turbine then drives the generator and produces electrical power. One of the main components in wind power plants is a generator to convert mechanical energy (rotary) into electrical energy [9]. The wind flowing with a certain precision moves the wind turbine then stirs the generator and produces electrical power [10, 11], where permanent magnet synchronous generators are in principle the same as conventional generators which have the main parts, namely rotors and stators [12], the difference lies in that permanent magnet synchronous generators do not require DC (Direct Current) current capping to produce GGL (Electric Electromotive Force) because the rotor uses permanent magnets [13]. In this study, the problem is how low wind speeds can move wind turbines and wind turbines can drive permanent magnet synchronous generators with the output power needed for household scale, permanent magnet synchronous generators need to be designed so that efficiency and optimum can produce the desired electricity. The purpose of this study is to make a laboratory-scale design prototype of a permanent magnet synchronous generator for wind power plants with low wind speed with high efficiency with easy operation and low cost and can be moved easily [14]. A generator is a dynamic electric machine that can convert mechanical energy in the form of motion into electrical energy [9], in construction the generator has two main parts, namely the rotor and the stator, where the stator is the stationary part and there is a coil that produces alternating voltage, while the rotor is the moving part that produces magnetism that induces the stator part [15]. The synchronous generator has the same rotor rotation as the rotation of the magnetic field on the stator, in phase there are two types, namely 1-phase and 3-phase generators, where in 3-phase generators there are three coils so that they produce a 3-phase voltage that is at a different angle of 120 degrees while for a 1-phase generator there is only one coil and produces a voltage of 1 phase and 3 phases, where in a 3 phase generator there are three coils so that it produces a different 3-phase voltage angle of 120 degrees while for a 1 phase generator there is only one coil and produces a 1 phase voltage. The permanent magnet synchronous generator is a generator that does not require DC (Direct Current) current capping to produce GGL (Electric Electromotive Force) because the rotor uses a permanent magnet [13]. In general, generators have a radial flux direction perpendicular to the axis, the edge of this permanent magnet synchronous generator has a field flux direction that is axial parallel to the axis [16].

By construction the simplest permanent magnetic field synchronous generator is that its stator uses a coil without an iron core and to produce its rotor magnetic flux using a disc-type permanent magnetic field [17]. This simple construction is very possible for alternative power plants to meet the electricity needs of residential houses far from the center of power generation, such as in small-scale power plant wind energy [18, 19], which must pay attention to mapping low wind conditions, because in Indonesia it has a wind speed range of 2.5 – 6 m/s. The results of mapping carried out by the National Institute of Aeronautics and Space (LAPAN) in 2005 in 120 locations and several regions in Indonesia have wind speeds from 2.5 m/s to above 5 m/s, see Table 1.
Table 1. Classification of wind energy potential [20]

<table>
<thead>
<tr>
<th>Class</th>
<th>Speed Wind (m/s)</th>
<th>Specific power (W/m²)</th>
<th>Capacity (kW)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale</td>
<td>2.5-4.0</td>
<td>&lt;75</td>
<td>s/d 10</td>
<td>Jawa, NTB, NTT, Maluku, Sulawesi</td>
</tr>
<tr>
<td>Middle scale</td>
<td>4.0-5.0</td>
<td>75-150</td>
<td>10-100</td>
<td>NTB, NTT, Sulsel, Sultra</td>
</tr>
<tr>
<td>Big scale</td>
<td>&gt;5.0</td>
<td>&gt;150</td>
<td>&gt;100</td>
<td>Selsel, NTB, NTT, Pantai Selatan Jawa</td>
</tr>
</tbody>
</table>

2 Literature review

2.1 Permanent magnet synchronous generator calculation basis

The basic principle of making a generator is to use Faraday's law which says, if a conductor is in an arbitrary magnetic field, then the conductor will form an electric electromotive force [21]. Conversely when the conductor coil is driven in a fixed permanent magnetic field. Where the magnitude of the voltage or electromotive force (GGL) that appears is proportional to the magnitude of the change in the flux of the magnetic field to time, which can be written in the equation below and depicted in Fig. 1.

\[ \varepsilon = -N \frac{d\phi}{dt} \]

where:

- \(\varepsilon\) = Induction voltage (Volt)
- \(N\) = Number of turns
- \(\phi\) = Fluk magnet (Weber)
- \(t\) = time (second)

Fig. 1. Working principle of AC generator [9]

The sign (-) in front of N signifies the induction voltage against the change produced by the induction voltage itself, as described by Lenz's Law which reads that if the coil is N in the magnet rotating at an angular velocity, then the magnetic field surrounding the coil will change continuously, and the induction voltage can be expressed by the equation below.
\[
\varepsilon = -N \frac{d\theta}{dt} \\
\varepsilon = -N \frac{d(\theta \cos \cos t)}{dt} \\
\varepsilon = * N * \sin \sin (t)
\] (2)

To determine the number of revolutions in the rotor at the standard frequency of 50 Hertz is determined by the number of magnetic poles used in the rotor and can be written with the equation below.

\[
f_e = \frac{n_m p}{120}
\] (3)

where:
- \(f_e\) = Frequency (Hertz)
- \(n_m\) = Mechanical rotation of the rotor (Rpm)
- \(p\) = Number of poles

### 2.2 Stator

In permanent magnet generators we use a stator using a coil that does not have an iron core which is commonly used for low rotation and low torque with a coil design that is not overlapping [18].

To determine the number of windings on the stator determines the magnitude of the resulting voltage. The coil on the coil determines whether the corroborated voltage or current depends on the parallel or series relationship on the coil relationship. The magnitude of the voltage per phase is expressed by the equation below [22].

\[
E_f = \pi \sqrt{2} f N_1 K_{w1} \Phi_f
\] (4)

where:
- \(f\) = Frequency (Hertz)
- \(N_1\) = number of turns per phase
- \(K_{w1}\) = winding factor
- \(\Phi_f\) = average magnetic flux (Wb)

Winding factor:

\[
k_{w1} = k_{d1} \times k_{p1}
\] (5)

where:
- \(k_{d1}\) = Distribution factor
- \(k_{p1}\) = pitch factor

Distribution factor:

\[
k_{d1} = \frac{\sin \sin \left(\frac{\pi}{2 m_1}\right)}{q_1 \sin \left(\frac{\pi}{2 m_1 q_1}\right)}
\] (6)

where:
- \(m_1\) = Number of phase
- \(q_1\) = Number of slots per magnet per phase

Pitch factor:

\[
k_{p1} = \sin \sin \left(\beta \times \frac{\pi}{2}\right)
\] (7)

\[
\beta = \frac{w_c (r)}{r_e (r)}
\] (8)
where:
\[ w_c(r) = \text{Coil distance} \]
\[ \tau_c(r) = \text{Magnetic distance} \]

Number of slots per magnet per phase \( q_1 \)
\[ q_1 = \frac{s_1}{2pm_1} \]  

\begin{align*}
\text{where:} \\
\ s_1 &= \text{slots on the stator} \\
2p &= \text{install magnets} \\
\end{align*}

Number of coils per phase \( n_c \)
\[ n_c = \frac{s_1}{m_1} \]  

\begin{align*}
\text{where:} \\
\ m_1 &= \text{Number of phase} \\
\end{align*}

Calculating the cross-sectional area of the turns
To determine the cross-sectional area on the stator winding can use this equation
\[ S_a = \frac{I_a}{a_w J_a} \]  

\begin{align*}
\text{where:} \\
\ S_a &= \text{Cross-sectional area of the turn (m}^2\text{)} \\
\ I_a &= \text{Stator current per phase (Ampere)} \\
\ a_w &= \text{Number of parallel wires} \\
\ J_a &= \text{Current density (Ampere/m}^2\text{)} \\
\end{align*}

Approximate \( \approx 4.5 \times 10^6 \) commonly used in AC machines for a capacity of 100 kW and for the diameter of the cross-section of the conductor using the formula.
\[ A = \pi r^2 \]
\[ d = \frac{4S_a}{\pi} \]

\begin{align*}
\text{where:} \\
\ d &= \text{turn diameter (m)} \\
\ S_a &= \text{Cross-sectional area of the turn (m}^2\text{)} \\
\end{align*}

### 2.3 Stator Winding

In this study, it used a stator made of copper wire turns covered with enamel with the specifications below (Table 2).

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Soft Grade 2 Enameled Copper Wire to BS EN 60317/20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating and material</td>
<td>Polyurethane Primary Insulation</td>
</tr>
<tr>
<td>Color</td>
<td>Transparent</td>
</tr>
<tr>
<td>Max. Operating Temperature</td>
<td>120°C and Melting Temperature : 480°C</td>
</tr>
<tr>
<td>Approval bodies</td>
<td>BS4520</td>
</tr>
</tbody>
</table>
Table 2. Copper wire specification based on BS EN 60317/20 standard [25]

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Current Rating (A)</th>
<th>Diameter (mm)</th>
<th>Tolerance (mm) on Conductor</th>
<th>Enamel Coat (mm)</th>
<th>Min. Increase in Dia.</th>
<th>Max. O.D.</th>
<th>Min.</th>
<th>Nom.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECW0.2</td>
<td>0.048</td>
<td>0.2</td>
<td>± 0.003</td>
<td>0.027</td>
<td>0.239</td>
<td>0.5237</td>
<td>0.5441</td>
<td>0.5657</td>
<td></td>
</tr>
<tr>
<td>ECW0.4</td>
<td>0.194</td>
<td>0.4</td>
<td>± 0.005</td>
<td>0.04</td>
<td>0.459</td>
<td>0.136</td>
<td>0.136</td>
<td>0.1407</td>
<td></td>
</tr>
<tr>
<td>ECW0.5</td>
<td>0.304</td>
<td>0.5</td>
<td>± 0.006</td>
<td>0.045</td>
<td>0.566</td>
<td>0.08462</td>
<td>0.08706</td>
<td>0.08959</td>
<td></td>
</tr>
<tr>
<td>ECW0.56</td>
<td>0.381</td>
<td>0.56</td>
<td>± 0.007</td>
<td>0.047</td>
<td>0.63</td>
<td>0.06736</td>
<td>0.0694</td>
<td>0.07153</td>
<td></td>
</tr>
<tr>
<td>ECW0.71</td>
<td>0.613</td>
<td>0.71</td>
<td>± 0.008</td>
<td>0.055</td>
<td>0.789</td>
<td>0.04198</td>
<td>0.04318</td>
<td>0.04442</td>
<td></td>
</tr>
<tr>
<td>ECW0.80</td>
<td>0.779</td>
<td>0.8</td>
<td>± 0.008</td>
<td>0.056</td>
<td>0.884</td>
<td>0.03305</td>
<td>0.03401</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>ECW1.0</td>
<td>1.21</td>
<td>1</td>
<td></td>
<td>0.063</td>
<td>1.094</td>
<td>0.02116</td>
<td>0.02176</td>
<td>0.0224</td>
<td></td>
</tr>
<tr>
<td>ECW1.25</td>
<td>1.91</td>
<td>1.25</td>
<td>± 0.013</td>
<td>0.067</td>
<td>1.349</td>
<td>0.01353</td>
<td>0.01393</td>
<td>0.01435</td>
<td></td>
</tr>
<tr>
<td>ECW1.5</td>
<td>2.74</td>
<td>1.5</td>
<td>± 0.015</td>
<td>0.071</td>
<td>1.606</td>
<td>0.0094</td>
<td>0.00967</td>
<td>0.00995</td>
<td></td>
</tr>
</tbody>
</table>

2.4 Rotor

The magnetic generator's rotor acts as the source of the primary magnetic field. The resultant magnetic field on the rotor is generated by the permanent magnet, hence no excitation current from the outside is needed. Iron plate serves as the rotor's material and provides magnetic support (Fig. 2).

![Fig. 2. Arrangement of the rotor on the permanent magnet generator [22].](image)

To determine the size of the average flux in the middle between 2 rotors can use the equation below.

\[
\Phi_f = B_{mg} \frac{\pi}{b_p} D_{out}^2 (1 - k_d^2)
\]

where:

\(B_{mg}\) = Maximum B in the middle between 2 rotors (Tesla)

\(k_d\) = Comparison of the radius in the magnet with the outer radius of the magnet

\(b_p\) = Number of poles

\[
k_d = \frac{R_{in}}{R_{out}} = \frac{D_{in}}{D_{out}}
\]

where:

\(R_{in}\) = Inner diameter
The distribution of normal flux components in the space between 2 rotors can be calculated by the equation.

\[
B_z(x, z) = B_{m0} \sin(\beta x) \frac{1}{\cos \left( \frac{\pi}{l a} \right)} \cos(\beta z) \tag{16}
\]

where:

\[ \beta = \frac{2\pi}{l a} \]

\[ l a \] = Length 1 wave
\[ x \] = Position
\[ t \] = Distance between poles
\[ z \] = The distance between the pole to the midpoint

\[ B_{m0} \] = Bmaks surface magnet

\[
B_{m0} = B_r \left[ 1 - \exp \left( -\beta h_m \right) \right] \frac{\sin(\pi n_m)}{\pi/n_m} \tag{17}
\]

where:

\[ B_r \] = Remanent magnetic
\[ h_m \] = Thickness of magnet
\[ n_m \] = Number of Magnetization Vectors per wave

2.5 Rotor magnet permanent

In this study, the rotor used permanent magnets from using permanent magnets that are easy to get in the market and have been widely used, namely Neodymium type NdFeB 52 (Neodymium-Iron Boron) [23] which has a strong magnet and is easy to get (Fig. 3).

Fig. 3. Demagnetization curves for different permanent magnet materials
2.6 Power Output

Determine the output power by using the following equation:

\[ P = V \times I \times \cos \varphi \]  

(18)

\[ P = \sqrt{3} \times V \times I \times \cos \varphi \]  

(19)

where:

- \( P \) = Power (Watt)
- \( V \) = Voltage (Volt)
- \( I \) = Current (Ampere)
- \( \cos \varphi \) = Power factor

3 Method

Fig. 4 is a flow chart diagram of the research stages method. In this study, the research stage was carried out beginning with the literature review, collecting data on wind speed and turbine speed, making design and prototype calculations, ensuring through simulation calculations, and if there were no problems continuing with the creation of final reports and journals to the conference.

3.1 Research equipment

The tools and materials utilized in this study's design and construction of the permanent magnet generator were as listed in Table 3 and were created using the software SolidWorks and Excel:

<table>
<thead>
<tr>
<th>No</th>
<th>Qty</th>
<th>Unit</th>
<th>Description</th>
<th>Materials</th>
<th>Dia</th>
<th>L</th>
<th>W</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Pcs</td>
<td>Plate base</td>
<td>St 37</td>
<td></td>
<td>250</td>
<td>200</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Pcs</td>
<td>Pillow bearing shaft 20mm</td>
<td>SS</td>
<td></td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Pcs</td>
<td>Shaft 1&quot;</td>
<td>St 37</td>
<td></td>
<td>20</td>
<td>475</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Set</td>
<td>Rotor Assembly</td>
<td>St 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Set</td>
<td>Stator Assembly</td>
<td>St 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Pcs</td>
<td>Support Stator 1</td>
<td>St 37</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Pcs</td>
<td>Support Stator 2</td>
<td>St 37</td>
<td>50</td>
<td>280</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>Pcs</td>
<td>Rod Locked Stator</td>
<td>St 37</td>
<td>10</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Pcs</td>
<td>Bush Clamp rotor</td>
<td>St 37</td>
<td>80</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Pcs</td>
<td>Pulley wheel</td>
<td>Al</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>3</td>
<td>Pcs</td>
<td>Pasak</td>
<td>St 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>Pcs</td>
<td>Magnet Permanen</td>
<td>N52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>5</td>
<td>kg</td>
<td>Wire copper enamel</td>
<td>copper</td>
<td></td>
<td></td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>9</td>
<td>Can</td>
<td>Resin</td>
<td>Resin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Research procedure

Following is an analysis of the planning and building of a 450 VA permanent magnet synchronous generator for home use at Sekolah Tinggi Teknologi Muhammadiyah Cileungsi before drawing any conclusions:

4 Results and discussion

4.1 Design prototype

Fig. 5 depict the prototype of a 450 VA permanent magnet synchronous generator for residential use.

Fig. 5. Front and rear view permanent magnet generator design

4.2 Permanent magnet synchronous generator fabrication drawing

It was necessary to produce the permanent magnet synchronous generators according to the meticulous fabrication drawings illustrated in Fig. 6.

Fig. 6. Drawing permanent magnet generator manufacturing assembly
4.3 Calculation simulation results

In this study, a simulation of the calculation of the permanent magnet generator prototype was also carried out, the following results:

- Determining the rotation of the generator

The normal frequency uses 50 Hz and the number of poles is 12 poles, so the expected permanent magnet generator is calculated by the equation below.

\[
f_e = \frac{n_m P}{120} = \frac{f_e P}{120} = \frac{50 \times 12}{120} = 500 \text{ rpm}
\]  

(3)

- Determine the number of windings

\[
N_1 = \frac{E_f}{\pi \sqrt{2} f \Phi_f k_w} = \frac{230}{3.14 \times \sqrt{2} \times 50 \times 0.000864} = 1110 \text{ turns}
\]

Since there are 3 phases, then the turns per phase 1110 turns divided by 3 = 370 turns

- Determine the output power of the generator

\[
P = \sqrt{3} \times V \times I \times \cos
\]

\[
P = \sqrt{3} \times 400 \times 0.779 \times 0.85
\]

\[
= 458 \text{ Watt}
\]

5 Conclusion

The following prototype was created in this study using simulation results from calculations for the permanent magnet synchronous generator: 1) 400 - volt three-phase and 230 - volt single-phase output voltage, 12 poles, 370 turns per phase, 12 windings, 500 rpm for the generator, 0.8 mm for the copper enamel windings, and a 458 watt output are the other specifications. The calculations’ conclusions are in line with the production plan for the prototype, which is anticipated to provide 450 Watts of electricity, and with the power requirements for the household class, but they still need to be validated by building a prototype and taking measurements. Therefore, it can be said for the time being that permanent magnet synchronous generators can be used in wind power plants that are designed for residential use.

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References


