The Effect of Design Parameters on Induced Electromotive Force and Losses of PM Machines

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Abstract

The impact of machine geometry on the performance of double-stator synchronous permanent magnet (PM) machine having different rotor pole numbers is investigated in this paper. The considered design parameters include: the split-ratio, rotor radial thickness, stator back-iron thickness, and rotor inner and outer radial lengths. It is observed that, there are optimum values for each of the design elements due to the changing condition of the electromagnetic reaction. Comprehensive analysis of the effects of the above mentioned design parameters on the fundamental back-electromotive force (EMF) and losses are given. The analysis shows that the 7-rotor pole machine has the best efficiency as well as the largest fundamental EMF value. It is also observed that, the least PM eddy current loss in addition to least overall core loss of the machine is seen in the 5-rotor pole machine.

Index terms— design parameters, efficiency, fundamental back-EMF, losses and PM machines.

1 Introduction

Author ? ?: Department of Electrical and Electronics Engineering, Michael Okpara University of Agriculture, Nigeria. Author ?: Department of Electrical Engineering, University of Nigeria Nsukka. e-mails: ccawah@ieee.org, profogbonnayaokoro@ieee.org enhancing the power factor of the given electric machine by appropriate selection of the PM pole-pairs is given in [7].

Moreover, the effect of different design elements of surface-mounted PM vernier machine on the overall performance of the machine is presented in [8]. The analysis shows that the design parameters have significant impact on the performance of the machine in terms of torque and power factor potentials. Thus, optimal value of the parameters must be used in order to achieve the best result.

A novel topology of dual excited PM machine with improved torque capacity is proposed in [9]. The given machine is suitable for direct drive applications since it could produce large torque at low operating speed. Further, novel two-phase double stator PM machine having concentrated windings and spokemounted PMs is proposed in [10]. The proposed machine in [10], is capable of producing larger torque density compared to that of traditional PM machine; albeit, with higher induced EMF harmonics.

Similarly, comparative study of flux switching PM (FSPM) machine and Toyota Prius IPM motor is given in [11]. The investigation shows that, although, the FSPM machine have lots of advantages such as better suitability for brushless AC control and low torque ripple over the IPM, it also have some drawbacks such as high PM usage and manufacturing cost.

Due to the fluctuating price and limited availability of rare-earth magnets, several machines which utilizes less or no PMs such switched reluctance machine (SRM), induction machine (IM) and PMassisted synchronous machines equipped with ferrite magnets are reviewed and quantitatively compared in [12], without significant trade-off of its efficiency and output torque capability. Further works on cost-effective PM machines with little or no rare-earth magnet materials such as dysprosium are detailed in [13] and [14]; however, with increased risk of demagnetization.

In this work, the impact of leading design geometry such as the split ratio, rotor radial thickness, back-iron thickness etc. on the fundamental back-EMF as well as the losses of double-stator flux switching PM (DS-SFPM) machine are considered. EVELOPMENT of high energy rare-earth materials as well as recent trends in power electronics and computer-aided tools have given rise to tremendous research on permanent magnet machines. Thus, the double-stator PM-, double-rotor PM-and flux switching PM machines are readily available and are demonstrated in the following literature [1], [2] and [3]. Similarly, flux modulated PM machines based on magnetic gearing principles are gaining wide attraction owing to their advantages of high output torque and efficiency as shown in [4] and [5].

The impact of design parameters have been researched extensively due to its great influence on the overall performance of electrical machines. It is proven in [6] that, design parameters such aspect ratio also known as split ratio, pole number, weight etc. are important factors to be considered during electrical machine design due to their influences on efficiency, torque density and cost. Furthermore, detailed account of the influence of key design parameters on power D factor of an integrated PM machine, as well as means of Abstract-The impact of machine geometry on the performance of double-stator synchronous permanent magnet (PM) machine having different rotor pole numbers is investigated in this paper. The considered design parameters include: the split-ratio, rotor radial thickness, stator back-iron thickness, and rotor inner and outer radial lengths. It is observed that, there are optimum values for each of the design elements due to the changing condition of the electromagnetic reaction. Comprehensive analysis of the effects of the above mentioned design parameters on the fundamental back-electromotive force (EMF) and losses are given. The analysis shows that the 7-rotor pole machine has the best efficiency as well as the largest fundamental EMF value. It is also observed that, the least PM eddy current loss in addition to least overall core loss of the machine is seen in the 5-rotor pole machine. A two-dimensional finite element analysis (2D-FEA) is employed in prediction of the entire results in this study. Moreover, comparison of the obtained results having different rotor pole numbers is also given. It should be noted that, the outer stator radius of the analyzed machine is 45mm with stack and air-gap lengths of 25mm and 0.5mm, respectively. Fig. 1 shows the structural view of the developed PM machine.

2 II.

3 Electromagnetic Performance

An optimal split-ratio value of about 0.55 is obtained in most of the analyzed machines except in that of 4-rotor pole machine whose optimum split-ratio value is about 0.67. This is evidenced in Fig. 2. It is worth noting that, the largest fundamental back-EMF value occurs in the 7-rotor pole machine, in all the investigated conditions, owing to its higher flux-linkage value. The induced electromotive force of the analyzed double-stator machine is given in equation (**??**), as the rate of flux-linkage with time. Thus, (1) where ? is flux-linkage, ?= flux per pole, N is number of turns per phase, ? is the rotor position, and ? is the rotational speed.

Further, the split-ratio of the analyzed machines is given as the ratio of the outer air-gap to the outer radius of the machine as given in equation (2).

()**2**

where SR is the split or aspect ratio of the machine, Roag= the radius of the outer air-gap, radius of the machine's outer size. As the radial thickness increases the time rate of change of flux per pole also increases, resulting to high back-EMF value. This increase will continue until the available slot area for the windings begins to decrease due to the increased size of the rotor width. This will eventually lead to reduced induced EMF as seen in Fig. **??**. There is initial sharp increase in the fundamental value of the EMF as the size of the back-iron increases owing to high distribution of the PM flux on the back-iron until about 2mm before deceasing as the flux leaks away due to the huge thickness of the stator yoke. The variation of induced EMF with stator back-iron is depicted in Fig. **??**.

4 III.

5 Effect of Design Geometry on Losses

Since the output of electrical machines are dependent on its losses, therefore, accurate prediction of losses in electrical machines could help to give insight about its thermal/heat dissipation design limits. Hence, we have devoted this section to the investigation of permanent magnet eddy current loss and core loss analysis under no-load condition at low speed of 400rpm. The influence of the design parameters on the loss characteristics of the developed machines at noload are displayed in Fig. 7(a)-(e). Depending on the objective(s), the machines could be designed to have minimum loss by employing the optimum values of the main design parameters.

It is worth noting from Fig. 7, that the 4-rotor pole machine exhibits the largest loss whilst the least loss occurs in the 5-rotor pole machine. The loss characteristics of the 7-and 8-rotor pole machines are almost identical in each variation with the leading design parameters.

The predicted losses are calculated using the traditional Steinmetz equation given in (3).

The variation of back-EMF with both the rotor outer and inner arcs/pitch ratio shown in Figs. **??** and 5, increases as the arc lengths increases, until it gets to its optimum peak value at the range of ~0.4-0.5 (for the different rotor poles), before decreasing due to the changing rate of flux linkage at each instance. Thus, there is an optimum value of the arcs to yield the maximum fundamental flux-linkage and EMF values. where Bm is the peak value of the flux density, f is the frequency; Kh, Ke, and Kc are the loss coefficients for hysteresis, excess and eddy current losses, respectively. In each case, smaller split ratio will result to increased PM length and larger space for the windings, thus giving rise to an increased air-gap flux density. The reverse condition and corresponding opposite effect is also obtainable, giving room for optimum yield. Note that, there is a sharp decrease in the loss variation with the back-iron thickness after about 2mm of the yoke size due to reduced space for the conductors as the back-iron increases. Note also, that a similar trend is observed in the variation of total core loss with the rotor radial thickness in all the investigated different rotor poles; although, with different amplitudes.

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© 2018 Global Journals Fig. **??**. shows the comparison of efficiency in the analysed machines, at different operating speed. It is obvious that, the odd rotor pole machines could produce better efficiencies, in particular, the 7-rotor pole machine compared to their even rotor pole counterparts. The worst case scenario being the 4-rotor pole machine. IV.

7 CONCLUSION

The influence of design parameters on the fundamental back-EMF and losses of double-stator PM machine is presented. It is observed that, there are optimum values for each of the design parameters owing to the varying electromagnetic reaction of the conducting coils. The analyses reveal that the 7-rotor pole machine exhibits the largest fundamental back-EMF as well as the best efficiency profile amongst the analyzed machines. Further, it is found that the least amount of losses occurred in the 5-rotor pole machine while the worst machine in terms of overall performance is the 4-rotor pole machine mainly due to its enormous harmonic characteristics. Year 2018 F Furthermore, the comparison of both PM eddy current losses, and the core losses of the DS-SFPM machines are displayed in Fig. 8. The predicted results reveal that the 8-rotor pole machine has the highest value of PM eddy current loss due to its large amount of harmonics as well as relatively high electrical frequency, in addition to its PM usage, since the machines were optimized independently. Moreover, the 4-rotor machine exhibits the largest amount of total core loss amongst its counterparts. This is possibly due to its enormous harmonics, inherent in even rotor pole machines. [1]

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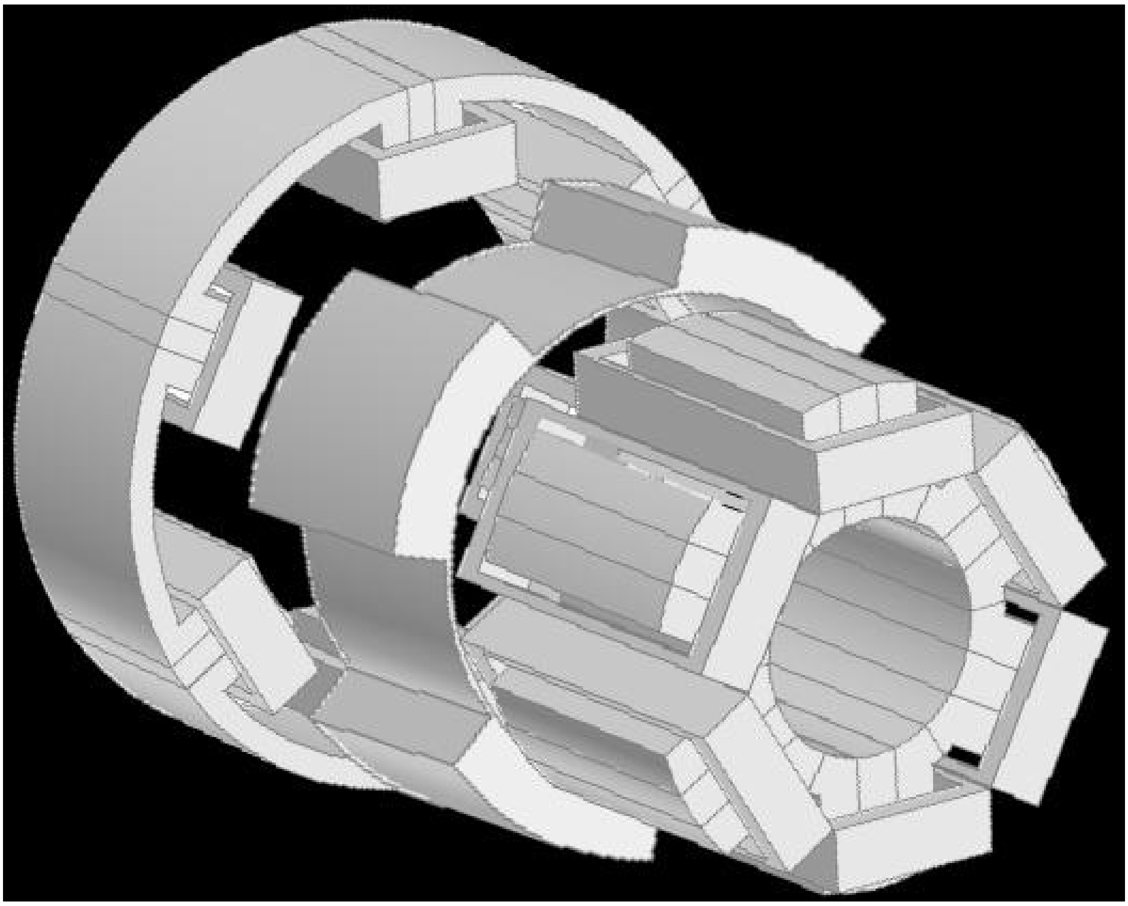

Figure 1: F

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Figure 2: Fig. 1 :

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Figure 3: Fig. 2 :

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Figure 4: Fig. 3 :FFig. 4 :Fig. 5 :Fig. 6 :

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Figure 5:

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