Two-Dimensional Analysis of PM Generator

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***Abstract*— Permanent Magnet Generator (PMG), a new generator concept, is considered to be a highly efficient, low maintenance and having several advantages such as high output potential, high power production. With such advantages, permanent magnet generator becomes more popular as the demands toward these machines increases rapidly. Above all the advances in PM, materials have the largest impact on the electrical machines. The analysis obtained is performed with a specialized software package using COMSOL Multi-physics having good accuracy based on finite element method. In this paper, the performance of generated voltage in the rotor winding of the generator is analyzed and the output voltage waveforms of generator have been presented.**

Keywords*— Permanent Magnets Generator, Generated voltage, Finite element method (FEM)

I. INTRODUCTION

Electrical machinery is generally used in all characteristics of the social action. In Industrial area, it is important for product quality. The permanent-magnet generator was one of the earliest forms of the electrical machine. The basic operation of electrical machines depends on electrical, magnetic and thermal elements. In low-speed applications of electrical generators always with the high number of poles are needed. the speed of usual generators of higher rpm is incompatible with the other rotational speed[1][2]. Permanent magnets have been extensively used to replace the excitation winding in Generator with the well-known advantages of simple rotor design without field windings, slip-rings and exciter, having higher overall efficiency[3]. In recent years, there has been an increase in the number of industries and applications with various problems. Over previous years, the changes in material's technology advances in permanent magnet (PM) have the largest impact on electrical machines[4]. The merits such as high efficiency, compact size, and high power density, PM machines are becoming inexpensive in many applications. In machines the replaced of the field winding with PM. It is used to create the fundamental acting field. The surface PM topology since this generator is used for high-speed application assembly compare to Interior PM Topology is chosen to give more mechanical strength to the rotor. The design and performance characteristic of PMG depend on the permanent magnet properties, structure, etc. Besides that, voltage has the influence to the available power of the PMG Thus, to gain the desired, number of poles, and other parameters must be selected properly[5]. In the PM Generator which made use of electromagnets for excitation. For many years, permanent-magnet generators have found little favour. There has been some use of permanent-magnet generators for brushless excitation, and there is an obvious advantage in the use of permanent magnets, in that slip rings and brushes are not required. Some designs have involved permanent magnetising windings in addition to the magnets [6]. Recently, there is an increasing tendency to study hybrid poles permanent magnet generator, which combines the advantages of PM generators with the different parameter so, the hybrid poles permanent magnet generator is better than others[7]. The iron-loss and magnetic eddy loss is distributed throughout the stator core and magnet poles. Furthermore, the loss is related to the space position. In the numerical calculation of electric machine field, winding configuration and no. of slot / pole combinations have a significant effect on rotor power loss[8]. Low maintenance, high reliability and efficiency requirements for wind power generator. Permanent magnet (PM) used on electric machinery offers these characteristics for a wide range of applications[9]. Basically, PM generators can be divided into radial-field and axial-field permanent magnet generator according to the flux direction in the air gap. However, the output voltage and the output power are varied by the flux paths. Permanent Magnet generator has numerous advantages such as high output voltage and high output power, high efficiency. Hence, the PM generator has an advantage of having a low natural adjustive rate of voltage[10][11]. In this paper generated voltage of the Permanent magnet generator is calculate by finite element method. The value and waveform of the voltage are obtained.

II. GENERATOR DESCRIPTION

A. Permanent Magnet Generator

Permanent Magnet generator considered in this paper is with a larger diameter than the length of the magnetic circuit, as in Fig.1. Constructive topology is different from the classical one.

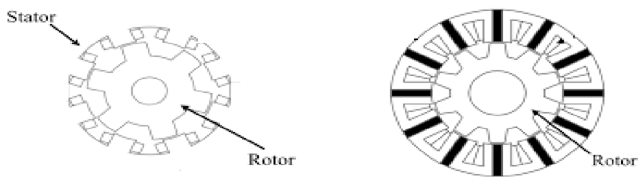

Fig.1: Two-dimensional model of Permanent Magnet Generator

An advantage of this type of generator is the most efficient magnets strengthening regardless of their arrangement, the centrifugal force pushing the magnets to the rotor core at high-speed operation. Thus, such structures can be used more safely at high-speed operation [12].

B. Electromagnetic Model

A mathematical model is the analytical model to solve the Flux density. Magnetic flux is formed between stator and rotor this relationship is given by Maxwell's equations[13].

Equations

$$\oint \vec{D}.d\vec{s} = \int \rho_v dv \tag{1}$$

$$\oint \vec{B}.d\vec{s} = 0 \tag{2}$$

$$\oint \vec{H}.\vec{dl} = \oint \left(\vec{J} + \frac{\partial \vec{D}}{\partial t} \right) .d\vec{s} \tag{3}$$

$$\oint \vec{E}.\vec{dl} = -\int \frac{\partial \vec{B}}{\partial t} .d\vec{s} \tag{4}$$

The fundamental equation of a 2-D magnetic field taking and moving into account can be written by using the magnetic vector potential, *A*, as follows:

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A}{\partial y}\right) = -J_S + \sigma\left(\frac{\partial A}{\partial t} + v\frac{\partial A}{\partial x}\right) \tag{5}$$

where μ is the permeability, *S J* is the current density in the stator windings, σ is the conductivity of the secondary, *v* is the velocity of the primary core. The magnetic nonlinearity of primary core and back iron is represented by their single-valued B-H curves [14]. The generated voltage is computed as the line integral of the electrical field.

$$V_i = NN \sum \frac{L}{A} \int E_Z dA \tag{6}$$

The resulting PDE

$$\sigma \frac{\partial A}{\partial t} + \nabla \times \left(\frac{1}{\mu} \nabla \times A \right) = 0 \tag{7}$$

where magnetic vector potential only has a *z* component.

C. Permanent Magnets

The permanent magnet used in the construction and design of the generator can be divided into three groups. The material properties of the permanent magnet play an important role in determining the stability of material applications like B-H properties. Alnico permanent magnet, Ferrite permanent magnet and Rare earth permanent magnets. The rare earth permanent magnets are also classified into two categories Samarium-cobalt (SmCo), Neodymium-Iron-Boron (NdFeB) The curve also shows the demagnetization of the permanent magnet. The Br value of SmCo Permanent magnet is 0.84[T] and Br value of NdFeB Permanent magnet is 1.23[T] [15][16].

The NdFeB, SmCo, AlNiCo and ferrite magnets in the year of donations as well shown in Fig.3[17].

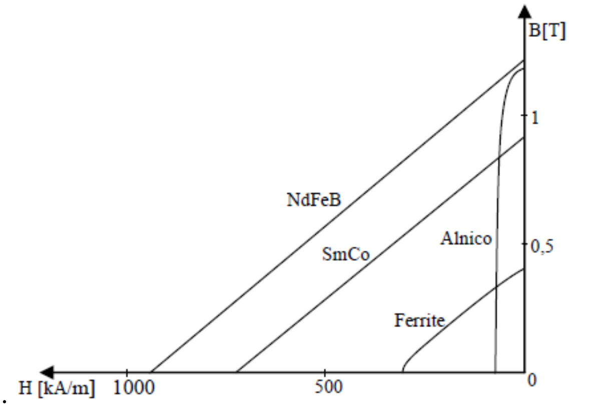

Fig.2: Demagnetization Curve of Permanent Magnets [16]

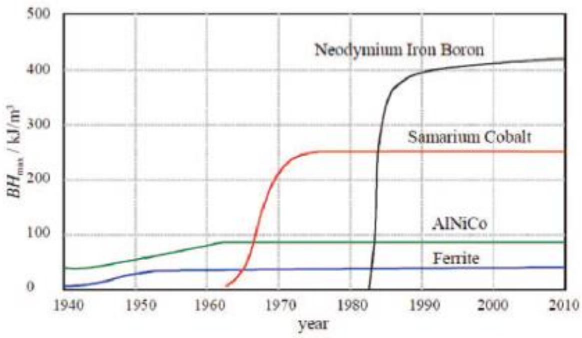

Fig.3: Development of Permanent Magnet material through years [17]

III. RESULTS AND DISCUSSION

To confirm the performance of the generated voltage using the preceding design procedure, Finite Element method (FEM). The variance procedure is initiated by this method FEM. The aim of FEM is finding the mode shapes very acutely. The finite element method (FEM) (its practical application often known as finite element analysis (FEA) i.e. a computer-based analysis method for field problems using the finite element method) is a numerical technique for result approximate solutions of partial differential equations (PDE). The 2-D time-stepping finite element analysis was conducted by using Galerkin's method used the meshes for the main part of the analysis model. In order to make flux density and generated voltage calculation more accurate[14]. This method subdivides an object into very small but finite-size elements. The concept introduces finite elements or shape functions, that describe the possible forms of the approximate solution. An adaptive meshing is performed with various magnetic vector potentials after inserting a boundary condition and sub-domain by this technique. FEM is the useful and effective method. On the base of this model, the precisely generated voltage can be obtained under different air gap length, current and current frequency. This is adopted because of generator width. In addition, it is the benefit to save computer time[18]. The analysis for the permanent generator is quite complex due to the presence of electromagnetic path. In this Multi physics solver which is referred to the generated voltage analysis with the electric angle and field is varied.

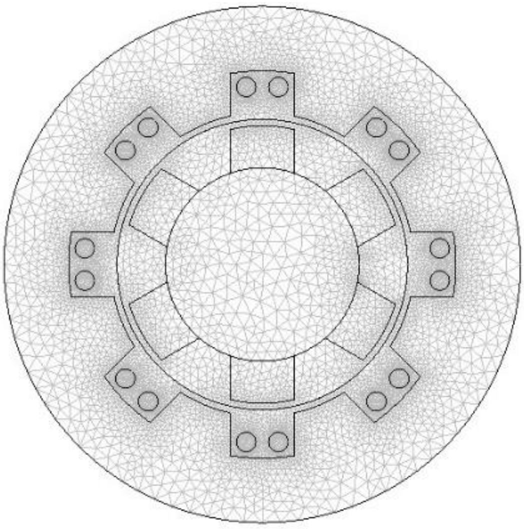

Fig.4: Meshing view of Permanent magnet generator

The generated voltage and electric angle have been performed to see the effect of fluxes. In Fig.4 shows the meshing technique of PMG. In the Permanent magnet generator, the generated voltage is governed by the change in the permanent magnet. Hence, change in properties of permanent magnet i.e. Br value in [T].

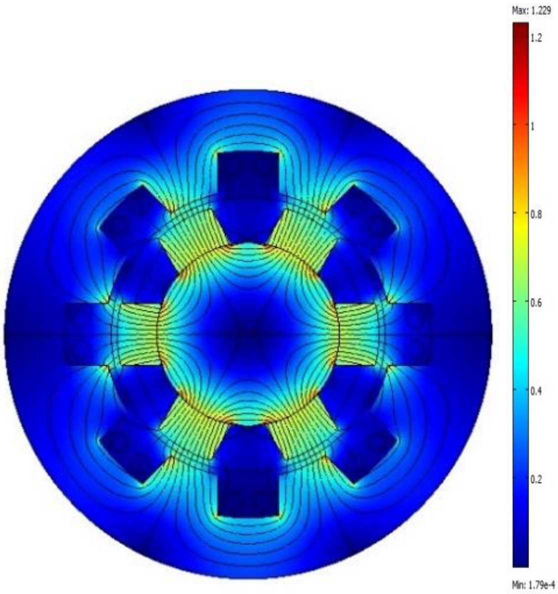

Fig.5: Magnetic Field around the Poles of Generator

The magnetic figure of the permanent magnet generator is shown in Fig.6 and its characteristics are shown in Fig.7 and Fig.8. The simulation result of the Permanent Magnet and generated voltage of the generator is investigated. From this simulation, it is observed that the range of generated voltage in the rotor winding is the sinusoidal signal at 60 rpm the voltage has amplitude is different. The amplitude of generated voltage around 1.8 V single turn winding as shown in Fig.7 and in Fig.8 the voltage have amplitude around 2.3V single turn winding.

According to the result of Permanent magnet, the voltage with electric angle is calculated. The characteristic of the generator is frequently varied. Which is an important element of the permanent magnet generator and the output waveform is also shown in Fig.7 and Fig.8.

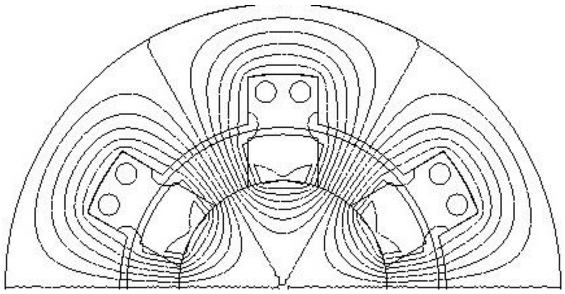

Fig.6: Magnetic Flux lines plot of PMG under generated voltage

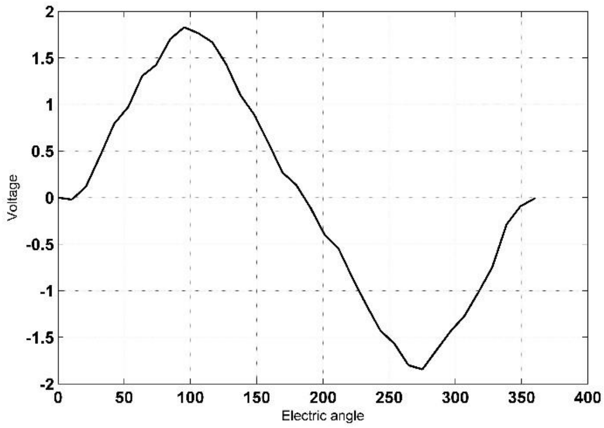

Fig.7: Generated voltage Waveform of SmCo permanent magnet

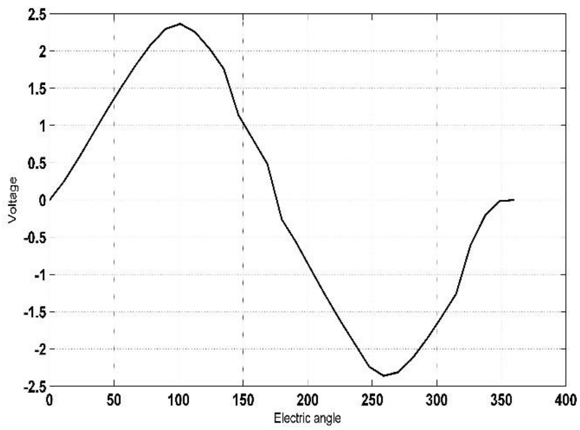

Fig.8: Generated voltage Waveform of NdFeB permanent magnet

IV. CONCLUSIONS

In this paper, generated voltage with respect to electric angle in Generator is analyzed with the help of finite element method. The COMSOL Multi-physics can be used as a useful tool for assessment of numerous critical parameters which affect the performance of permanent magnet Generator. The generator using NdFeB and SmCo permanent magnets was investigated. The results show that the voltage is influenced by the using of these permanent magnets. The selection of rare earth magnet materials is a trade-off between magnetic performance, thermal stability, design flexibility and cost.

NdFeB type magnets should be considered for high performance and low operating temperature. While SmCo magnets are the greatest choice for high performance and normal temperature applications. SmCo permanent magnets can be implemented to the permanent magnet generator instead of NdFeB magnets.

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