

## Designing Of Permanent Magnet Synchronous Machine For Applications In Small Hydro Power Plants

Jayashree Sharma<sup>1</sup> Gagandeep Sharma<sup>2</sup> Dr. Sanjay Marwaha<sup>3</sup>

M. Tech Student<sup>1</sup>, DAV Institute of Engineering and Technology, Jalandhar

Assistant Professor<sup>2</sup>, DAV Institute of Engineering and Technology, Jalandhar

Professor<sup>3</sup>, Sant Longowal Institute of Engineering and Technology, Longowal (Sangrur)

### ABSTRACT-

The need of the hour, as we all genuinely know from the global scenario is the production of electricity from the renewable resources of energy. Most widely used among them are the solar and the wind potential. Besides these, the hydroelectric resources also play a remarkable role as hydroelectricity accounts for a major share in the energy sector throughout the world. The trend at present is of the stand alone hydro power plants wherein the turbine used is the Hydrokinetic turbine, which works with the speed of flow of the water stream. Permanent magnet synchronous machines, known for their robust nature, variable speed, and high power to weight ratio are the most suitable ones for the construction of the turbine for low speed operation. This paper presents the design of permanent magnet synchronous machine and the machine has been modeled and simulated in RMXprt and Ansys Maxwell.

**NOMENCLATURE** - PMSG (permanent magnet synchronous generator), RMXprt (rotational machine expert), HKT (hydrokinetic turbine), UHT (ultra high temperature)

### I. INTRODUCTION

Renewable energy extraction techniques have gained momentum in the wake of depleting natural resources. Many developed and developing countries alike are currently focused on producing more renewable energy. This focus is supported by tremendous investments.[1] This change is necessary to curb the effect of rise in oil prices globally.[2] As for a country like India, where the chances of generating electricity from wind as the resource is low due to the reasons of the geographical constraints, the hydroelectricity plays the major role. The need, economy and the potential of the hour are the stand alone small hydro power plants which could generate energy enough to supply the electricity for the vicinity [3]. A hydro power plant has the greatest potential thus far as a renewable energy resource. As observed from the recent trends in other major contributors like China, Brazil, India and Canada, developing better technologies for hydrokinetic energy extraction offers promising returns as well hence improving the economy of the country.[4].

### II. MINI HYDRO PLANT

Mini hydro power plants are used for producing hydroelectric power which is used to serve a small community or rural areas depending on the requirement. The definition states that a plant generating electrical power of up to 1000 kilowatts (kW) is generally termed as mini hydro [5]. Mini

hydro power plants are generally classified into micro hydro power plants, the limit for which is taken as less than 100 kW. These are usually preferred for the production of electricity sized for small enterprises and can be connected to electric distribution networks as an alternative source of low-cost renewable energy. Since mini hydro projects have minimal water reservoirs, their impact on the environment is lower in comparison with large hydro power plants [6]. Hydroelectric power as discussed here employs the hydrokinetic turbine. The difference between the classical method and the one employed here is that in the former, water is fed from a reservoir through a way or a channel into the turbine [7]. But the hydrokinetic turbine as the name suggests, uses the kinetic energy of the flow of water usually of a stream or a river to produce electricity. They are generally installed along rivers with a high flow rate. They harness the natural flow and elevation drop of a river to produce electrical power. Because of having no sizeable water reservoir, they cannot operate according to the electrical power demand like dam hydropower plants do [8]. Because of these factors, the mini hydropower plants are generally much smaller in size, have a lower power output, and are much less adaptable to variations in energy consumption than dam hydropower plants. The potential of mini stand alone hydro power plants can be seen from the table below which presents the latest state wise data of India.

TABLE 1. State wise data of the potential hydro power plants [9]

Sl. No	States	Central Sector		State Sector		Private Sector		Total	
		No.	MW	No.	MW	No.	MW	No.	MW
1.	Himachal Pradesh	2	816	7	892	6	749	15	2457
2.	Jammu & Kashmir	4	2450	4	1473	0	0	8	3923
3.	Uttarakhand	12	4374	7	1655	5	829	24	6858
4.	Punjab	0	0	1	168	1	75	2	243
5.	Madhya Pradesh	3	166	0	0	0	0	3	166
6.	Andhra Pradesh	0	0	3	1560	0	0	3	1560
7.	Kerala	0	0	6	373	0	0	6	373
8.	Karnataka	0	0	2	400	0	0	2	400
9.	West Bengal	1	120	2	66	0	0	3	186
10.	Sikkim	1	520	0	0	10	1935	11	2455
11.	Arunachal Pradesh	3	1610	0	0	23	7969#	26	9579
12.	Assam	0	0	1	150	0	0	1	150
13.	Manipur	2	1566	0	0	0	0	2	1566
14.	Tamil Nadu	0	0	1	500	0	0	1	500
15.	Meghalaya	0	0	1	54	1	450	2	504
	<b>TOTAL</b>	<b>28</b>	<b>11622</b>	<b>35</b>	<b>7291</b>	<b>46</b>	<b>12007</b>	<b>109</b>	<b>30920</b>

# Includes only 600 MW out of 2400 MW Ssang Lower H. E. Project for capacity addition during 12<sup>th</sup> Plan.

### III. CONSTRUCTION DESIGNS

The design methodology for the construction process of the required permanent magnet synchronous machine is a tedious process as it involves a great deal of mathematical calculations using the derived equations involving the parameters of both the stator and the rotor. The design process needs to be very accurate as proper functioning of machine and the required induction of flux depends on the area involved too.

The maximum rotor diameter that can be constructed can be calculated by the equation

$$D_{rmax} = \frac{V_r (length/min)}{1.2n_m (rev/min)\pi} \quad (1)$$

The parameter  $v_r$  represents the maximum peripheral speed of the rotor. The mechanical speed of the rotor is represented by  $nm$ . This equation can be used to double check the rotor parameters after the design has been finalized according to the power requirement.[10].

After the rotor, the outer part or the stator needs to be designed, for which the equation used is

$$\frac{D^2L}{l} = V_o \quad (2)$$

The parameter  $D$  is the stator bore diameter and the length of the machine is represented by  $l$ . The output power divided by the rotor mechanical speed is defined as the torque and is represented by  $\tau$ . [11] The importance of this equation lies in the fact that it is used to determine how big the motor size needs to be in order to create the required torque. Since cooling method plays a key role in the designing of

the machine, so a constant is considered defined by  $V_o$ .

We have considered the assumption that the stator outer diameter is estimated to be 1.2 times the stator bore diameter.[12] but considering the space limitation, it has been decided to make the diameter much larger than the machine length.

The parameter named Slot pitch is calculated by the equation

$$\gamma = \frac{\pi.P}{N_s} \quad (3)$$

where  $p$  represents the number of poles.  $N_s$  defines the number of stator slots.

The next dimension named the coil pitch can be calculated by

$$\rho = \pi \frac{N_m}{N_p} \quad (4)$$

It can be seen that, as speed decreases, for a fixed/pre-determined frequency of the synchronous field, the no. of poles will increase. Thus the no. of magnets on the rotor must be increased.[13] Subsequently, a larger magnetic field is required to produce higher power (the higher the flux, the higher the voltage induced and, hence, the higher power produced) for a given number of poles. It is governed by the equation,

$$\phi_g = B_{av} \left( \frac{\pi DL}{P} \right) \quad (5)$$

Increasing the no. of poles increases the no. of slots on the stator. Increasing the slot number reduces the tooth ripples. Unfortunately it also contributes to both a weaker stator tooth and a more complex stator structure. Manufacturing a complex stator and winding the coils is a tedious task, particularly if it must be constructed in-house [14].

The rotor pole pitch and stator pole pitch are essentially the same and is calculated as:

$$\theta_p = \tau_p = \frac{2\pi}{N_M} \quad (6)$$

The amount of rotor surface area covered by the north and south poles of the rotor is termed as 'embrace'. Normally the embrace is valued 50% to 75% is allowed.[15] Pole embrace affects the voltage waveform, torque ripple and leakage-flux factor. The permanent magnets so chosen must possess sufficient residual flux density, magnetic coercive force and deliver higher power density. The choice also depends on the lower cost, thermally, magnetically and chemically .[16] It is found that Neodymium magnets and samarium cobalt magnets satisfy most of the above requirements.

The construction for the standalone hydro turbine here involves the construction of stator and the rotor. The rotor has been designed using the permanent magnet core from the inbuilt directory of the user defined primitive in the RMXprt and the simulations were carried using finite element analysis. [17] The mathematical values were given to the parameters

involved. The stator comprises the outer part of the machine and here it has been designed using the switched reluctance core as we needed the terminals in the winding to exist. There is a magnetic flux linkage from the magnets to the stator and this flux needs a path to flow from one pole to the other. The back iron provides this path and hence it needs to be wide enough to sustain magnetic saturation. The material used for stator is usually copper or silicon steel with soft magnetic laminations in order to reduce the leakage flux.[18]

### 3.1 ROTOR

The rotor consists of the permanent magnet core with the specifications as follows

Table no. 2 Specifications of parameters of rotor

SPECIFICATIONS OF PARAMETERS	UNITS ( mm)
Core diameter on gap side	240
Core diameter on yoke side	215
Length	100
Poles	78
Embrace	0.5
Thickness of the magnets	8
Width of the magnets	30
Rib	3

The use of permanent magnets on the rotor eliminates both the complexity of rotor windings and rotor copper losses, resulting in a simple structure with increased efficiency. The number of magnets used is equal to the number of poles. Since the material needs to be the magnetic material, samarium cobalt and neodymium ferrite have been the potential choices due to their excellent physical and magnetic properties including high remanence and coercivity, excellent thermal stability, high resistance to demagnetizing influences, corrosion resistance, and high energy product.[19] A great deal of research has been conducted to identify not only better magnetic materials but also better electromechanical structural solutions. These advancements give hope to low power and low speed small scale machines such as the one constructed in this article. There are also UHT and superconducting magnets being researched for MW – GW range machines which offer other advantages. The common notion is that higher voltages can be achieved by increasing the size (thickness) of the magnets. Magnet thickness however is limited to 11-12 mm. This factor must be considered when a PMSG is designed. The magnetic properties of the selected materials are as under.

Table no. 3. Material properties

MATERIAL PROPERTY	SmCo24	Steel 1008
RELATIVE PERMEABILITY	1.0631381	BH CURVE
BULK CONDUCTIVITY	1111111siemens/m	2000000siemens/m
MAGNETIC COERCIVITY	-	0A/m
	756000.0003A/m	

### 3.2 STATOR

The specifications taken are as under

Table no. 4 Specifications of parameters of stator

SPECIFICATIONS OF PARAMETERS	UNITS( mm)
Core diameter on gap side	290
Core diameter on yoke side	240
Length	100
Poles	80
thickness of the yoke	9
Pole embrace	0.5

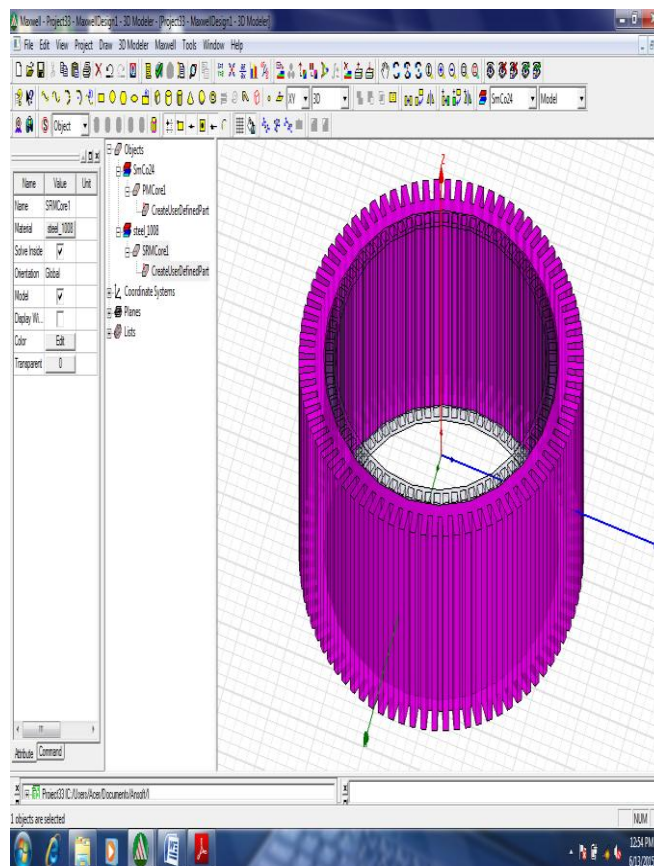


Figure no. 1. The simulated model of the designed permanent magnet synchronous machine

#### IV. MACHINE SIMULATION -

Once the machine is designed it needs to undergo performance optimization. This is carried out through the ANSYS software – RMXprt® and Maxwell 3D®. Thus the process of machine design is always iterative. The simulation results are as follows:-

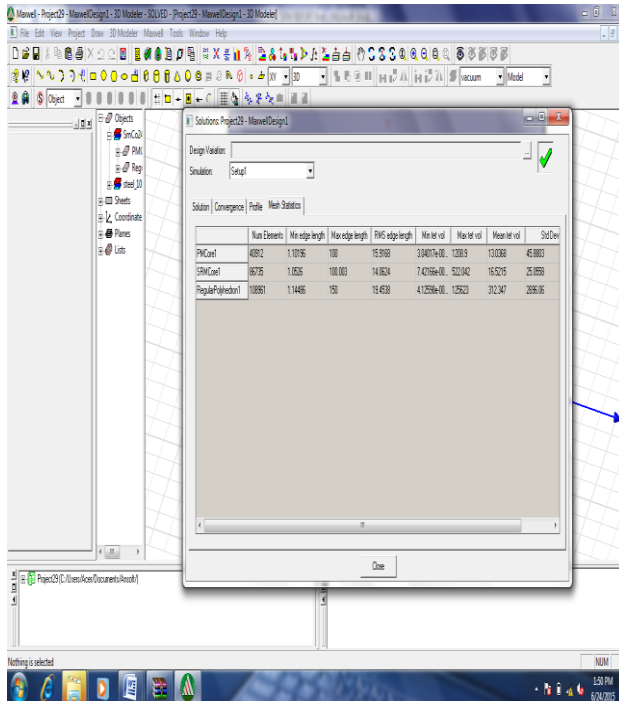


Figure no. 2 The screenshot shows the minimum and maximum voltage that has been induced in the permanent magnet and switched reluctance core.

Table no. 5 the values of voltages induced in the respective cores

	Minimum tet voltage (V)	Maximum tet voltage (V)	Mean tet voltage (V)	Standard deviation (V)
PMcore	3.04017	1208.9	13.036	45.880
SRMcore	7.42166	522.042	16.521	25.055

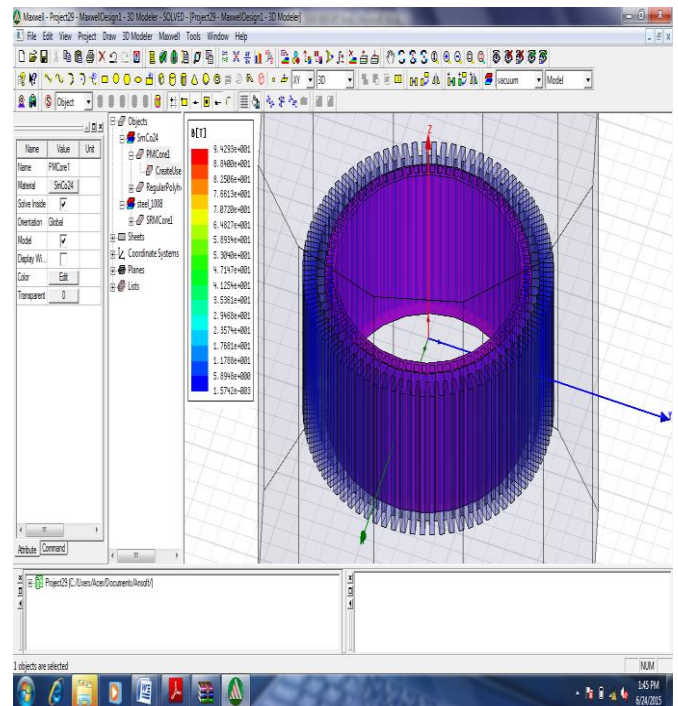


Figure no. 3 The screenshot shows the magnetic field values being induced in the two cores.

Table no. 6 the values of magnetic flux density induced in the respective cores

Magnetic flux density (T)
0.94
0.88
0.82
0.76
0.70
0.64
0.58
0.53
0.47
0.41
0.35
0.29
0.23
0.17
0.58

#### V. CONCLUSION

This paper concludes the model of the permanent magnet synchronous machine which is being designed particularly for applications in small hydro power plants. The turbine used here is the hydrokinetic turbine which produces power using the flow of the stream or river. The model has been simulated using the finite element analysis and the Ansys Maxwell software. The values of the voltage

and flux induced clearly states the authenticity of the designed machine.

## VI. FUTURE SCOPE

The distributed sources of energy undoubtedly represents the face of the power industry in the coming era and keeping this fact in mind, hydroelectric power accounts for one of the major shares throughout the world. Considering particularly the case of India, where rural electrification still is a challenge, mini hydro power plants which utilize the services of hydrokinetic turbine employing permanent magnet synchronous machine play a key role in meeting the energy demands.

## REFERENCES

- [1] British\_Petroleum, "BP Statistical Review of World Energy June 2012," 2012, pp: 1 - 48
- [2] R. Gelman, "2010 renewable Energy Data Book," Scott Gossett, Ed.: US Department of Energy, 2010, pp: 136
- [3] Rathor, "Energy Statistics 2012 - Govt. of India." Central Statistics Office, April 2013, pp: 99
- [4] A. McCrone, "Global Trends in Renewable Energy Investment - 2012," Frankfurt School of Finance & Management, 24 July 2012, pp: 82
- [5] UJWALBHARAT.GOV.IN , MINISTRY OF NEW AND RENEWABLE ENERGY GOVERNMENT OF INDIA
- [6] Hydropower Electricity Generation, 2013 by Lab-Volt Ltd., ISBN 978-2-89640-574-9 (Printed version) ISBN 978-2-89640-575-6 (CD-ROM)
- [7] "Marine energy more than just a drop in the ocean," accessed on, <http://www.lunarenergy.co.uk/>
- [8] S. E. Ben Elghali, M. E. H. Benbouzid, and J. F. Charpentier, "Marine Tidal Current Electric Power Generation Technology: State of the Art and Current Status," in *Proc. Electric Machines & Drives Conference, 2007. IEMDC '07. IEEE International, 2007*, Vol. 2, pp: 1407-1412, 10.1109/iemdc.2007.383635.
- [9] <http://www.eai.in/ref/ae/hyd/hyd.html>
- [10] Chang Jiang , Huangqiu Zhu and Zhenyue Huang, "Optimal Design and Analysis on Bearingless Permanent Magnet-type Synchronous Motors Using Finite Element Method", *Power Electronics and Motion Control Conference, 2006*, Vol 2, pp:1-5, August 2006
- [11] T. Liu, S. Huang, Q. i. Deng, Q. Pu, and K. Huang, "Effect of the Number of Slots per Pole on Performance of Permanent Magnet Generator Direct-Driven by Wind Turbine," presented at 2011 *International Conference on Electrical Machines and Systems (ICEMS), 2011*.
- [12] H. Liu, W. Brokaw, J. Harms, W. Wu, M. Epstein, T. Chalfant, A. Camarano, Y. Hu, Y. Bai, L. Chow and T. Wu , "Design and Optimization of Permanent Magnet Switch Reluctance Machine for Renewable Energy Application", *Electrical machines (ICEM), 2012 XXth International Conference*, pp: 612-617, September 2012
- [13] Baiba Ose-Zala, Vladislav Pugachov, and Nikolay Levin, " Start-Up Torques of Permanent Magnet Synchronous Generator With Non-Overlapping Concentrated Windings", 978-1-4799-5022-5/14/, *IEEE 2014*
- [14] Tayfun Gundogdu, Guven Komurgoz, "Design of Permanent Magnet Machines with Different Rotor Type", *World Academy of Science, Engineering and Technology*, Vol 4, 2010-10-29
- [15] Chun-Yu Hsiao \*, Sheng-Nian Yeh and Jonq-Chin Hwang, "Design of High Performance Permanent-Magnet Synchronous Wind Generators", *ISSN 1996-1073* [www.mdpi.com/journal/energies](http://www.mdpi.com/journal/energies), Published: 4 November 2014
- [16] "Sm-Co magnet properties," Dexter Magnetic Technologies inc.. Ed., 2010.
- [17] [https://en.wikipedia.org/wiki/Finite\\_element\\_method](https://en.wikipedia.org/wiki/Finite_element_method)
- [18] Y.G. Guo(1), J.G Zhu(1), P.A. Watterson(1) and W. Wu(2), " Comparative Study of 3D Flux Electrical Machines with Soft Magnetic Composite Cores", *IEEE Industry Applications Conference, 2002*, Vol 2, pp: 1147-1154
- [19] A. Darijani, A. Kiyoumars(C.A.), B. Mirzaeian Dehkordi, H. A. Lari, S. Bekhrad and S. Rahimi Monjezi, "Design of a Permanent-Magnet Synchronous Generator for a 2 MW Gearless Horizontal-Axis Wind Turbine According to its Capability Curves", *Iranian Journal of Electrical & Electronic Engineering, 2015*.