Optimization of Solar Water Pumping System
Shirish V. Singh¹, Sunil Bhatt ²

¹ Central India Institute Technology, Indore
² Professor, Dept. of Electrical and Electronics Engineering, Central India Institute Technology, Indore

Abstract - The Non-Renewable energy sources are been excessively consumed in last few decades. Therefore to promote the use of renewable source i.e. Solar energy as a clean source of energy for most common application i.e. water pumping with properly designed system to optimum use of solar energy is been studied in this paper. The photovoltaic panel gives output in DC. For simplicity the systems are employing PMDC motor for this application so that the output DC power can be fed directly to the motor which has been coupled with the pumps to deliver water. But along with this advantage it has large number of dis-advantages which results in competing the performance with BLDC motors.

1. INTRODUCTION
The PMDC motor with 15 slot armature 2 pole segmented magnet of SmCo grade Sm2Co17 26H. Br = 10.6 kG, Hc = 784 kA/m. The motor working temperature when loaded at 0.3 hp is 78°C. Due to less power rating motor the magnet eddy current is to be reduced therefore the magnets are been segmented. On the other hand reliability of the motor is less and losses are more due to carbon brushes supplying current. These brushes have to be replaced after regular interval to ensure proper working of the motor. As well as the power vs. efficiency profile is linear.

2. DESIGN PROCEDURE AND STEPS
The biggest confusion for designer to design a motor of independent power source of stator and rotor is to collaborate both stator and rotor design. A poor design collaboration will result in lesser power factor. Therefore it is also necessary to fix the design step either to design stator first or the rotor first. Further iteration will improve the design. Here the rotor permanent magnet is been designed first than the stator lamination, winding. The material selection should be compatible with PWM supplies with higher frequencies.

3. Design topology
The stator is distributed wound to increase the number of slot for same number of pole with lesser and frequency thereby also reducing the hysteresis loss, eddy current loss, and copper loss due to increase in resistance with higher operating frequencies. The surface mount magnet rotor is designed to reduce the manufacturing difficulty and cost. If the service factor is required is less the rotor should be designed with interior permanent magnet design to increase reluctance torque and to reduce cogging torque with lesser number of stator slot and poles.

4. Parameters Details
The motor is designed to work on a single panel of 300 Wp.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rated Power</td>
<td>0.3 hp</td>
</tr>
<tr>
<td>2</td>
<td>Minimum Operating Voltage</td>
<td>36 V, DC</td>
</tr>
<tr>
<td>3</td>
<td>Rated Speed</td>
<td>1750</td>
</tr>
<tr>
<td>4</td>
<td>Rated Torque</td>
<td>2 Nm</td>
</tr>
<tr>
<td>5</td>
<td>Cogging torque</td>
<td>&lt;10% of rated torque</td>
</tr>
<tr>
<td>6</td>
<td>Efficiency</td>
<td>More than 80 % at rated torque</td>
</tr>
</tbody>
</table>

Table. No.1 Parameters of motor

5. Permanent Magnet design
Material Grade: NdFeB – N35-M
Back emf max:
\[\text{Back emf max} = \frac{V_{dc}}{\sqrt{2}}\]
\[= \frac{36}{\sqrt{2}}\]
\[= 25.45 \text{ VAC}\]
Maximum Speed: 1750 rpm
Torque required:
\[\text{Power} = \frac{2\pi N}{2\pi N}\]
\[
\frac{224 \times 60}{2\pi \times 3300} = 0.648 \text{ Nm}
\]
\[T = KD^2L\]
\[K = 6000\]
\[L = \frac{0.64}{6000 \times (0.042)^2}\]
\[L = 60.46 \text{ mm}\]
\[L_{\text{considered}} = 62 \text{ mm}\]
\[\text{Number of pole} = 4\]
\[\text{Number of stator slots} = 12\]
\[\phi_r = B_r \times A_m\]
\[\theta_{\text{radian}} = r \times l\]
\[\theta_{\text{degree}} = 87\]
Therefore, \[\theta_{\text{radian}} = 0.0174533 \times 87 = 1.51844\]
\[r = 18.25 \text{ mm}; l = 62 \text{ mm}\]
\[0.01825 \times 1.51844 \times 0.062\]
\[A_m = 0.001718114 \text{ m}^2\]
\[B_r = 1.17T\]
\[\phi_r = 1.17 \times 0.001718114\]
\[= 0.002010192 \text{ wb}\]
\[P_{mo} = \frac{\mu_0 \times \mu_{\text{rec}} \times A_m}{l_m}\]
\[P_{mo} = \frac{\mu_0 \times 10^{-7} \times 1.04347 \times 0.00178114}{0.003}\]
\[= 7.781 \times 10^{-7}\]
\[A_g = \left[\theta_{\text{radian}} \times (0.042 - 0.00125) + 2 \times g \right] \times (l + 2 \times g)\]
\[A_g = \left[1.51844 \times (0.042 - 0.00125) + 2 \times 0.0025\right] \times (0.06 + 2 \times 0.0025)\]
\[A_g = 0.0043469 m^2\]
\[A_g = \left[1.51844 \times 0.042 \times 0.062\right] / 2\]
\[A_g = 0.001977 m^2\]
\[C_0 = \frac{A_m}{A_g}\]
\[C_0 = 0.001718114 / 0.001977\]
\[C_0 = 0.648 / 4.44 \times 110 \times 32\]
\[\theta = 9.09 \times 10^{-4} \text{ wb}\]
\[= 0.86905\]
\[B_g = \frac{C_0}{\left[1 + P_m + P_s + P_g \right]} \times B_r\]
\[B_g = \frac{0.86905}{\left[1 + 1.1 \times 0.5 \times 0.7\right]} \times 1.2\]
\[B_g = 0.538 T\]
\[B_m = \frac{1 + P_{r1} \times R_g}{\left[1 + P_m + P_{m1} + P_{g1}\right]} \times B_r\]
\[B_m = \frac{1 + 0.85 \times (-0.95)}{\left[1 + 1.1 \times 0.5 \times 0.7\right]} \times 1.2\]
\[B_m = 0.166 T\]
\[H_m = \frac{B_r - B_m}{\mu_0 \times \mu_{\text{rec}}}\]
\[H_m = \frac{1.2 - 0.166}{4 \pi \times 10^{-7} \times 1.04347}\]
\[H_m = 788952 \text{ A/m}\]
\[PC = \frac{\mu_{\text{rec}} \times 1 + P_{r1} \times R_g}{P_{mo} \times R_g}\]
\[PC = 1.04347 \times \frac{1 + 0.85 \times (-0.95)}{(0.98 \times 0.95)}\]
\[PC = 0.215\]
\[g = K_c \times g\]
\[g^* = 0.92 \times 0.00125\]
\[g^* = 0.00115\]
\[B_m = \frac{PC}{P_{mo} + \mu_{\text{rec}}}\]
\[B_m = 0.215 + 1.04347 \times 1.17\]
\[B_m = 0.1998 T\]
\[E_b = 2 \times N \times B_g \times 1 \times \gamma \times \omega\]
\[E_b = 2 \times 32 \times 0.538 \times 0.062 \times 0.042 \times 2 \pi / 2 \times 3300 \times 60\]
\[E_b = 15.48 \text{ V/phase}\]
\[E_b(l - l) = \sqrt{3} \text{ V/phase}\]
\[E_b(l - l) = 1.732 \times 15.48\]
\[E_b(l - l) = 26.81 \text{ V}\]
\[\phi = \frac{E_b}{4.44 \times f \times N}\]

6. Stator lamination design.

Number of stator slot = 12
Shape of slot = Tapper
Outer Diameter of stator = 92mm
Inner Diameter of stator = 42mm
Core Back = 0.00852 m

Area of Core Back = \( h_p \times K_i \times 1 \)

\( K_i = 0.96 \) – By manufacturer

Area of Core Back = 0.00852 \* 0.96 \* 0.062

Area of Core Back = 0.00050592 \( \text{m}^2 \)

\[ \text{Flux density in core back} = \frac{\phi}{2 \times \text{Area of Core Back}} \]

\[ \text{Flux density in core back} = \frac{9.09 \times 10^{-4}}{2 \times 0.00050592} \]

Flux density in core back = 0.898 T

Tooth width = 0.00472 m

Area of tooth = \( b_t \times K_i \times 1 \)

Area of tooth = 0.00472 \* 0.96 \* 0.062

Area of tooth = 0.000279744 \( \text{m}^2 \)

Area of teeth per phase

\[ = \text{Area of tooth} \times \text{Number of tooth per pole} \]

\[ \text{Area of teeth per phase} = 0.000279744 \times 12 \]

Area of teeth per phase = 0.000839232 \( \text{m}^2 \)

\[ \text{Flux density in teeth} = \frac{\phi}{\text{Area of teeth per phase}} \]

\[ \text{Flux density in teeth} = \frac{9.09 \times 10^{-4}}{0.000839232} \]

Flux density in teeth = 1.083 T

*Note – Flux density are been calculated at No – Load

Slot Area = 169.8 mm\(^2\)

Turns per phase = 32

Number of parallel path = 11

Double layer distributed winding

Gauge = 0.75 mm

Overall diameter = 0.81 mm

Area of overall diameter = \( \frac{\pi}{4} \times D^2 \)

Area of overall diameter = \( \frac{\pi}{4} \times 0.81^2 \)

Area of overall diameter = 0.5150 mm\(^2\)

Number of conductor per slot = 8 \* 11 \* 2 = 176

Area of conductors = 176 \* 0.5150 = 90.64 mm\(^2\)

Fill factor = \( \frac{90.64}{169.8} \) \* 100 \% = 53.38 \%

I. Results

Figure. No.2 (a) Winding over hang temperature (62.4°C) at service factor 1.35 (b) Housing temperature (53.9 °C) at service factor 1.35 (c) Terminal Box temperature (44.5°C) at service factor 1.35 (d) Winding over hangs temperature (48.7°C) at service factor 1.00

Figure. No.3 Cogging torque

Cogging torque = \( T_{max} - T_{min} \)

\[ = 0.120 - 0.042 = 0.078 \text{ Nm} \]
Figure No.4 Steady state torque spectrum

Figure No.5 Steady state speed spectrum

Figure No.6 H-Q Curve with BLDC motor

Figure No.7 η % Vs H Curve with BLDC motor

Figure No.8 H-Q Curve with PMDC motor

Figure No.9 η % Vs H Curve with PMDC motor
7. Conclusion

The performance with BLDC was much better as compared to PMDC in spite of lower rating motor. Also the motor can be easily overloaded which enhances the use of BLDC motor for solar powered in water pumping application.

8. References