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(/ / , / / , / /)

(THD)

:

[]

dc

[]

[]

SHE-PWM SHE

dc

dv/dt

SHE PWM

H

[]

s s-1

PWM

dc

SHE-

[]

PWM

s-1

SHE

SHE

PWM

SHE-PWM

[]

)

(Maple Mathematica

SHE

SHE-PWM

SHE-PWM

[]

[]

SHE-PWM

[]

s-1

PWM

[]

$$\theta_3, \dots, \theta_2, \theta_1$$

()

dc

H

$$V_1 \quad M = V_1 / sV_{dc}$$

()

$$+V_{dc} \quad 0 \quad -V_{dc}$$

$Q_4 \quad Q_1$

$Q_4 \quad Q_3 \quad Q_2 \quad Q_1$

$Q_3 \quad Q_2$

$+V_{dc}$

Q_1

$-V_{dc}$

$Q_4 \quad Q_2 \quad Q_3$

SHE-PWM

PWM

$m=2s+1$

m

SHE

dc

s

k

PWM

(k=3)

()

k

$ks-1$

s

dc

()

-

()

$$V(\omega t) = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{dc}}{n\pi} (\cos(n\theta_1) \pm \cos(n\theta_2) \pm \cos(n\theta_3) \pm \dots \pm \cos(n\theta_{ks})) \sin(n\omega t)$$

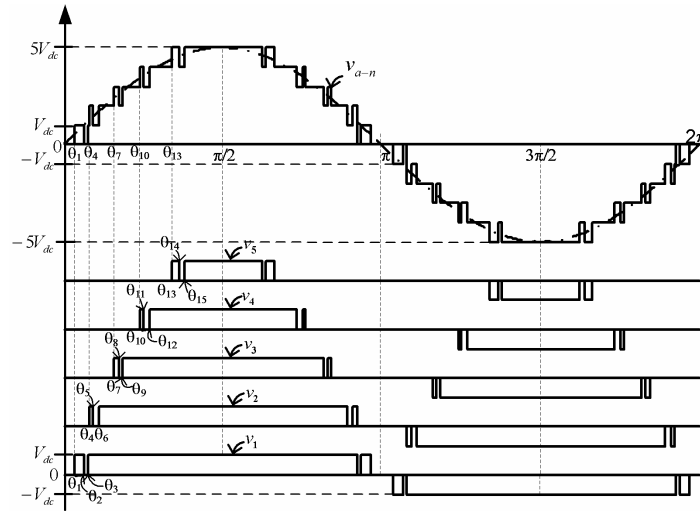
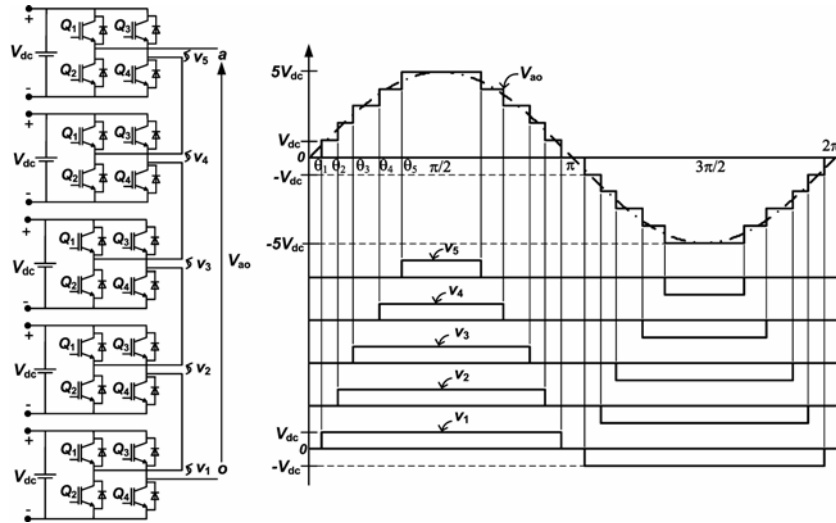
: $\theta_{ks} \quad \theta_1$

$$0 < \theta_1 < \theta_2 < \dots < \theta_{ks} < \pi / 2$$

()

$$V_{dc} \quad dc \quad s \quad s-1$$

$$V(\omega t) = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{dc}}{n\pi} (k_1 \cos(n\theta_1) + k_2 \cos(n\theta_2) + k_3 \cos(n\theta_3) + \dots + k_s \cos(n\theta_s)) \sin(n\omega t)$$



.SHE-PWM :

$3ks-2$

ks

k

$3ks-1$

$$\begin{cases} \cos(\theta_1) \pm \cos(\theta_2) \pm \dots \pm \cos(\theta_{ks-1}) \pm \cos(\theta_{ks}) = (s\pi/4)M \\ \cos(5\theta_1) \pm \cos(5\theta_2) \pm \dots \pm \cos(5\theta_{ks-1}) \pm \cos(5\theta_{ks}) = 0 \\ \cos(7\theta_1) \pm \cos(7\theta_2) \pm \dots \pm \cos(7\theta_{ks-1}) \pm \cos(7\theta_{ks}) = 0 \\ \dots \\ \cos((3ks-2)\theta_1) \pm \cos((3ks-2)\theta_2) \pm \dots \pm \cos((3ks-2)\theta_{ks}) = 0 \end{cases}$$

$\theta_{ks}, \dots, \theta_2, \theta_1$

V_f

()

[]

ks

$ks-1$

()

ks

$$\bar{y}_i(t+1) = \begin{cases} \bar{y}_i(t) & \text{if } f(\bar{y}_i(t)) \leq f(\bar{x}_i(t+1)) \\ \bar{x}_i(t+1) & \text{if } f(\bar{y}_i(t)) > f(\bar{x}_i(t+1)) \end{cases} \quad () \quad m$$

$$\hat{y}(t) \in \{\bar{y}_1(t), \bar{y}_2(t), \dots, \bar{y}_m(t) \mid f(\hat{y}(t)) = \min\{f(\bar{y}_1(t)), f(\bar{y}_2(t)), \dots, f(\bar{y}_m(t))\}\} \quad ()$$

$$\bar{v}_i \quad ()$$

$$[-V_{\max}, +V_{\max}]$$

$$V_{\max} = \lambda(x_{\min} - x_{\max}) \quad ()$$

$$\lambda$$

ω

ω

n

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \cdot iter \quad ()$$

$$\bar{v}_i \quad ()$$

$$\omega > 0$$

$$\bar{x}_i$$

$$c_2 \quad c_1$$

$$c_1 > 0$$

\bar{y}_i

\bar{y}

$$c_2 > 0$$

$c_2 \quad c_1$

i

$$\theta_{ks}, \dots, \theta_2, \theta_1$$

$r_2 \quad r_1$

()

()

$3ks-1$

ks

$3ks-2$

ks

()

()

$$\bar{v}_i(t+1) = \omega \cdot \bar{v}_i(t) + c_1 \cdot r_1 \cdot (\bar{y}_i - \bar{x}_i) + c_2 \cdot r_2 \cdot (\hat{y} - \bar{x}_i) \quad ()$$

$k=1$

$$\bar{x}_i(t+1) = \bar{x}_i(t) + \bar{v}_i(t+1) \quad ()$$

$f \quad i$

\bar{y}_i

\hat{y}

()

k	$k=1$
f	$f(\theta_1, \theta_2, \dots, \theta_{ks}) = 100 \times [M - \frac{ V_l }{sV_{dc}} +$
$\bar{y}_i(0) = \bar{x}_i(0)$	$(\frac{ V_5 + V_7 + \dots + V_{3ks-2 \text{ or } 3ks-1} }{sV_{dc}})]$
$[-V_{\max}, +V_{\max}]$	$f(\theta_1, \theta_2, \dots, \theta_{ks}) = 100 \times [M - \frac{ V_l }{sV_{dc}} +$
$\tilde{y}(0)$	$(\frac{ V_5 + V_7 + V_{11} + \dots + V_{49} }{sV_{dc}})]$
$\bar{y}_i(0)$	$\tilde{y}(0)$
$\tilde{y}(0) \in \{\bar{y}_1(0), \bar{y}_2(0), \dots, \bar{y}_m(0)\} f(\tilde{y}(t)) =$	$\min\{f(\bar{y}_1(0)), f(\bar{y}_2(0)), \dots, f(\bar{y}_m(0))\}$
$t = t+1 :$	$()$
$()$	$()$
$()$	$()$
$()$	$()$
$()$	$()$
f	$f(\theta_1, \theta_2, \dots, \theta_{ks})$
$()$	$0 < \theta_1 < \theta_2 < \dots < \theta_{ks} < \pi / 2$
$()$	dc
$()$	s
$()$	k
$()$	n
$()$	i
$()$	$\bar{v}_i(0)$
$()$	$\bar{x}_i(0)$
$()$	k
$()$	$\bar{x}_i(0)$
$()$	$[x_{kmin}, x_{kmax}]$
$()$	$[0, \pi / 2]$

()

$$k=3$$

$$f(\theta_1, \theta_2, \dots, \theta_{15}) =$$

$$100 \times \left[\left| M - \frac{|V_1|}{5V_{dc}} \right| + \left(\frac{|V_5| + |V_7| + |V_{11}| + \dots + |V_{49}|}{5V_{dc}} \right) \right]$$

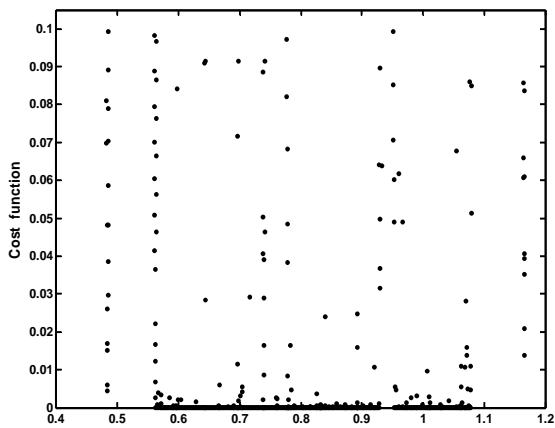
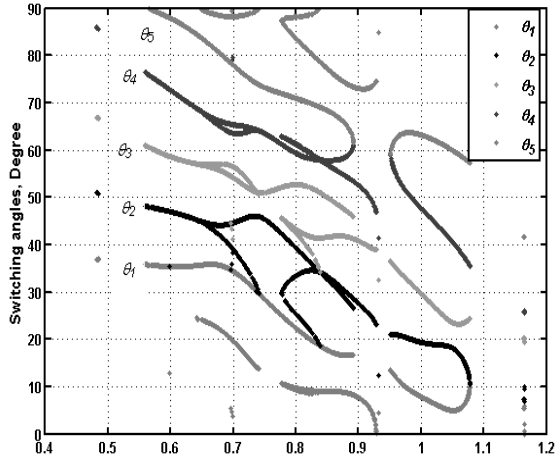
()

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$$f(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5) =$$

$$100 \times \left[\left| M - \frac{|V_1|}{5V_{dc}} \right| + \left(\frac{|V_5| + |V_7| + |V_{11}| + |V_{13}|}{5V_{dc}} \right) \right]$$

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($\theta_5, \dots, \theta_2, \theta_1$) :

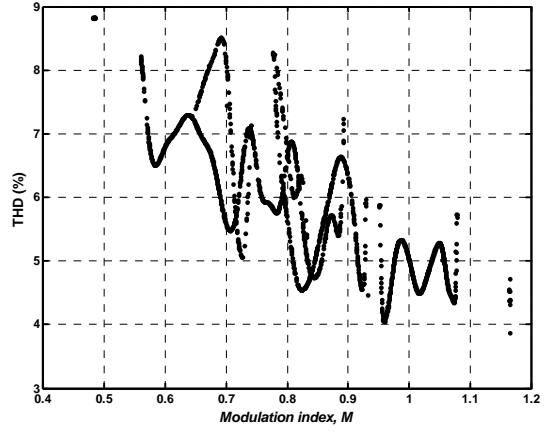
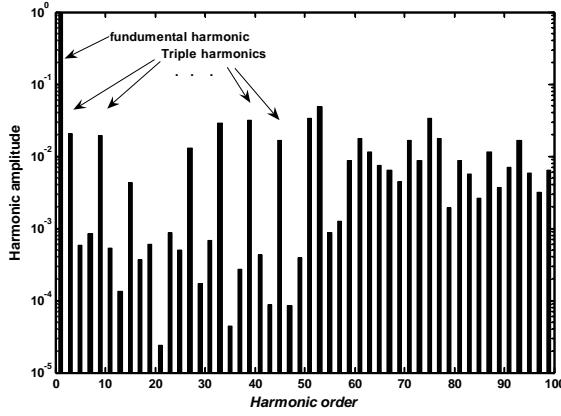
THD

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()

$k=3$

()



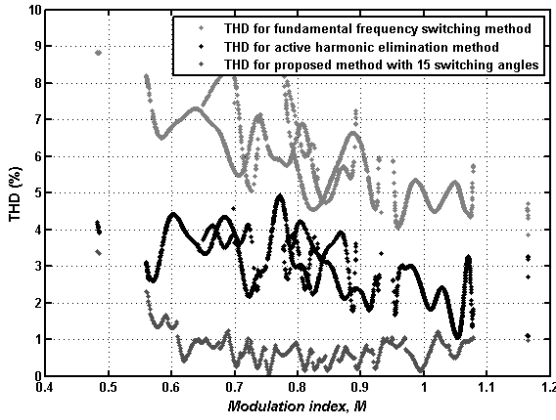
($\theta_5, \dots, \theta_2, \theta_1$) :

THD (

$\theta_1, \theta_2, \dots, \theta_{15}$

() $k=3$ SHE-PWM

$M=1$



THD :

$k=3$

$M=1$

- $\theta_1 = 6.19^\circ, \theta_2 = 11.56^\circ, \theta_3 = 13.89^\circ, \theta_4 = 14.06^\circ$
- $\theta_5 = 16.48^\circ, \theta_6 = 19.77^\circ, \theta_7 = 28.40^\circ, \theta_8 = 31.07^\circ$
- $\theta_9 = 33.03^\circ, \theta_{10} = 43.01^\circ, \theta_{11} = 44.97^\circ, \theta_{12} = 48.49^\circ$
- $\theta_{13} = 61.10^\circ, \theta_{14} = 65.49^\circ, \theta_{15} = 68.08^\circ$

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()

THD

/ %

[]

/ % THD

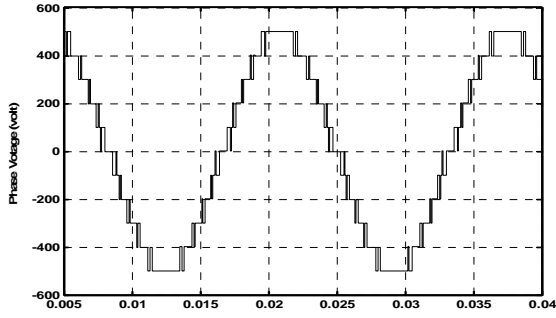
$M=1$

$$THD = \sqrt{\sum_{n=5,7,11,\dots}^{49} V_n^2} / V_1 \quad ()$$

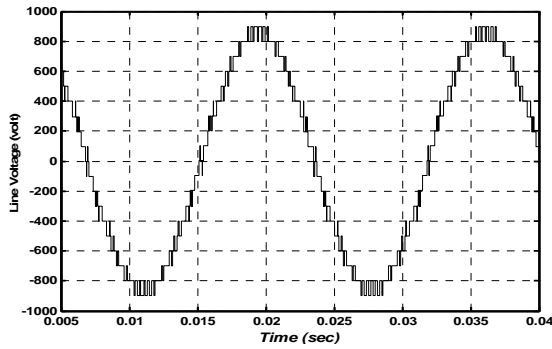
()

() () Y
()

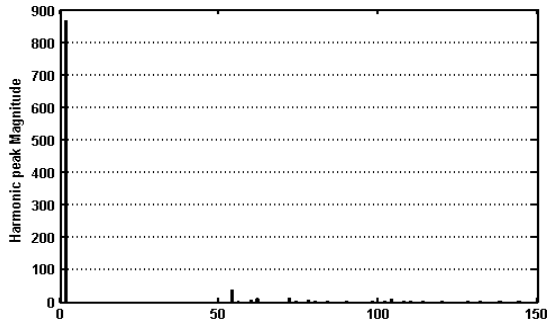
$\theta_1 = 0.57^\circ, \theta_2 = 2.81^\circ, \theta_3 = 6.82^\circ, \theta_4 = 8.53^\circ$
 $\theta_5 = 11.14^\circ, \theta_6 = 12.23^\circ, \theta_7 = 15.51^\circ, \theta_8 = 18.31^\circ$
 $\theta_9 = 21.03^\circ, \theta_{10} = 21.90^\circ, \theta_{11} = 27.01^\circ, \theta_{12} = 28.62^\circ$
 $\theta_{13} = 31.23^\circ, \theta_{14} = 35.47^\circ, \theta_{15} = 36.37^\circ, \theta_{16} = 38.76^\circ$
 $\theta_{17} = 39.57^\circ, \theta_{18} = 43.44^\circ, \theta_{19} = 49.69^\circ, \theta_{20} = 52.18^\circ$
 $\theta_{21} = 58.18^\circ, \theta_{22} = 60.04^\circ, \theta_{23} = 64.18^\circ, \theta_{24} = 72.70^\circ$
 $\theta_{25} = 75.23^\circ$



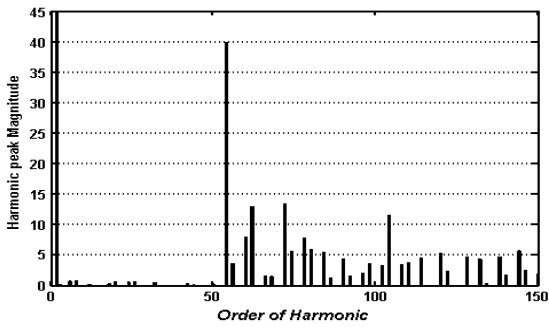
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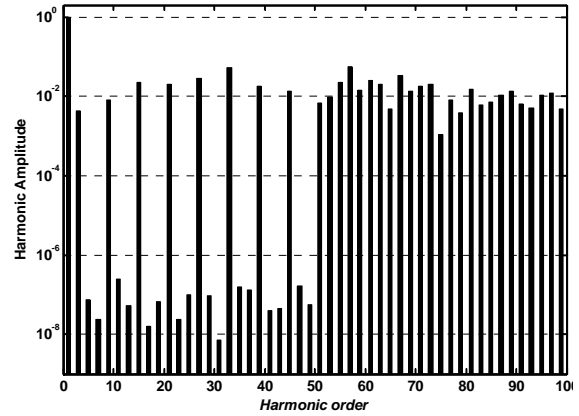
Y (

M=1, k=3

M=1

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/ e %



M=1

k=5 SHE-PWM

MATLAB/SIMULINK

MATLAB/SIMULINK

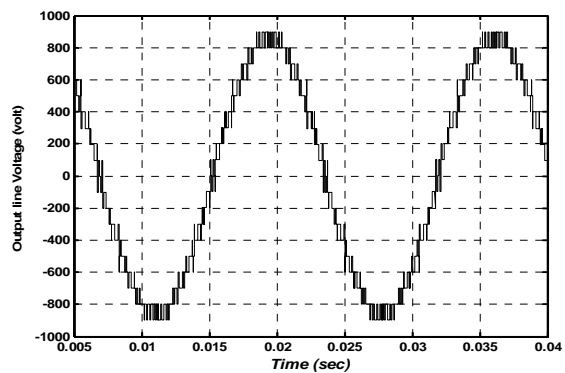
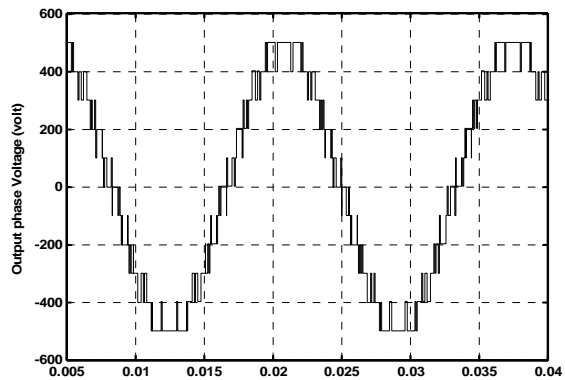
dc ()

k=3 M=1

() ()

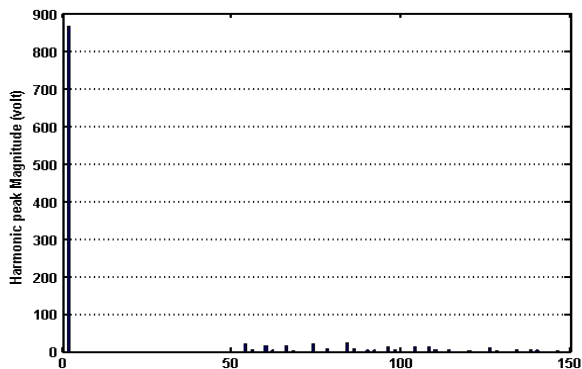
FFT

() ()
 Y () ()
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THD

THD



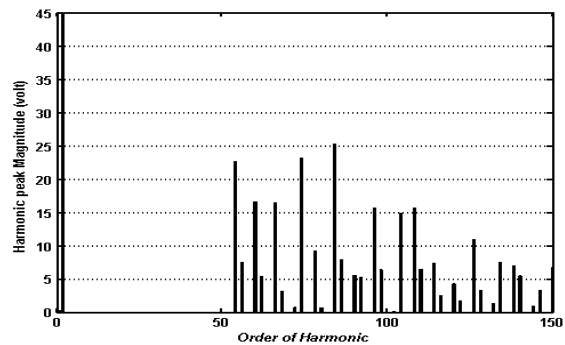
α_k

$N(\alpha_k, \sigma)$

σ k

THD

SHE-PWM



Y

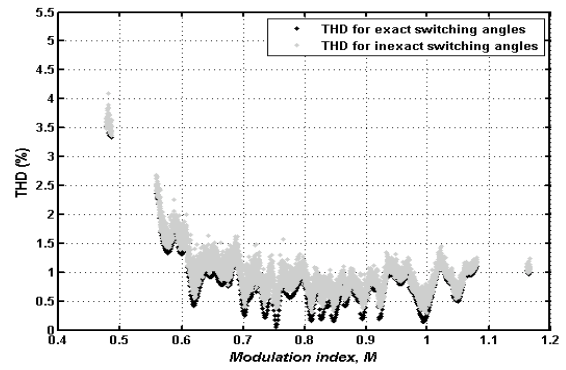
$M=1, k=5$

$k=5$ $M=1$

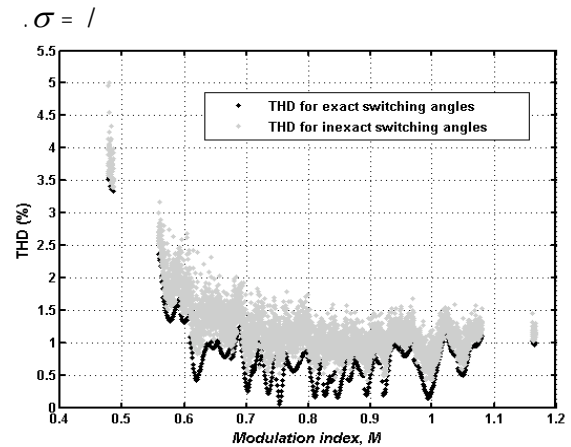
$\sigma = |$ $\sigma = |$

σ

$\sigma = /$
 () THD $N(\alpha_k, \sigma)$
 () ()
 σ
 THD () THD



THD :



THD :

$\sigma = /$

MATLAB

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- 1 - Sinusoidal PWM
 - 2 - Non-Sinusoidal PWM
 - 3 - Space Vector PWM (SVPWM)
 - 4 - Selective Harmonic Elimination (SHE)
 - 5 - Selective Harmonic Elimination PWM (SHE-PWM)
 - 6 - Resultant Theory
 - 7 - Active Harmonic Elimination
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