Solar Powered Water Pumping System

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Abstract – *At rural areas where the possibility of electricity transmission is less or irregularity in electrical supply the need of water supply can be fulfilled in a best way with the use of Renewable energy source i.e. Solar radiation. By observing the performance of PMDC motor we are designing the Brushless DC Motor with much more compact design and much better performance. The main challenge is to design a motor with less cogging torque and less harmonics and the additional feature to design the motor which can work in BLDC as well as PMSM controller. The motor is designed use of NdFeB permanent magnet which will increase the motor cost but also increase the reliability of the motor with a long run time. The skewing of magnet is ignored to reduce the cogging torque but to reduce it to some extent the rotor surface is bifurcated which also help in maintaining the air gap flux density curve more flat. To improve the back-emf waveform shape the motor is designed with distributed wounded stator with integral value of slots per pole per phase which is compatible with an existing sensor less EC Drive. To reduce the harmonics and maintaining the overhang length to get reduced copper loss and reduced temperature the slots per pole per phase is selected as 2.*

1. INTRODUCTION

To restrict CO_2 emission and to giving easy solution for water pumping in remote area. This involve introduction of solar supply in combination with pump and to optimize the system performance with proper design of complete system. PMDC is replaced with Sensor less BLDC with MPPT and get maximum output at lower irradiation also. The electrical steel used is of higher grade to reduce no load loss and NdFeB magnet are introduced to design the motor with higher service factor so that in future enhancement there is a possibility to improve the power rating with proper selection of drive. The electrical steel grade is taken similar but SmCo is been replaced with NdFeB.

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 lower power rating of motor the magnet eddy current is to be reduced therefore the magnets was been segmented.

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 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.

Sr. No.	Description	Value
1	Rated Power	0.3 hp
2	Minimum Operating Voltage	36 V,DC
3	Rated Speed	1750
4	Rated Torque	2 Nm
5	Cogging torque	<10% of rated torque. Due to higher service factor otherwise <2%
6	Efficiency	More than 80 % at rated torque

Table. No.1 Parameters of motor

5. Permanent Magnet design

Material Grade: NdFeB – N35-M
Back emf max:

$$= \frac{Vdc}{\sqrt{2}}$$

$= \frac{36}{\sqrt{2}}$
$= 25.45\,VAC$
Maximum Speed: 1750 rpm
Torque required:
$\frac{Power}{2\pi N}$
$= \frac{224*60}{2\pi*3300}$
=0.648 Nm
$T = KD^2L$
$K = 6000$
$L = \frac{0.64}{6000*(0.042)^2}$
$L = 60.46\,mm$
$L_{considered} = 62\,mm$
$Number\ of\ pole = 4$
$Number\ of\ stator\ slots = 12$

$$\emptyset_r = B_r * A_m$$

$= \theta_{radian} * r * l$
$\theta_{degree} = 87$
$Therefore, \quad \theta_{radian} = 0.0174533 * 87 = 1.51844$
$r = 18.25\,mm\,; l = 62\,mm$
$= 0.01825 * 1.51844 * 0.062$
$A_m = 0.001718114\,m^2$
$B_r = 1.17\,T$
$\emptyset_r = 1.17 * 0.001718114$
$= 0.00201019\,wb$
$P_{mo} = \frac{\mu_0 * \mu_{rec} * A_m}{l_m}$
$P_{mo} = \frac{4\pi * 10^{-7} * 1.04347 * 0.00178114}{0.003}$
$= 7.781 * 10^{-7}$
$A_g = [\theta_{radian} * (0.042 - 0.00125) + 2 * g] * (l + 2 * g)$
$A_g = [1.51844 * (0.042 - 0.00125) + 2 * 0.0025] * (0.06 + 2 * 0.0025)$
$A_g = 0.0043469\,m^2$
$A_g = \frac{[1.51844 * 0.042 * 0.062]}{2}$
$\emptyset = \frac{15.48}{4.44 * 110 * 32}$
$\emptyset = 9.09 * 10^{-4}$wb

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

$A_g = 0.001977\,m^2$
$C_\emptyset = \frac{A_m}{A_g}$
$C_\emptyset = \frac{0.001718114}{0.001977}$
$= 0.86905$
$B_g = \frac{C_\emptyset}{\{1 + P_m * P_{ss} * P_g\}} * B_r$
$B_g = \frac{0.86905}{\{1 + 1.1 * 0.5 * 0.7\}} * 1.2$

$$B_g = 0.538\,T$$

$B_m = \frac{1 + P_{r1} * R_g}{\{1 + P_m * P_{ss} * P_g\}} * B_r$
$B_m = \frac{1 + 0.85 * (-0.95)}{\{1 + 1.1 * 0.5 * 0.7\}} * 1.2$
$B_m = 0.166\,T$
$-H_m = \frac{B_r - B_m}{\mu_0 * \mu_{rec}}$
$-H_m = \frac{1.2 - 0.166}{4\pi * 10^{-7} 1.04347}$
$-H_m = 788952\ A/m$
$PC = \mu_{rec} * \frac{1 + P_{r1} * R_g}{P_{mo} * R_g}$
$PC = 1.04347 * \frac{1 + 0.85 * (-0.95)}{(0.98 * 0.95)}$
$PC = 0.215$
$g` = K_c * g$
$g` = 0.92 * 0.00125$
$g` = 0.00115$
$\frac{B_m}{B_r} = \frac{PC}{PC + \mu_{rec}}$
$B_m = \frac{0.215}{0.215 + 1.04347} * 1.17$
$B_m = 0.1998\,T$
$E_b = 2 * \mathrm{N} * B_g * \mathrm{l} * \mathrm{r} * \omega$
$E_b = 2 * 32 * 0.538 * 0.062 * \frac{0.042}{2} * \frac{2\pi * 3300}{60}$
$E_b = 15.48$ V/phase
$E_b(\mathrm{l} - \mathrm{l}) = \sqrt{3}$V/phase
$E_b(\mathrm{l} - \mathrm{l}) = 1.732 * 15.48$
$E_b(\mathrm{l} - \mathrm{l}) = 26.81$ V
$\emptyset = \frac{E_b}{4.44 * f * N}$

$Area\ of\ Core\ Back = h_y * K_i * \mathrm{l}$
$K_i = 0.96 - \ By\ manufacturer$
$Area\ of\ Core\ Back = 0.00852 * 0.96 * 0.062$

$$Area\ of\ Core\ Back = 0.00050592\,m^2$$

$Flux\ density\ in\ core\ back = \frac{\emptyset}{2 * Area\ of\ Core\ Back}$
$Flux\ density\ in\ core\ back = \frac{9.09 * 10^{-4}}{2 * 0.00050592}$
$Flux\ density\ in\ core\ back = 0.898$ T

Tooth width = 0.00472 m
$Area\ of\ tooth = b_t * K_i * \mathrm{l}$
$Area\ of\ tooth = 0.00472 * 0.96 * 0.062$

$Area\ of\ tooth = 0.000279744\ m^2$

$Area\ of\ teeth\ per\ phase$
$= Area\ of\ tooth * \ Number\ of\ tooth\ per\ pole$

$Area\ of\ teeth\ per\ phase = \ 0.000279744 * \dfrac{12}{4}$

$Area\ of\ teeth\ per\ phase = 0.000839232\ m^2$

$Flux\ density\ in\ teeth = \dfrac{\emptyset}{Area\ of\ teeth\ per\ phase}$

$Flux\ density\ in\ teeth = \dfrac{9.09 * \ 10^{-4}}{0.000839232}$

$Flux\ density\ in\ teeth = 1.083\ T$

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

$Slot\ Area \ = \ 169.8\ mm^{\ 2}$

$Turns\ per\ phase \ = \ 32$

$Number\ of\ parallel\ path \ = \ 11$

$Double\ layer\ distributed\ winding$

$Gauge \ = \ 0.75\ mm$

$Overall\ diameter = 0.81\ mm$

$Area\ of\ overall\ diameter = \dfrac{\pi}{4} * D^2$

$Area\ of\ overall\ diameter = \dfrac{\pi}{4} * 0.81^2$

$Area\ of\ overall\ diameter = 0.5150\ mm^{\ 2}$

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

$Area\ of\ conductors = 176 * 0.5150 = 90.64\ mm^{\ 2}$

$Fill\ factor \ = \dfrac{90.64}{169.8} * 100\ \% \quad = 53.38\ \%$

Cogging torque = Tmax – Tmin
=0.120 - 0.042 = 0.078 Nm

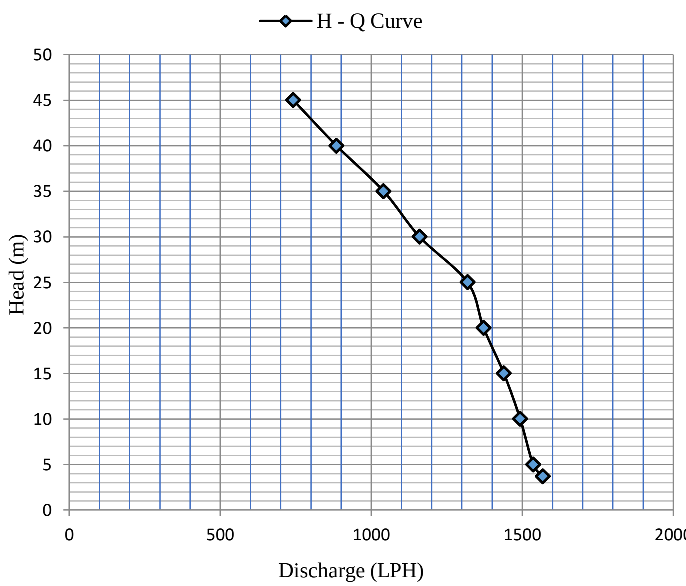

Figure. No.1 H-Q Curve with BLDC motor

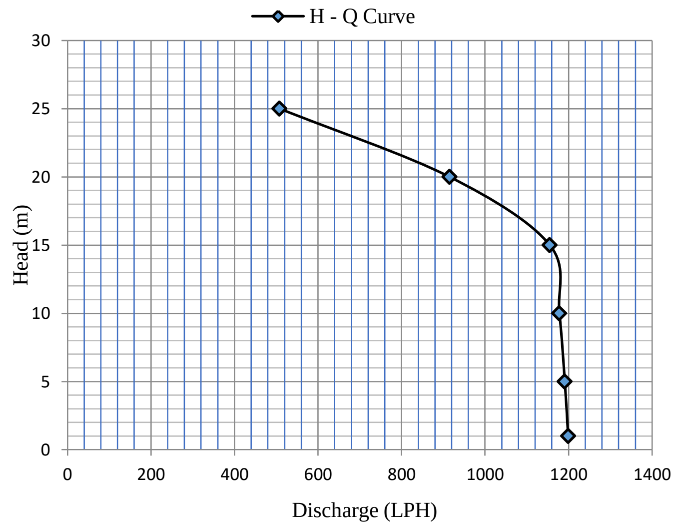

Figure. No.2 Ŋ - H Curve with BLDC motor

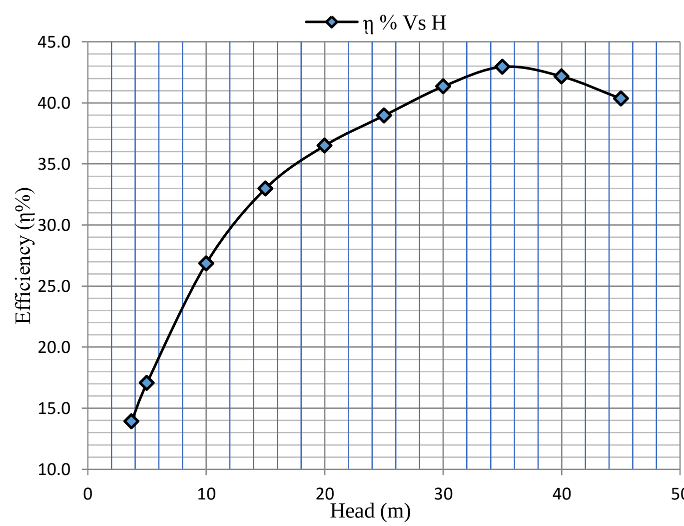

Figure. No.3 H-Q Curve with PMDC motor

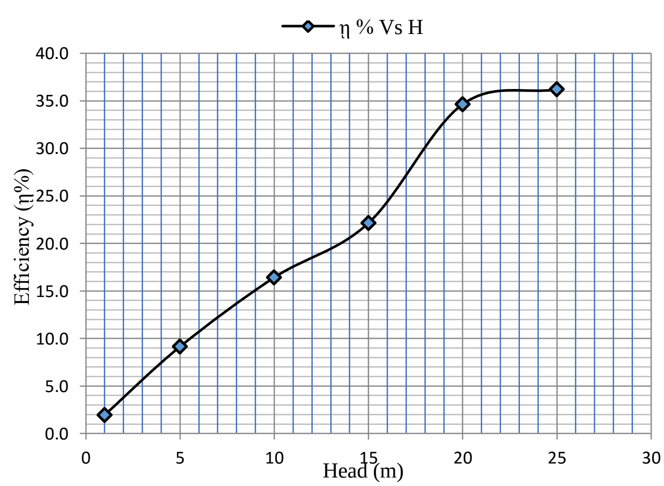

Figure.No.4 Ŋ - H Curve with PMDC motor

300 Wp				
Head	**LPH**	**LPM**	**Power**	**Efficiency**
3.6	1564	26.1	113.4	13.8
5	1536	25.6	122.7	17.1
10	1493	24.9	151.5	26.9
15	1439	24.0	178.4	33.0
20	1372	22.9	210.0	35.6
25	1300	21.5	230.7	39.0
30	1160	19.3	234.0	40.5
35	1041	17.4	231.2	42.9
40	885	14.8	228.8	42.2
45	742	12.4	225.5	40.3

Table. No.2 Performance of BLDC with 300 Wp @ Solar radiation 1000 W/m2 with Temp 25 ˚C

7. CONCLUSION

The initial investment will result in life long better performance. Also the performance with BLDC was much better as compared to PMDC for lower rating motor. The motor can be easily overloaded which enhance the use of BLDC motor for solar powered in water pumping application

8. REFERENCES

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[3] Fundamental of Power Electronics, Chapter 12 "Basic Magnetic Theory", Part III
[4] Book By: J.R Hendershot, T.J.E Miller "Design of Brusless Permanent Magnet Motors

300 Wp				
Head	**LPH**	**LPM**	**Power**	**Efficiency**
1.2	1206	20.1	167.4	2.1
5	1191	19.9	177.5	9.1
10	1178	19.6	195.5	16.4
15	1155	19.3	213.2	22.1
20	915	15.3	143.9	34.6
25	508	8.5	95.6	36.2
30	340	6.7	85.6	33.2

Table. No.3 Performance of PMDC with 300 Wp @ Solar radiation 1000 W/m2 with Temp 25 ˚C

While using positive displacement pump with the motor above reading have been noted.