ESD34 Enersine Active Power Filter Application Note of VFD

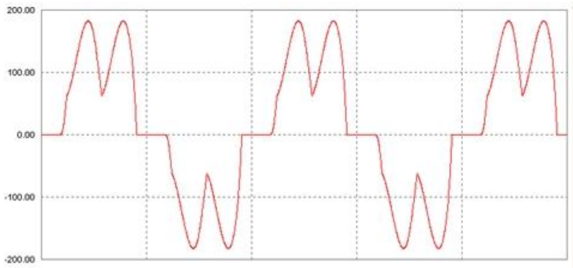
1. Introduction

This application note describes the subject of VFD/VSD harmonic current calculation and outlines the application of Enersine Active Power Filter in harmonic distortion problem mitigation.

VFD (Variable Frequency Drive) or VSD (Variable Speed Drive) that consists of Thyristors, utilizing Pule Width Modulation (PWM) with low inductance rating, generally has a very fast rate of change in term of current (di/dt) during operation. In some instances, this high di/dt may cause the system voltage to be distorted (eg. Voltage Notch/Sag) and causing other equipment on the same supply bus to experience malfunction.

Therefore, it is generally recommended to install a 3% ~ 5% AC input line choke in series to the VFD/VSD. This AC input choke can help reduce the di/dt cause by the VFD/VSD and prevent system voltage distortion as well as ensuring for optimum operation with Active Filter connected in shunt.

Without 5% input line choke



Within 5% input line choke

> Note: In most cases, install a 5% input AC choke in front of VFDs, the THDi will reduce to 40%.

2. VFD Harmonic Current Calculation

2.1 Existing VFD System

Please conduct the following measurement at the location of the APF to be install as below:

I_{in} : VFD Input current (RMS)
I_H : VFD input total harmonic current
$THD_{i(F)}$: VFD Input current harmonic total distortion(Fundamental)
$THD_{v(F)}$: VFD Input voltage harmonic total distortion(Fundamental)

The VFD harmonic current : $I_H = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^2})} \times THD_i$

If $THD_{v(F)}$ value is between 3% ~ 5%, the voltage distortion factor is "1.1".
If $THD_{v(F)}$ value is between 5% ~ 8%, the voltage distortion factor is "1.2~1.3".
If $THD_{v(F)}$ value is more than 8%, the voltage distortion factor is "1.4".
Consider the "Voltage Distortion Factor", after APF compensation and improve the power quality the than VFD total harmonic current will become:

$$I_H = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^2})} \times THD_i \times VoltageDistortionFactor$$

Example :

We measure the information from site:
I_{in} : 150 A
$THD_{i(F)}$: 38%
$THD_{v(F)}$: 4.3%

The VFD harmonic current is: $\frac{150A}{(\sqrt{(1^2 + 0.38^2})} \times 0.38 \times 1.1 = 58.6A$

2.2 VFD Harmonic Current Calculation

S_{in}	:	Capacity of VFD input
HP_{out}	:	VFD output capacity
V_{in}	:	VFD input voltage
I_{in}	:	VFD Input current
I_H	:	VFD input total harmonic current

We assume : $S_{in} = HP_{out}$

The VFD input current : $I_{in} = \dfrac{S_{in}}{\sqrt{3} \times V_{in}}$

The VFD harmonic current : $I_H = \dfrac{I_{in}}{(\sqrt{(1^2 + THD_i^2)}} \times THD_i$

Example:

The VFD specification as below list:

V_{in}	:	380 V
HP_{out}	:	100 kW
$THD_{i(F)}$	:	40%

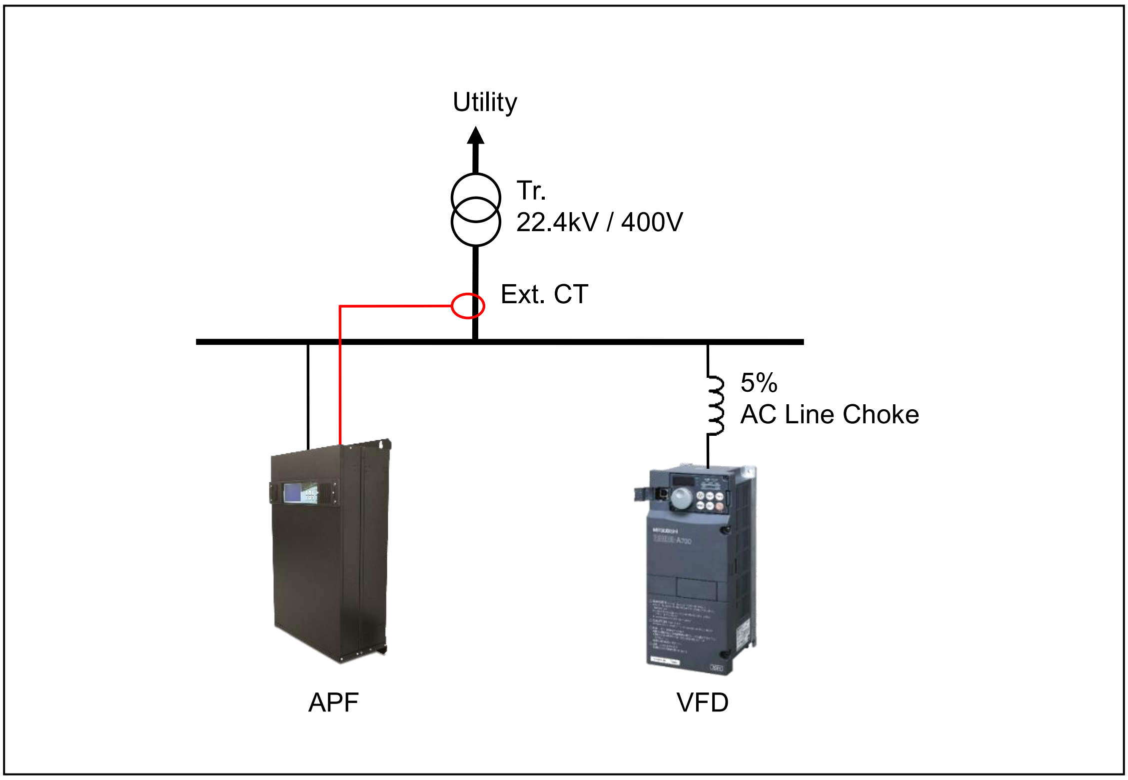
Assume $S_{in} = HP_{out}$. So, the VFD capacity is 100kVA

The VFD input current is: $\dfrac{100kVA}{(\sqrt{(3)} \times 380} = 151.9A$

The VFD harmonic current is: $\dfrac{151.9A}{(\sqrt{(1^2 + 0.4^2)}} \times 0.4 = 56.4A$

3. ESD34 Enersine APF Capacity selection

3.1 Case1_APF apply to standalone VFD



In this system, there is a 100kVA 400V 6 pulse VFD:

Voltage rated	400V
VFD input current @ full load	160A
VFD input THDi @ full load	40%
VFD input PF @ full load	0.81 lagging

And the improve target PF is 0.95 and THDi <5%

Formula & Calculation:

Calculate the harmonic current from VFD:

$$I_H = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^{\,2})}} \times THD_i = \frac{160A}{(\sqrt{(1^2 + 0.4^2)}} \times 0.4 = 56.4A$$

Calculate the reactive current:

$$DPF_1 = PF_1 \times \sqrt{1 + THD_i^{\,2}} = 0.81 \times \sqrt{1 + 0.4^2} = 0.872$$

$$I_Q = I_{RMS} \times PF_1 \times \left[\tan(\cos^{-1} DPF_1) - \tan(\cos^{-1} DPF_2)\right]$$

$$I_Q = 160\,A \times 0.81 \times \left|\tan(\cos^{-1} 0.872) - \tan(\cos^{-1} 0.95)\right| = 30.2A$$

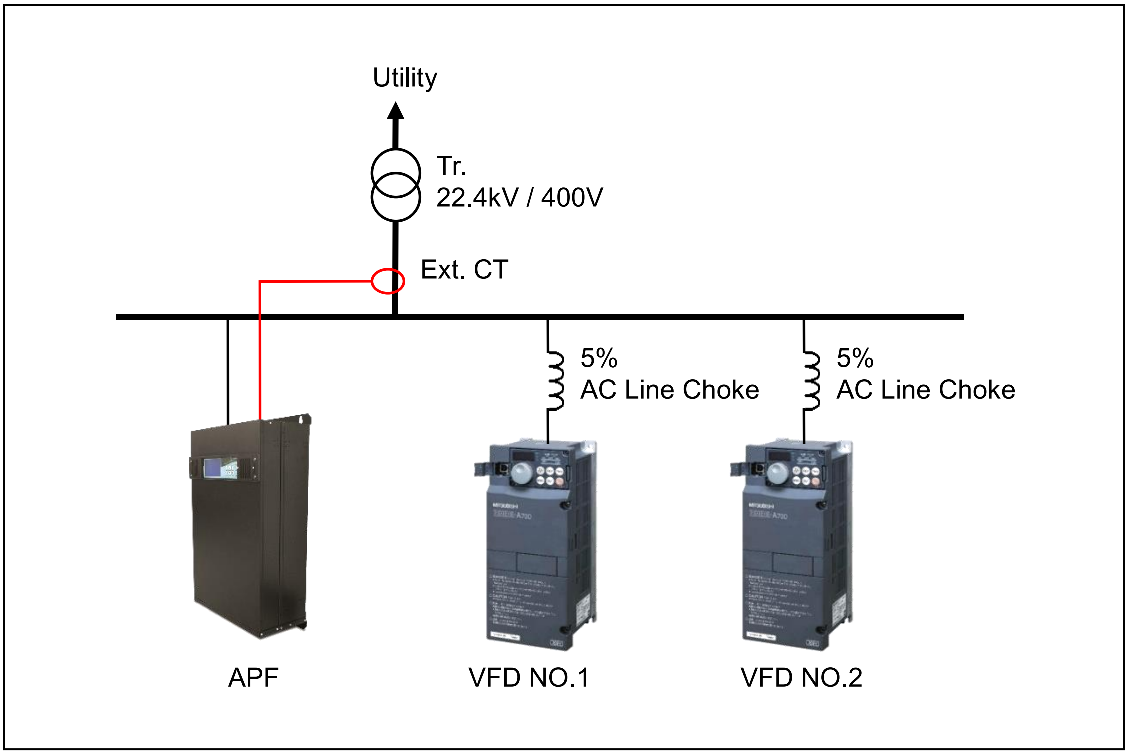
Calculate the capacity of Enersine ESD34 APF:

$$I_{APF} = \sqrt{I_H^{\,2} + I_Q^{\,2}} = \sqrt{56.4^2 + 30.2^2} = 64A$$

The current rating has to be greater than 64A. Therefore it is recommended to select 90A Enersine ESD34 APF (Control Module x 1 + Power Module x 3)

Note: **PF1 : Power Factor before Improvement**
DPF1 : Displacement Power Factor before Improvement
DPF2 : Displacement Power Factor after Improvement

3.2 Case2_APF apply to VFDs Group



There are two VFDs in this system - one is 100kVA 400V 6 pulse VFD and the other is 50kVA 400V 6 pulse VFD:

VFD NO.1	
Voltage rated	400V
VFD input current @ full load	160A
VFD input THDi @ full load	40%
VFD input PF @ full load	0.81 lagging

VFD NO.2	
Voltage rated	400V
VFD input current @ full load	70A
VFD input THDi @ full load	45%
VFD input PF @ full load	0.76 lagging

And the improve target PF is 0.95 and THDi <5%

Formula & Calculation:

Calculate the harmonic current from VFD NO.1 & VFD NO.2:

$$I_{H(VFD\_1)} = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^2)})} \times THD_i = \frac{160A}{(\sqrt{(1^2 + 0.4^2)})} \times 0.4 = 56.4A$$

$$I_{H(VFD\_2)} = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^2)})} \times THD_i = \frac{70A}{(\sqrt{(1^2 + 0.45^2)})} \times 0.4 = 28.7A$$

$$I_{H(Total)} = I_{H(VFD\_1)} + I_{H(VFD\_2)} = 56.4A + 28.7A = 85.1A$$

Calculate the reactive current from VFD NO.1:

$$DPF_{1(VFD\_1)} = PF_{1(VFD\_1)} \times \sqrt{1 + THD_{i(VFD\_1)}{}^2} = 0.81 \times \sqrt{1 + 0.4^2} = 0.872$$

$$I_{Q(VFD\_1)} = I_{RMS(VFD\_1)} \times PF_{1(VFD\_1)} \times \left[\tan(\cos^{-1} DPF_{1(VFD\_1)}) - \tan(\cos^{-1} DPF_{2(VFD\_1)})\right]$$

$$I_{Q(VFD\_1)} = 160A \times 0.81 \times \left[\tan(\cos^{-1} 0.872) - \tan(\cos^{-1} 0.95)\right] = 30.2A$$

Calculate the reactive current from VFD NO.2:

$$DPF_{1(VFD\_2)} = PF_{1(VFD\_2)} \times \sqrt{1 + THD_{i(VFD\_2)}{}^2} = 0.81 \times \sqrt{1 + 0.45^2} = 0.833$$

$$I_{Q(VFD\_2)} = I_{RMS(VFD\_2)} \times PF_{1(VFD\_2)} \times \left[\tan(\cos^{-1} DPF_{1(VFD\_2)}) - \tan(\cos^{-1} DPF_{2(VFD\_2)})\right]$$

$$I_{Q(VFD\_2)} = 70A \times 0.81 \times \left[\tan(\cos^{-1} 0.833) - \tan(\cos^{-1} 0.95)\right] = 19A$$

$$I_{Q(Total)} = I_{Q(VFD\_1)} + I_{Q(VFD\_2)} = 30.2A + 19A = 49.2A$$

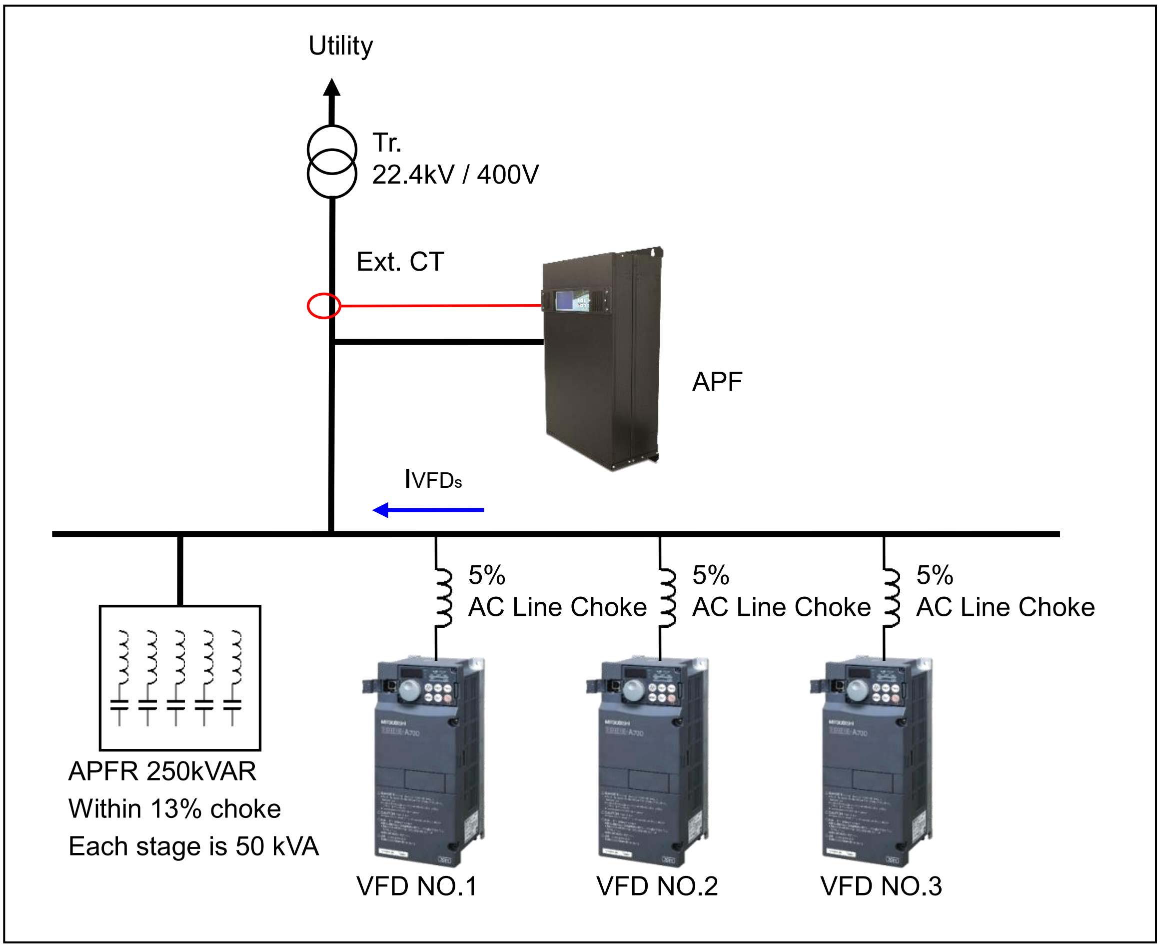
Calculate the capacity of Enersine ESD34 APF:

$$I_{APF} = \sqrt{I_{H(Total)}{}^2 + I_{Q(Total)}{}^2} = \sqrt{85.1^2 + 49.2^2} = 98.3A$$

The current rating has to be greater than 98.3A. Therefore it is recommended to select 120A Enersine ESD34 APF (Control Module x 1 + Power Module x 4)

Note: **PF1 : Power Factor before Improvement**
DPF1 : Displacement Power Factor before Improvement
DPF2 : Displacement Power Factor after Improvement

3.2 Case3_ APF apply to VFDs Group within 250kVAR APFR



There are three VFDs in this system, one is 200kVA 400V 6 pulse VFD, and the others are 100kVA 400V 6 pulse VFD:

VFD NO.1 (200kVA)	
Voltage rated	400V
VFD input current @ full load	330A
VFD input THDi @ full load	35%
VFD input PF @ full load	0.85 lagging

VFD NO.2 & No.3 (100kVA)	
Voltage rated	400V
VFD input current @ full load	160A
VFD input THDi @ full load	40%
VFD input PF @ full load	0.81 lagging

And the improve target PF is 0.98 and THDi <5%

Formula & Calculation:

Calculate the harmonic current from VFD NO.1, VFD NO.2 & NO.3:

$$I_{H(VFD\_1)} = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^2)})} \times THD_i = \frac{330A}{(\sqrt{(1^2 + 0.35^2)})} \times 0.35 = 109A$$

$$I_{H(VFD\_2)} = \frac{I_{in}}{(\sqrt{(1^2 + THD_i^2)})} \times THD_i = \frac{160A}{(\sqrt{(1^2 + 0.4^2)})} \times 0.4 = 56.4A$$

$$I_{H(Total)} = I_{H(VFD\_1)} + I_{H(VFD\_2)} + I_{H(VFD\_3)} = 109A + 56.4A + 56.4A = 221.8A$$

Calculate the reactive current from VFD NO.1:

$$DPF_{1(VFD\_1)} = PF_{1(VFD\_1)} \times \sqrt{1 + THD_{i(VFD\_1)}^{\;2}} = 0.85 \times \sqrt{1 + 0.35^2} = 0.90$$

$$I_{Q(VFD\_1)} = I_{RMS(VFD\_1)} \times PF_{1(VFD\_1)} \times \left[\tan(\cos^{-1} DPF_{1(VFD\_1)}) - \tan(\cos^{-1} DPF_{2(VFD\_1)})\right]$$

$$I_{Q(VFD\_1)} = 330\,A \times 0.85 \times \left[\tan(\cos^{-1} 0.90) - \tan(\cos^{-1} 0.98)\right] = 78.9A$$

Calculate the reactive current from VFD NO.2 & NO.3:

$$DPF_{1(VFD\_1)} = PF_{1(VFD\_1)} \times \sqrt{1 + THD_{i(VFD\_1)}^{\;2}} = 0.85 \times \sqrt{1 + 0.4^2} = 0.872$$

$$I_{Q(VFD\_1)} = I_{RMS(VFD\_1)} \times PF_{1(VFD\_1)} \times \left[\tan(\cos^{-1} DPF_{1(VFD\_1)}) - \tan(\cos^{-1} DPF_{2(VFD\_1)})\right]$$

$$I_{Q(VFD\_1)} = 160\,A \times 0.81 \times \left[\tan(\cos^{-1} 0.872) - \tan(\cos^{-1} 0.98)\right] = 72.1A$$

$$I_{Q(Total)} = I_{Q(VFD\_1)} + I_{Q(VFD\_2)} + I_{Q(VFD\_3)} = 78.9A + 72.1A + 72.1A = 223.1A$$

Calculate the reactive current APFR of each stage:

Each APFR stage is 50 kVAR, the reactive current is:

$$I_{APFR(50kVAR)} = \frac{kVAR}{\sqrt{3} \times V_{in}} = \frac{50kVAR}{\sqrt{3} \times 400} = 72.2A$$

The total current from three VFDs is “223.1A”. To correct the power factor, the APFR need provide 3 stages into the power system.

$$I_{APFR(150kVAR)} = I_{APFR(50kVAR)} \times 3 = 72.2A \times 3 = 216.6A$$

And the remaining reactive current is:

$$I_{Q(Remaining)} = I_{Q(Total)} - I_{APFR(150kVAR)} = 223.1A - 216.6A = 6.5A$$

Calculate the capacity of Enersine ESD34 APF:

$$I_{APF} = \sqrt{I_{H(Total)}^{\;2} + I_{Q(Remaining)}^{\;2}} = \sqrt{221.8^2 + 6.5^2} = 221.9A$$

The current rating has to be greater than 98.3A. Therefore it is recommended to select 240A Enersine ESD34 APF (Two 120A APF unit operating in parallel, and each APF unit including one Control Module + four Power Modules)

Note: **PF1 : Power Factor before Improvement** **DPF1 : Displacement Power Factor before Improvement** **DPF2 : Displacement Power Factor after Improvement**