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# Effect of Pole Angle Variation on Electric Machine Back EMF/MMF Structure

Engr. Dr. Anazie E.A[1], Engr. Samson Ugochukwu[2*]
Engr. Dr. Josiah C. Onuegbu[3] and Engr. Onyedikachi S.N[4]
*Department Of Electrical Engineering*
*Namdi Azikiwe University Awka, Anambra State, Nigeria.,*

***ABSTRACT:*** *Back emf/mmf caused by machine armature reaction is responsible for smooth operation of electrical machines, thus any alteration in its structure, affects the operation of the machine. Pole angle plays a very vital role in shaping the structure of back emf/mmf. Hence in machine design, depending on the desired output characteristics, the pole angle has to be carefully designed to suit in. This article clearly specified relations used to determine machine pole angle and demonstrated the effect of pole angle variation on back emf/mmf structure with the help of MotoSolve 5.10, a machine design application patented to Infolytica cooperation, Canada. The result of the demonstration were illustrated and discussed.*

***Index items:*** *Electric machine, Pole angle, Back EMF/MMF Structure, Wave form, Permanent Magnet, Synchronous Motor.*

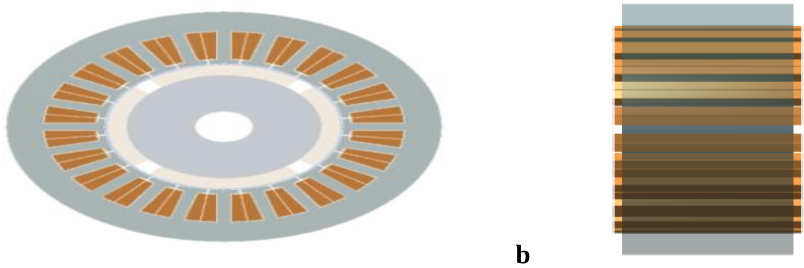
## I. INTRODUCTION

Universality of electric machine had led to continued interest in its design and construction. Engineers had innovated electrical machines over the years and beyond in search of better ways to achieve desired results geared towards meeting a particulars need or the other of humanity. Miniaturization technology necessitated by robotic engineering had led to adaptation of electric machines to fit in virtually every where especially the permanent magnet type.

Nevertheless, scholars, researcher and scientist whose interest lies in machine design had continued to dissect and further study critical elements of electrical machine with an aim to improve in subsequent design of electric machines. [1] Proposes a method to improve the wave form of back emf to obtain sinusoidal wave form. It studied the nature of crater created on the wave surface and suggested a means to eliminate it in other to reduce torque ripple, noise and vibration and improve the machine performance. The rounding effect of stepped mmf/emf due to fringing which approximated the back emf/mmf wave form to nearly sinusoidal structure was investigated in [2]. However, due to saturation or iron in the region of maximum mmf/emf tends to flatten the top of the back emf/mmf wave form. [3] Carried out finite element optimization to improve electromagnetic performance from points of view of slot/pole matching and magnetic-pole embrace. A condition which led to improved electromagnetic performance, such as torque ripple, cogging torque, average torque and back EMF structure. [4] Carried out a comparative analysis of on the back emf/mmf of four different motor with different topologies using finite element analysis and analyzed the harmonic distributions in each case. [5, 6] Described how back emf or mmf in the case of PMSM (Permanent Magnet Synchronous Motor) is generated by excitation circuit and further explained the effect of pole angle variation on the structure of back emf/mmf wave form. [7] Discussed the nature of back emf/mmf wave form structure for a balanced three phase AC system.

## II. MACHINE MODEL

The model studied in this article is shown below. The model is 24 slots, 4 poles, and interior rotor PMSM motor created using MotorSolve 5.10



**a**. **b**

**Figure 1** Design Model (a) x-y plane view, (b) y-z plane view with stator core made transparent.

## III. POLE ANGLE

Mathematically, the arc length or the angular distance spanned by pole of electrical machine is determined by number of magnetic poles created by alternating/direct current magnetic fields set up in the amateur coil of the machine as follows;

$$\tau_{pp} = \frac{360^0}{P} = \frac{2\pi}{P}(rad) \qquad 1$$

Where P is the effective number of poles (North-South) pairs created in the machine; $2\pi$ or $360^0$ is the mathematical degrees formed in any circular object. It can as well be estimated by first determining the number of slots per pole and slot pitch as follows;

$$\tau_{sp} = \frac{360^0}{Q} = \frac{2\pi}{Q}(rad) \qquad 2$$

The electrical equivalent of the pole pitch or angle can be determined using the relation stated in [2, 6, 7]

$$\frac{2\pi}{P}_{(mech)} = \pi_{(elect)} \implies P = 2 \qquad 3$$

This gives a ration of 2:1

The resultant pole angle can be adjusted manually by applying the principle of pitching or chording in electrical machine winding or with the help of MotorSolve 5.10 by simply changing the pole angle value and observing the resultant output.

$$W = \tau_p \frac{m.q - S}{m.q} = \tau_p \frac{Y_Q}{m.q}, S\ is\ an\ integer\ number \qquad 4$$

When coils are pitched, the resultant field curve fits better to ideal sinusoidal three phase AC system; the pole angle is expected to be $120^0$ electrical degrees spaced apart. In machine model presented in this article, the pole angle is $90^0$ mechanical degrees or $180^0$ electrical degrees. This can be adjusted to get $120^0$ electrical degrees if the pitching value is $^2/_3$ i.e. selecting *S* value of 2. Other values of pole angle can be arrived at which are less than or greater than $120^0$ electrical degrees by changing the value of *S* value used to calculate machine pitch. Fractional values of S can as well be used to obtain intermediate value of pole angle.

## IV. Wave Forms

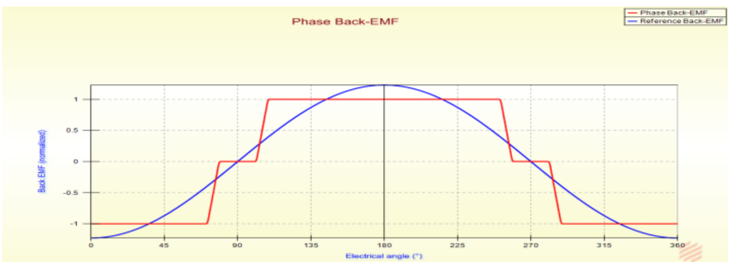



**Figure 2a:** Phase back EMF/MMF normalized i.e. per unit value with electric pole angle of $180^0$

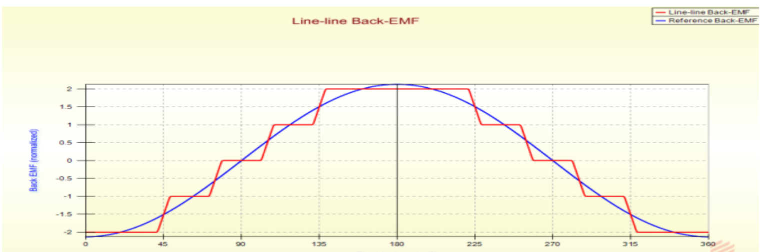



**Figure 2b:** Line-line back EMF/MMF normalized i.e. per unit value with electric pole angle of $180^0$

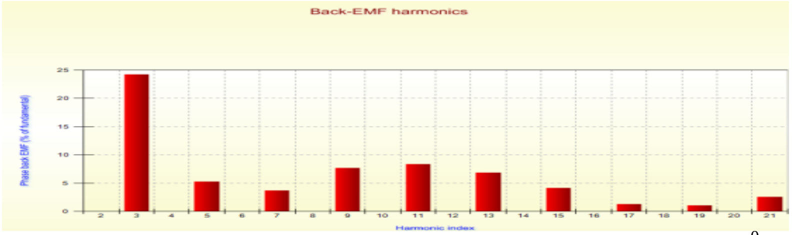



**Figure 2c:** Back EMF/MMF harmonics factor with pole angle of $180^0$C

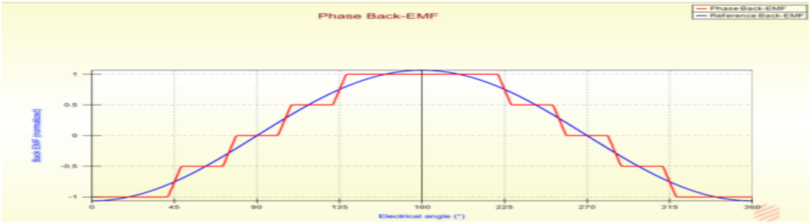



**Figure 3a:** phase back EMF/MMF normalized i.e. per unit value with electric pole angle of $120^0$

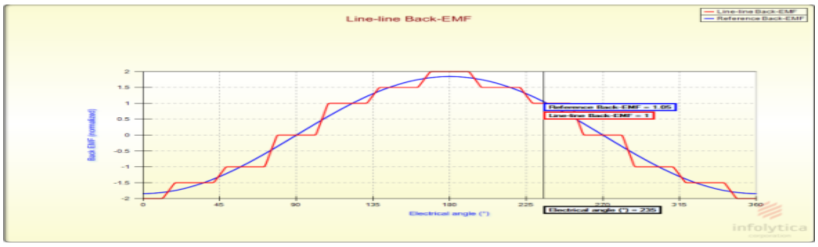



**Figure 3b:** Line-line back EMF/MMF normalized i.e. per unit value with electric pole angle of $120^0$

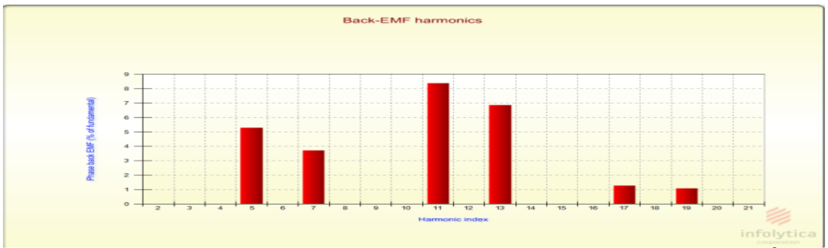



**Figure 3c:** Back EMF/MMF harmonics factor with pole angle of $120^0$C

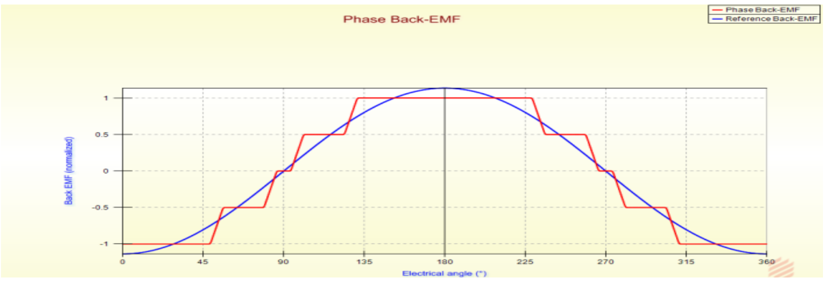



**Figure 4a:** phase back EMF/MMF normalized i.e. per unit value with electric pole angle of $135^0$

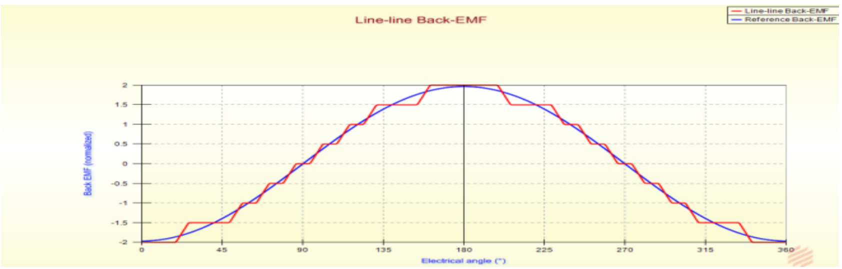



**Figure 4b:** Line-line back EMF/MMF normalized i.e. per unit value with electric pole angle of $135^0$

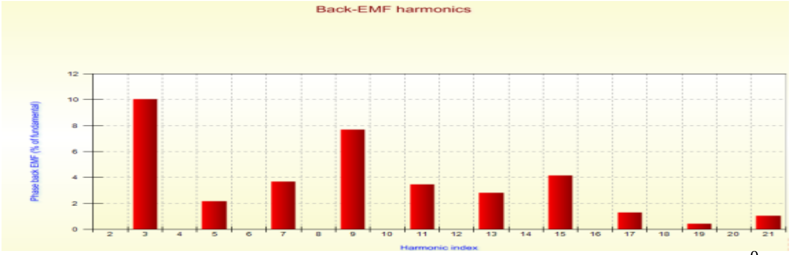



**Figure 4c:** Back EMF/MMF harmonics factor with pole angle of $135^0$C

## V. BACK EMF/MMF STRUCTURE ANALYSIS.

A close look at the wave forms shows that adjustment of the machine pole angle actually affects the shape of back emf/mmf normalized and back emf/mmf harmonics. Fig 3a, 3b and 4a, 4b shows a closer approximation of the input wave form. This implies that the induced emf/mmf closely follows the input voltage source. In fig. 3c the $3^{rd}$ harmonics is completely eliminated owning to the balanced nature of the three phase y-connected system which is usually displaced by $120^0$C electrical degrees. Fig. 2a and 2b shows that when the pole angle is designed to be $180^0$C electrical degrees apart, the back emf/mmf shape; both phase and line-line are far from the ideal shape of the input or reference voltage source. This introduces a high value of back emf/mmf harmonics (shown in fig 2c), which would generate high torque ripple and possibly destabilize the operation of the motor.

## VI. CONCLUSION

The variation of pole angle has been shown to alter the structure of back emf/mmf structure which directly impacts the machine operations. If smooth or close to smooth sinusoidal characteristics is desired, the pole angle is adjusted to near $120^0$ electrical degrees as in the case of balanced three phases AC system. This reduces unnecessary pulsating effect of $3^{rd}$, $5^{th}$ and $7^{th}$ harmonics. This condition also reduces ripple torque and thus improves the overall efficiency of the machine.

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