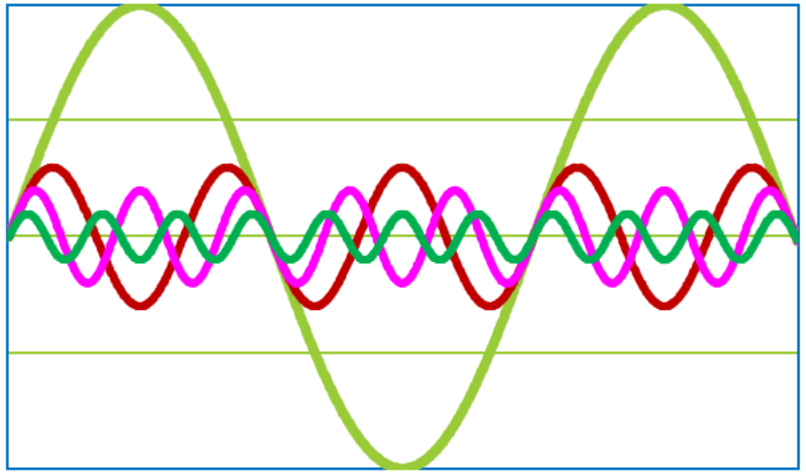
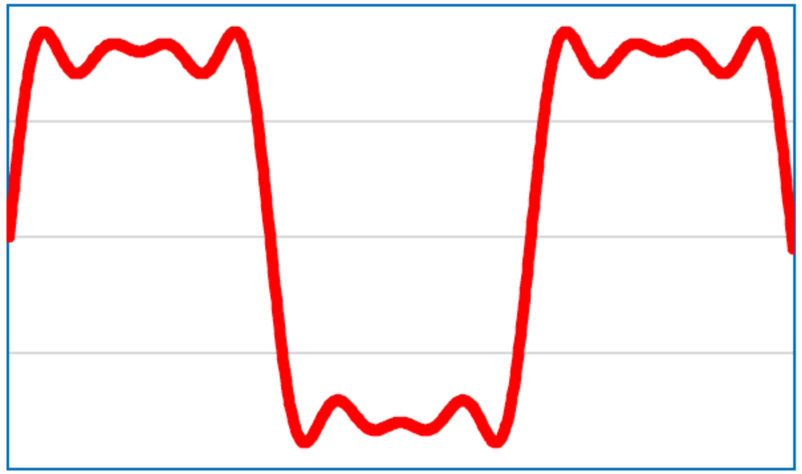
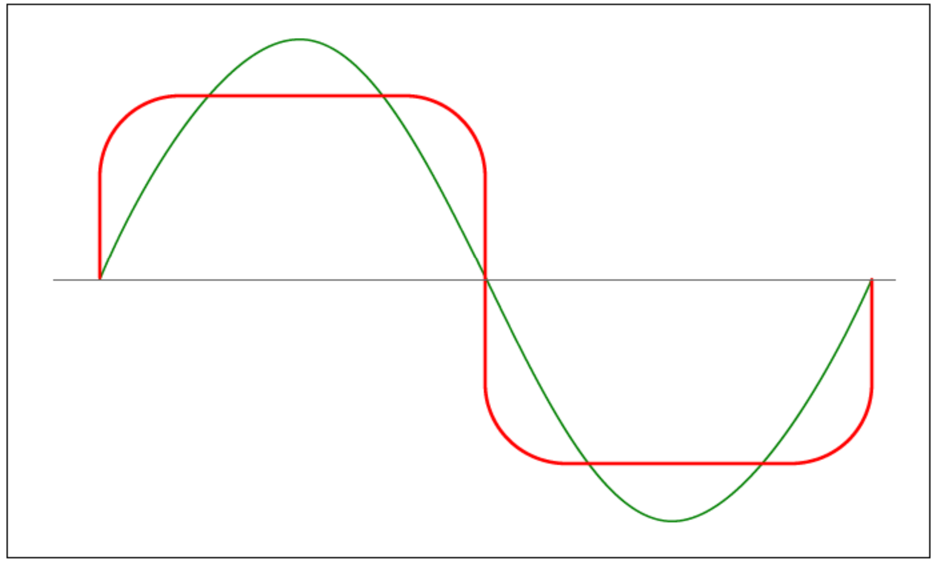
Harmonics





- Defined as sinusoidal voltages and currents at frequencies other than the fundamental frequency.
- Harmonic frequencies are integer multiples of the fundamental frequency

$$f(x) = a_0 + \sum_{n=0}^{\infty}[a_n \cos(nx) + b_n \sin(nx)]$$



K_c and K_d for Harmonic Frequencies

$$K_{cn} = \cos\frac{n\alpha}{2}$$

$$K_{dn} = \frac{\sin\frac{mn\beta}{2}}{m\sin\frac{n\beta}{2}}$$

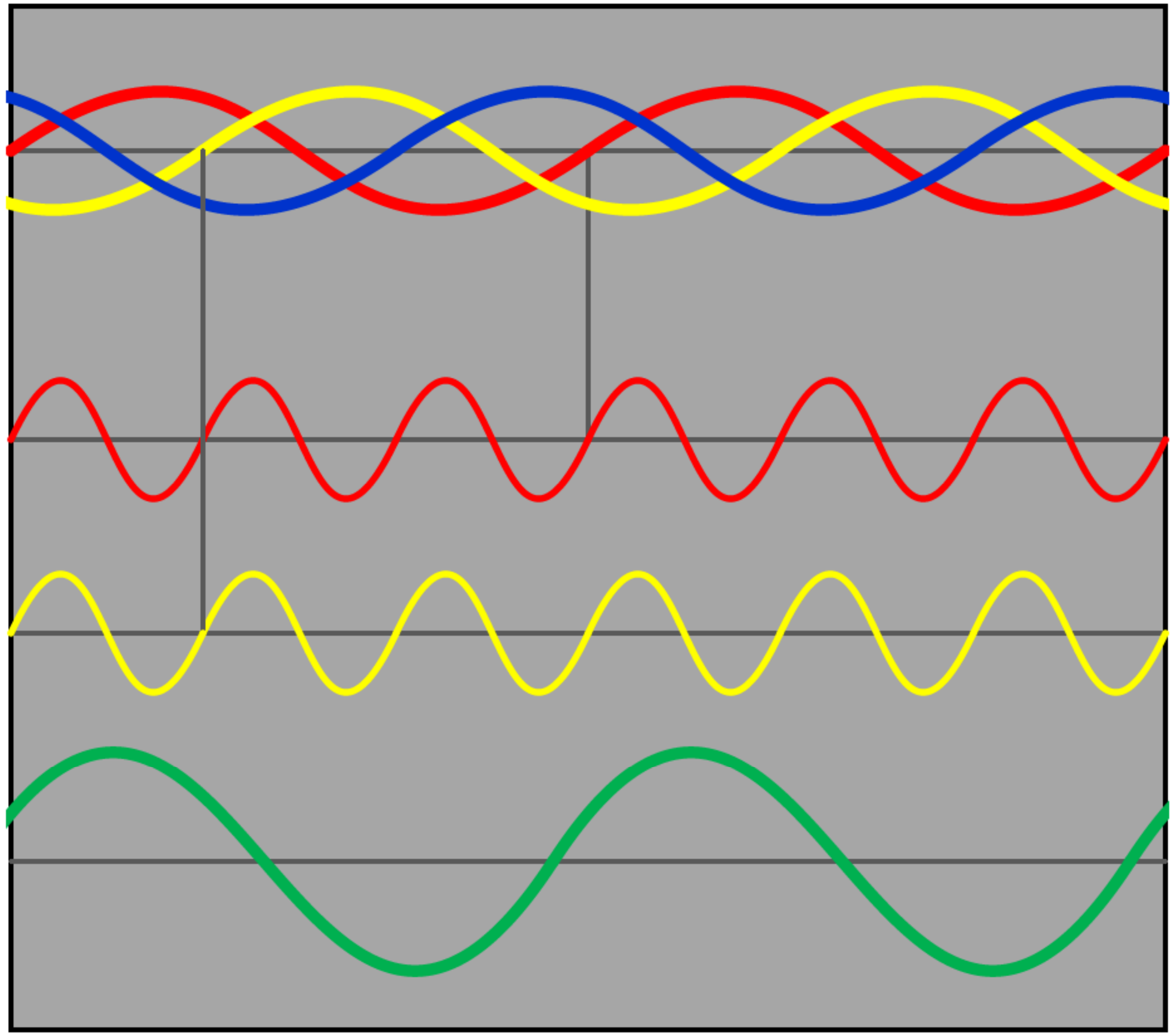
where n is the harmonic order

if $n = 5$ and $\alpha = 36°$

$$K_{c5} = \cos\frac{5\times 36}{2} = 0$$

Short chording can help to eliminate harmonics

Line voltage with harmonics in generated emf



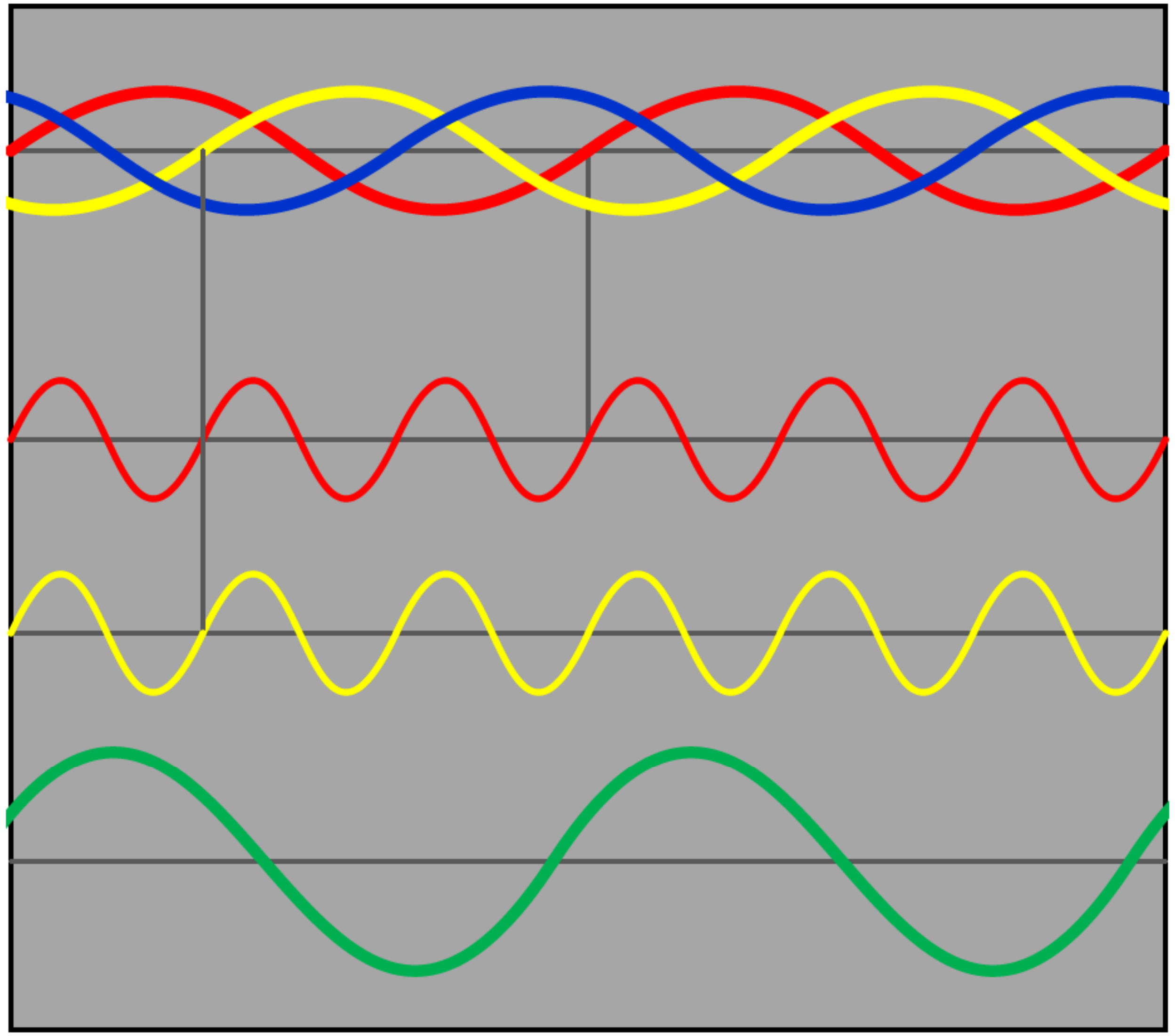
Phase voltage

Third Harmonic voltages

Line voltage

$$V_{RY} = V_R - V_Y$$

Line voltage with harmonics in generated emf



Phase voltage

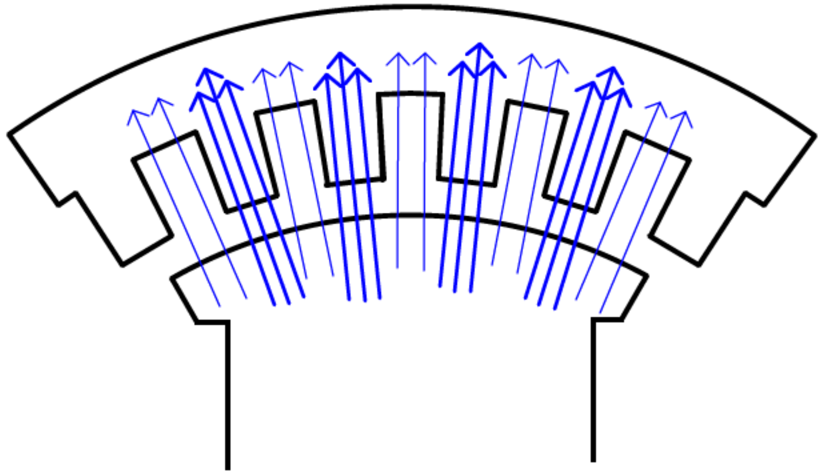
$V_{RY} = V_R - V_Y$

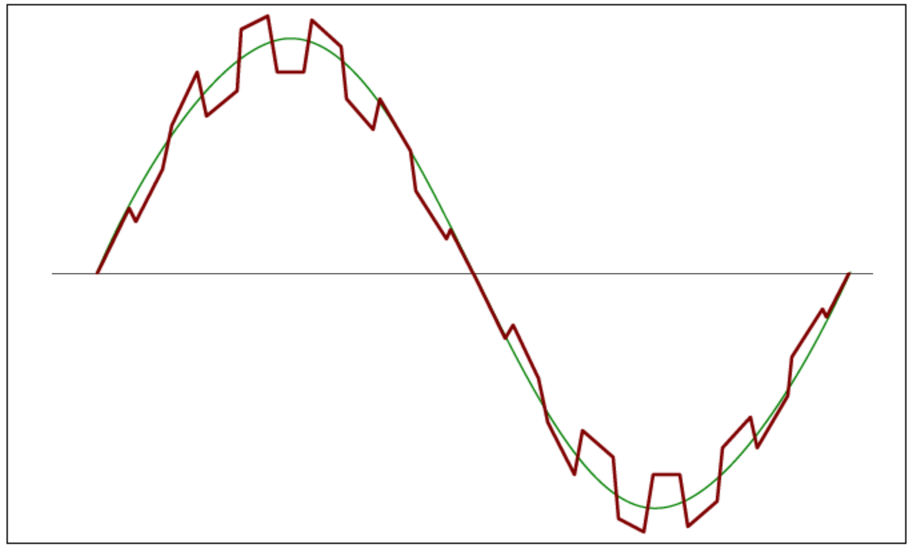
Third Harmonic voltages

Line voltage

Third harmonics cancel in line voltage

Slot Harmonics



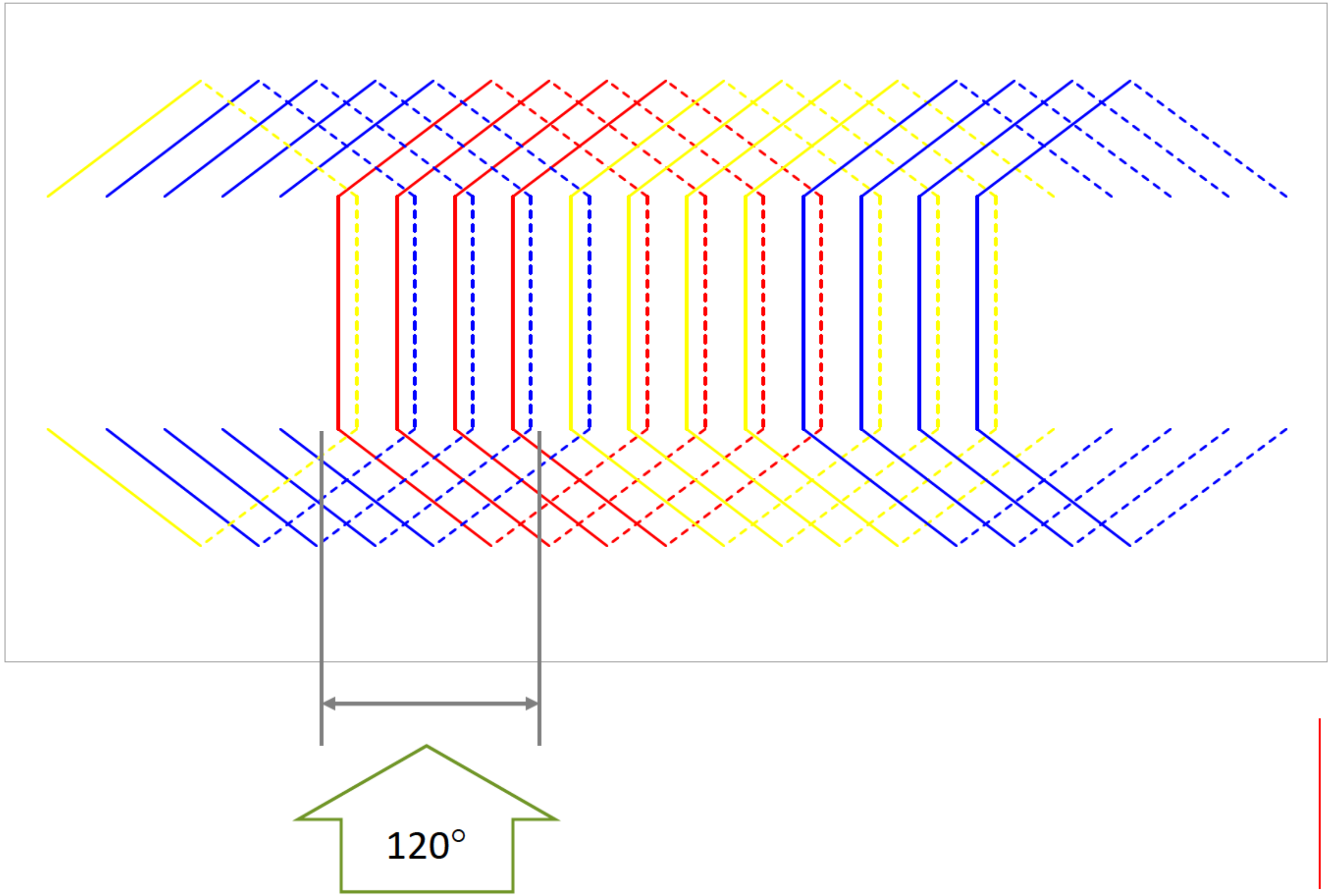


- Distortion of flux occur due to variation of reluctance between the slot area and tooth area
- Distortion of flux produce distortion in voltage waveform which is known as slot harmonics
- Slot harmonics is reduced either by skewing of field poles or by incorporating fractional slot winding

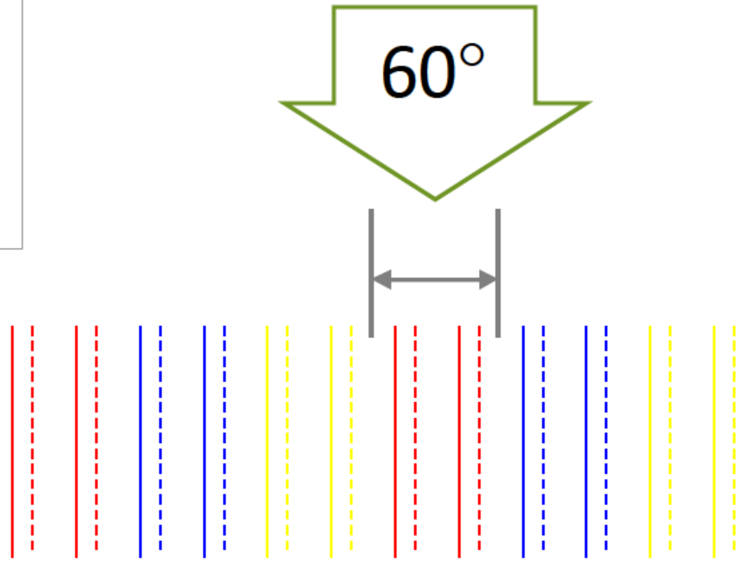
Methods for Elimination of Harmonics

- 120 Degrees phase spread
  - Eliminates 3rd order harmonics
- Short Chording
  - Eliminates 5th and 7th order harmonics
- Fractional slot winding
  - Eliminates slot harmonics
- Skewing of field poles or armature slots
  - Eliminates slot harmonics
- Star connection
  - Eliminates triplen (order 3, 9, 15 etc) harmonics

120 Degree Phase Spread Winding

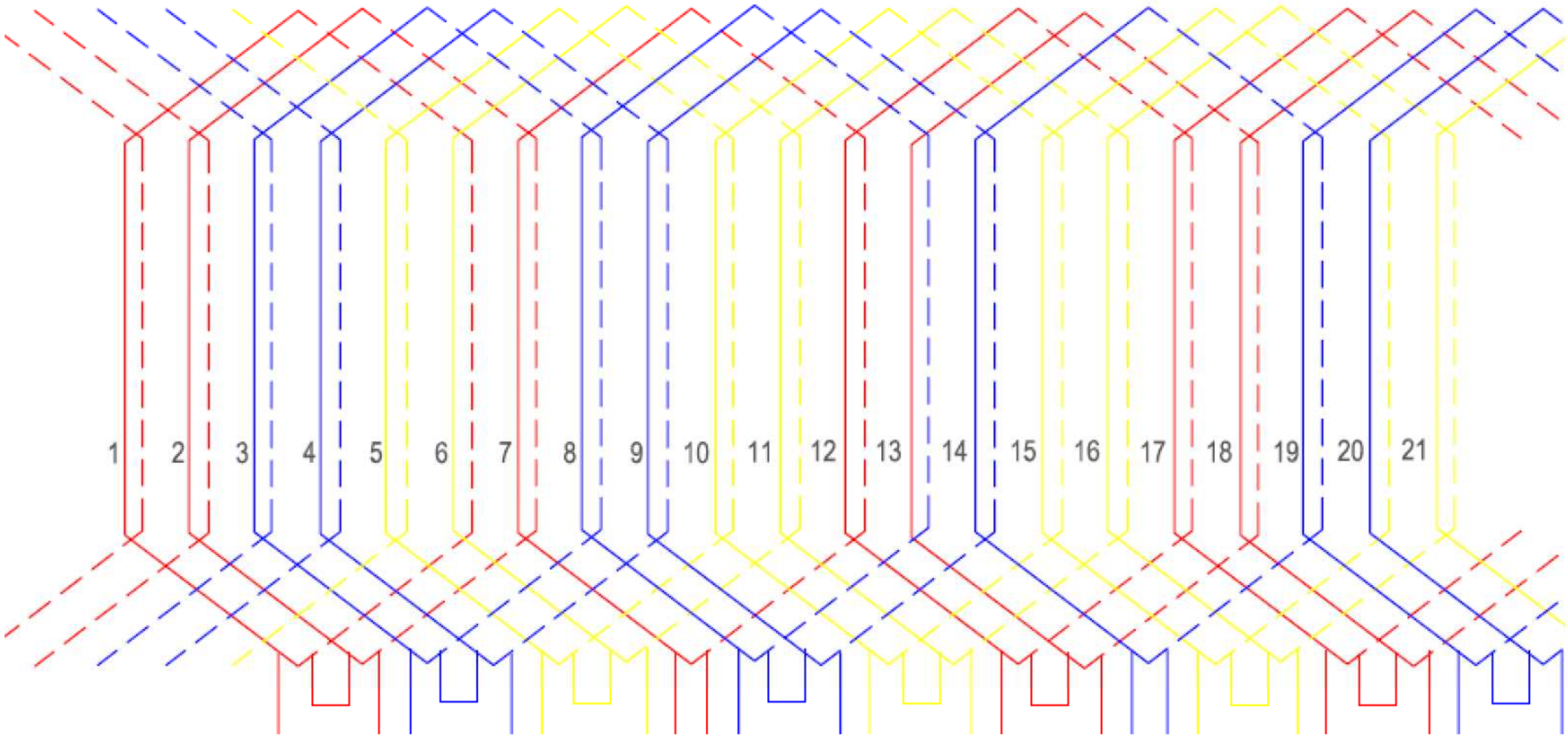


120 degree phase spread results in reduction of third harmonics voltages



Fractional Slot Winding

- Slots per pole per phase is not an integer
- Reduces slot harmonics



4 pole
3 phase
21 slot
double layer
winding

Example 1.3

Calculate the rms value of induced voltage per phase of a 3 phase, 10 pole, 50 Hz, alternator with 2 slots per pole per phase and 4 conductor per slot in 2 layers. The coil span is 150 degrees. Flux per pole has a fundamental component of 0.12 Wb and a 20 % third harmonic component. Also find the line voltage.

$$\text{Slots/pole/phase, } m = 2 \qquad \text{Slots/pole} = 2 \times 3 = 6$$

$$\text{Slot angle, } \beta = \frac{180}{\text{Slots/pole}} = \frac{180}{6} = 30°$$

$$\text{Short chording angle, } \alpha = (180 - 150) = 30°$$

$$\text{Number of turns, } T = \frac{10 \times 2 \times 4}{2} = 40$$

$$K_c = \cos\frac{\alpha}{2} = \cos\frac{30}{2} = 0.966$$

$$K_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}} = \frac{\sin\frac{2\times 30}{2}}{2\times\sin\frac{30}{2}} = 0.966$$

$$\text{Per phase fundamental voltage} = 4.44\, K_c\, K_d\, \Phi\, f\, T$$

$$= 4.44\times 0.966\times 0.966\times 0.12\times 50\times 40 = 995 \text{ volts}$$

$$K_{c3} = \cos\frac{3\alpha}{2} = \cos\frac{3\times 30}{2} = 0.707$$

$$K_{d3} = \frac{\sin\frac{mn\beta}{2}}{m\sin\frac{n\beta}{2}} = \frac{\sin\frac{2\times 3\times 30}{2}}{2\times\sin\frac{3\times 30}{2}} = 0.707$$

$f_3 = 150 \text{ Hz}$ $\qquad \Phi_3 = \dfrac{0.2 \times 0.12}{3} = 0.008 \text{ Wb}$

$$\text{Per phase third harmonic voltage} = 4.44\, K_{c3}\, K_{d3}\, \Phi_3\, f_3\, T$$
$$= 4.44 \times 0.707 \times 0.707 \times 0.008 \times 150 \times 40 = 106 \text{ volts}$$

$$\text{Per phase voltage} = \sqrt{E_1{}^2 + E_3{}^2}$$
$$= \sqrt{995^2 + 106^2} = 1000 \text{ volts}$$

$$\text{Line voltage} = \sqrt{3} \times 995 = 1723.4 \text{ volts}$$