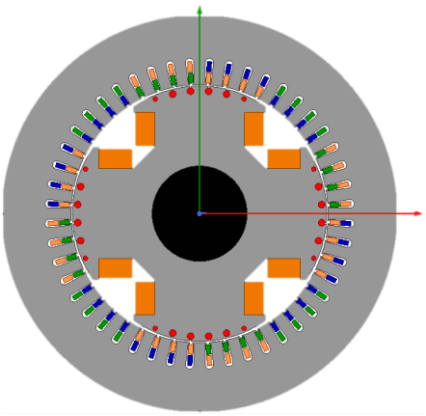
TECHNICAL ARTICLE

Influence of the Winding Pitch on the Alternator



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1. INTRODUCTION

This article aims to address the pitch effect on the generator parallelism and present the advantages and disadvantages of the stator winding pitch, as well as how it affects the performance and harmonic content of the alternator.

2. VOLTAGE HARMONICS

The alternator generates a waveform voltage that is described in terms of the magnitude of the voltage, its fundamental frequency, and the magnitude of the voltage harmonics in its frequencies.
The harmonics are multiple of the fundamental frequency of the waveform generated by the alternator. As the alternators are magnetically symmetrical, only odd harmonics and the lower-order harmonics are harmful, because the higher the order, the lower the magnitude of the harmonic.

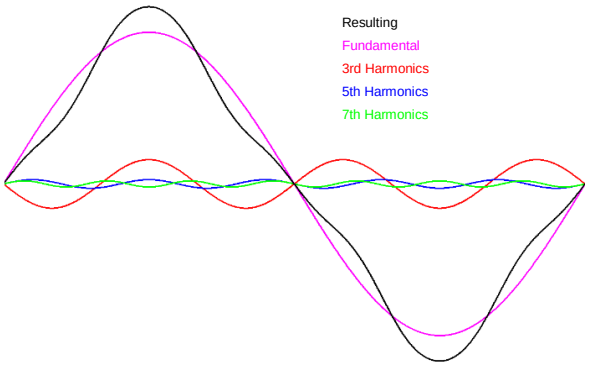

Figure 1: Relation between waveform and harmonics

Figure 1 shows the resulting waveform along with the 3rd, 5th and 7th order harmonics and the fundamental one. It is noticed that there are falls in the resulting waveform when the 3rd order harmonic is negative, and a peak when the 3rd order harmonic is positive, this happens with other harmonics as well, but in this example, the 3rd order harmonic has a higher magnitude.

2.1. Harmonics Effects

Harmonics generate undesirable effects on the alternator that may lead to failures in the machine and in the loads that are being powered.
The most critical problem is the heating of the winding, the core, and the rotor that the harmonics generate, because it may cause the machine to overheat.
Third order harmonics result in neutral current, which can flow between parallel machines or if the neutral of a star connection is grounded, this current may create permanent voltages on the ground and cause problems in the telecommunications system. In addition, it also hinders the design of electrical panels, because instruments that are not True RMS cannot perform the reading and the protection relays may not work correctly.
However, the 5th and 7th order harmonics result in increased iron and copper losses due to the skin effect, as they are at a higher frequency. If the load is from a motor, high-frequency harmonics will induce twice their own frequencies into the motor rotor, thus generating overheating that will reduce the life of the motor insulation.
When the load is capacitive the 5th and 7th order harmonics reduce the capacitive reactance, which allows an increase in the harmonic current flow, resulting in distortion of the waveform.
Non-linear loads generate high harmonic currents that cause distortion in the alternator's waveform, if they are single-phase and connected in a balanced way in the three-phase alternator, the currents of the 3rd harmonic add up in the neutral resulting in a high neutral current.
Another factor is the voltage waveform, because the more harmonics there are in a generated wave, the greater the distortion of the voltage wave. When the distortion is too high, the voltage regulator will have trouble detecting, making the readings inaccurate and making it difficult to adjust the voltage.

3. WINDING PITCH

The winding pitch is the geometrical arrangement of the coils in the stator grooves. There are full pitch and fractional pitch machines.
The full pitch is when the coil arrangement is exactly at one pole pitch of the rotor (Figure 2), whereas the fractional pitch is when the coil arrangement is smaller than one pole pitch of the rotor (Figure 3 and Figure 4).

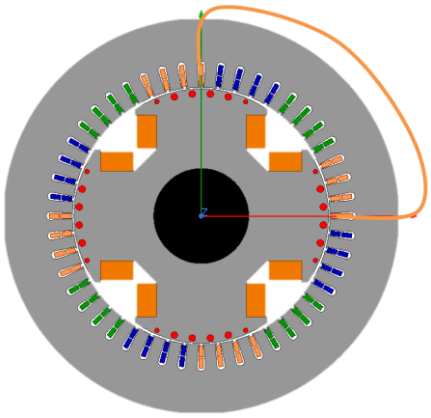

Figure 2: Full pitch winding

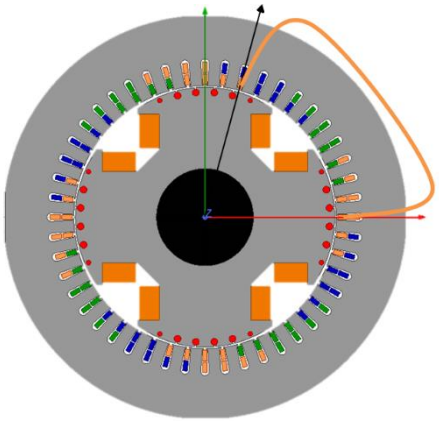

Figure 3: Fractional pitch winding (5/6)

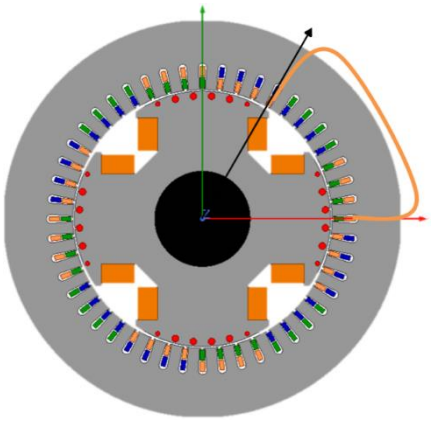

Figure 4: Fractional pitch winding (2/3)

4. PITCH x HARMONICS

The winding pitch is one of the design parameters that determines the harmonic content in the voltage wave. Depending on the pitch used in the machine, it may eliminate some harmonics, but unfortunately it does not eliminate all of them and, consequently, it can still increase other harmonics.
2/3 pitch windings eliminate 3rd order harmonics, however, they can increase 5th and 7th order harmonics, according to Figure 5.

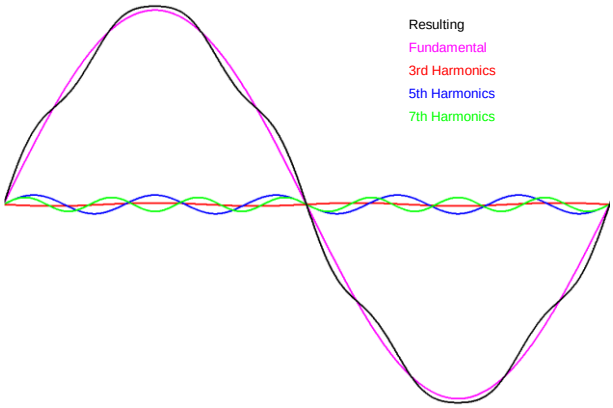

Figure 5: Harmonics with 2/3 pitch winding

5/6 pitch windings eliminate 5th and 7th order harmonics, however, they can increase 3rd order harmonics, according to Figure 6.

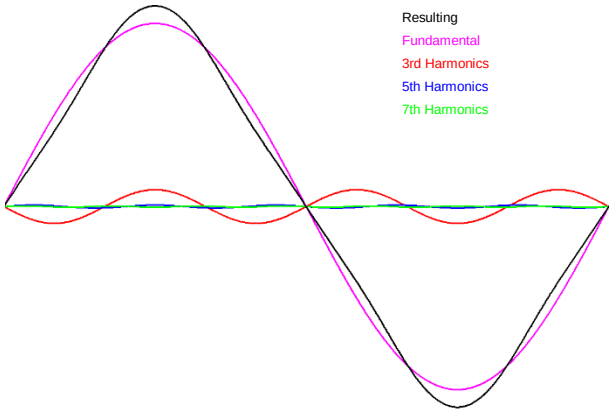

Figure 6: Harmonics with 5/6 pitch winding

5. GENERATOR PARALLELISM

There are some precautions that must be taken when connecting generators in parallel, such as an excitation system capable of ensuring the sharing of kVAr, motor capable of sharing kW, both generators with the same percentage of voltage drop at load start, harmonic content of the waveform, etc.
The most critical problem is the circulation current between the generators. This current is generated when there is a difference in the voltage waveform

between the two machines, making the 3rd harmonics circular current between the machines that have a Y connection with the grounded neutral, as shown in Figure 7.

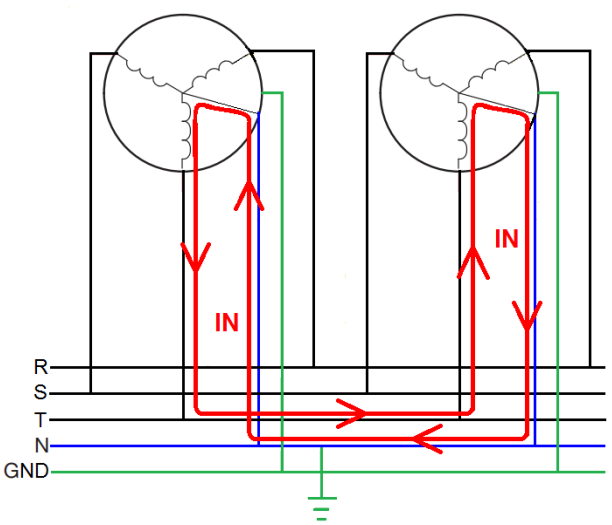

Figure 7: Circulating neutral current

This difference between the waveforms of the voltages happens due to the harmonics generated. When two alternators connected in parallel have the same harmonic content, there is no circulating neutral current.

Since the current circulating through the neutral, between one machine and the other is the current of the 3rd harmonic, its amplitude will have the greatest influence.

Thus, we can write that the amount of neutral current circulating between the generators in parallel depends on the difference between the amplitudes of the generated 3rd harmonics voltage and the reactance of the generators, according to the equation below:

$$I_{T3} = \frac{V'_3 - V''_3}{(X0_1 + X0_2 + XL)}$$

$I_{T3} = Total\ current\ of\ the\ third\ harmonics;$
$V'_3 = Amplitude\ of\ the\ third\ harmonics\ of\ the\ first\ generator;$
$V''_3 = Amplitude\ of\ the\ third\ harmonics\ of\ the\ second\ generator;$
$X0_1 = Sequence\ reactance - zero\ from\ the\ first\ generator;$
$X0_2 = Sequence\ reactance - zero\ from\ the\ second\ generator;;$
$XL = Inductive\ reactance\ of\ the\ connection\ line.$

It can be observed through the equation that the greater the difference between the 3rd harmonics voltages, and the smaller the zero sequence reactance, the greater the circulating current between the neutral of the generators. Figure 8 shows the resulting current that circulates between two generators when they have a difference in the amplitude of the 3rd harmonics.

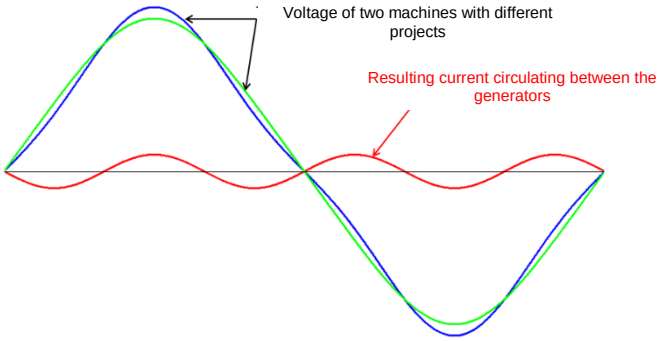

Figure 8: Circulating neutral current and voltages resulting from the two machines

To avoid circulating neutral current, it is recommended that both machines have the same design using 2/3 pitch, so that the voltage waveforms are equal, resulting in a zero current. If it is not possible to have the same designs, we advise to always predict the smallest difference between the 3rd harmonics voltages where the zero sequence reactances are not so low. Another solution is to use reactors or resistors to limit this current.

6. CONCLUSION

Both winding pitches have benefits. The correct selection for the application is the one that will bring more benefits to the customer.
The designer will always try to optimize the generator waveform to have low THD and minimize the cost, regardless of the pitch used. A well-designed generator may have a low THD with any pitch.

Table 1 shows the applications where it is recommended to use 2/3 and 5/6 pitches.

Table 1

	Pitch 2/3	Pitch 5/6
Single-phase non-linear loads	X	
Less active material quantity on the machine		X
Fault current, minor neutral phase		X
Parallel generator operation	X	
Three-phase low-voltage four-wire systems	X	
Medium and high-voltage three-phase systems		X
Easy design of electrical panels	X	