Power Electronics & Best Practices

Dedicated Adjustable Speed Drive Low-Voltage MCC

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Presentation Outline

The Site Requirement

Installation of Variable Speed Drives

Active Harmonic Filters

Conclusion

Site description

- Large oil-extraction facility near Caspian Sea
- Total load 88 MW
- Several 10kV motors, largest 12 MW
- Approximately 2000 low-voltage motors
- Low-voltage process loads supplied at 690V (400V for lighting, HVAC etc.)
- 184 low-voltage variable speed drives (VFDs) ranging from 5kW to 37kW
- Process supplied by local generation (gas turbines)

Low-voltage process load design criteria

- Fully withdrawable technology required, w w w as per IEC 60439-1
- Intelligent MCC with interfacing via redundant serial link:
  - DCS motor control interface for process control
    - Start / stop
    - Speed control
  - Emergency shutdown
  - Electrical Monitoring & Control System interface for maintenance data
- Strong limitation of harmonic currents injected by non-linear loads required due to use of local generation

Solution selected by client

- Install all low-voltage VFDs in dedicated MCCs:
  - Eliminates harmonic currents in other equipment
  - Reduces amount of harmonic mitigation equipment
- These particular MCCs supply only VFD loads
- Double-ended MCCs with auto-transfer scheme to provide suitable availability
- Harmonic filtering in each VFD MCC to reduce harmonic currents to acceptable level
- Redundancy in harmonic filtering equipment to avoid shut-down due to failure of a single piece of equipment

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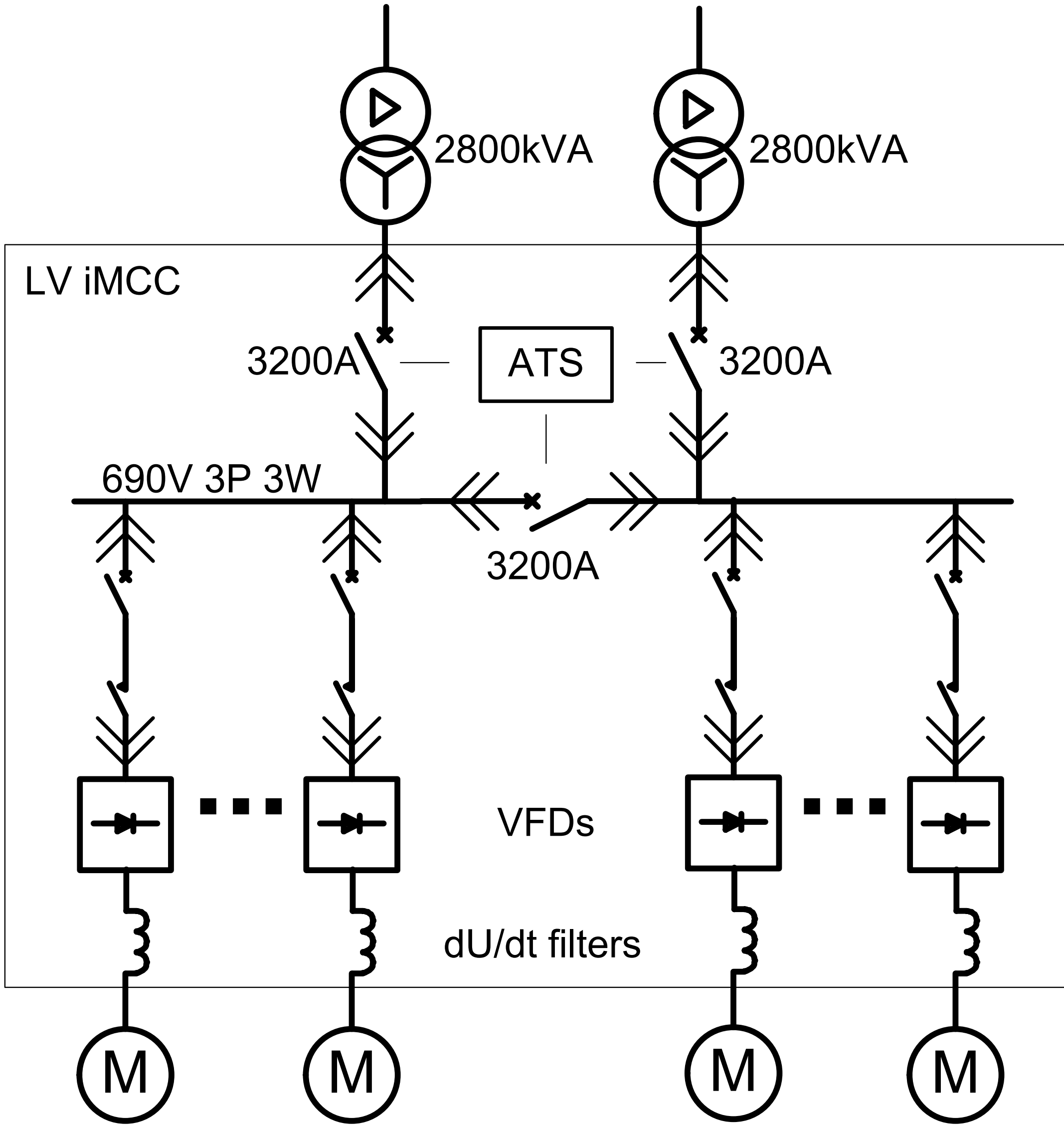
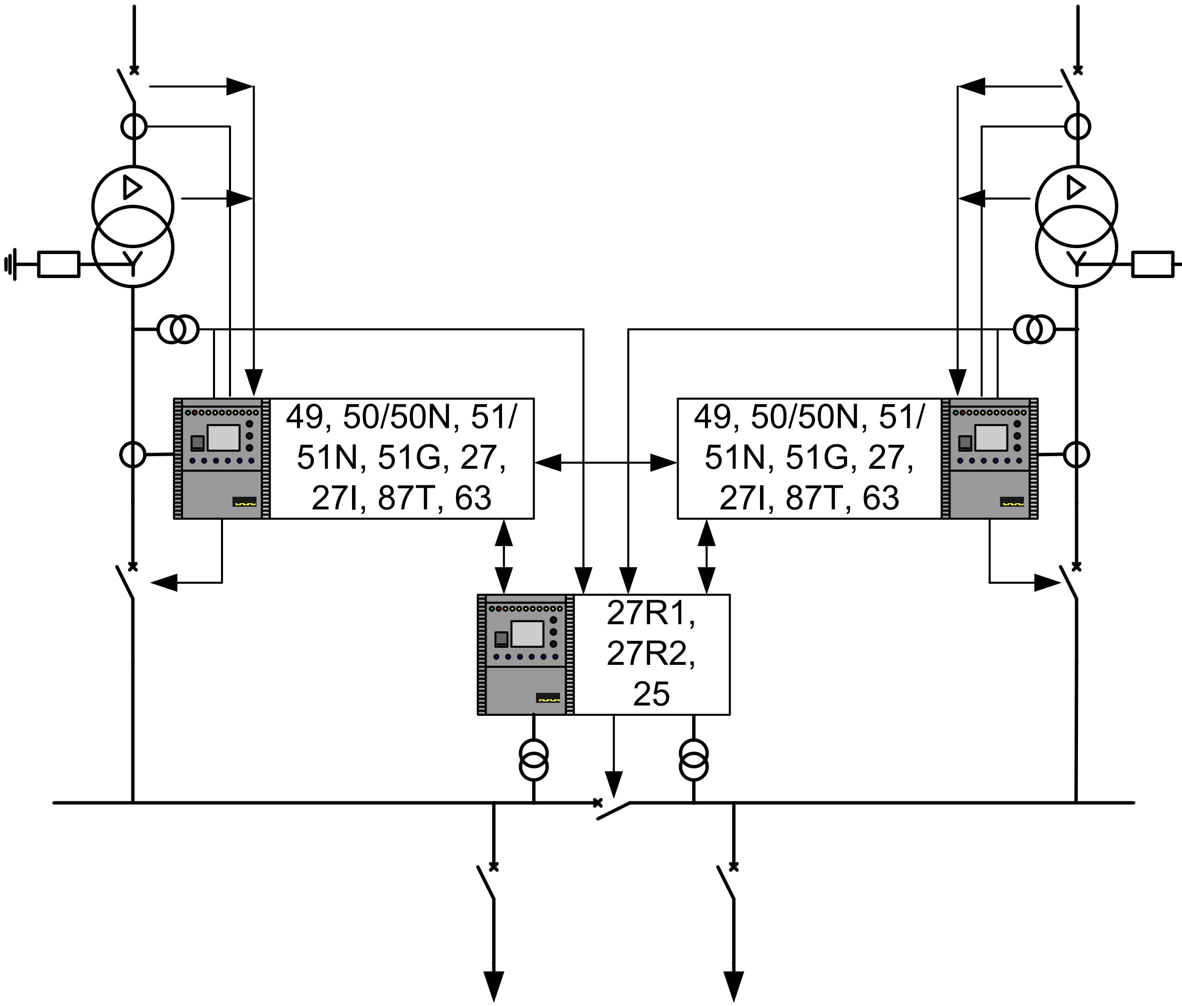
Installation of VFDs in MCC

- Withdrawable motor starters required for availability (same concept as all other MCCs)
- VFDs installed fixed-mounted in MCCs for better ventilation
- dU/dt filters
  - for each VFD
  - Characteristics based on distance to motor
- Standard incoming / bus-tie
  - ATS as all other MCCs
  - ATS logic in protection relays



ATS implemented in protection relays

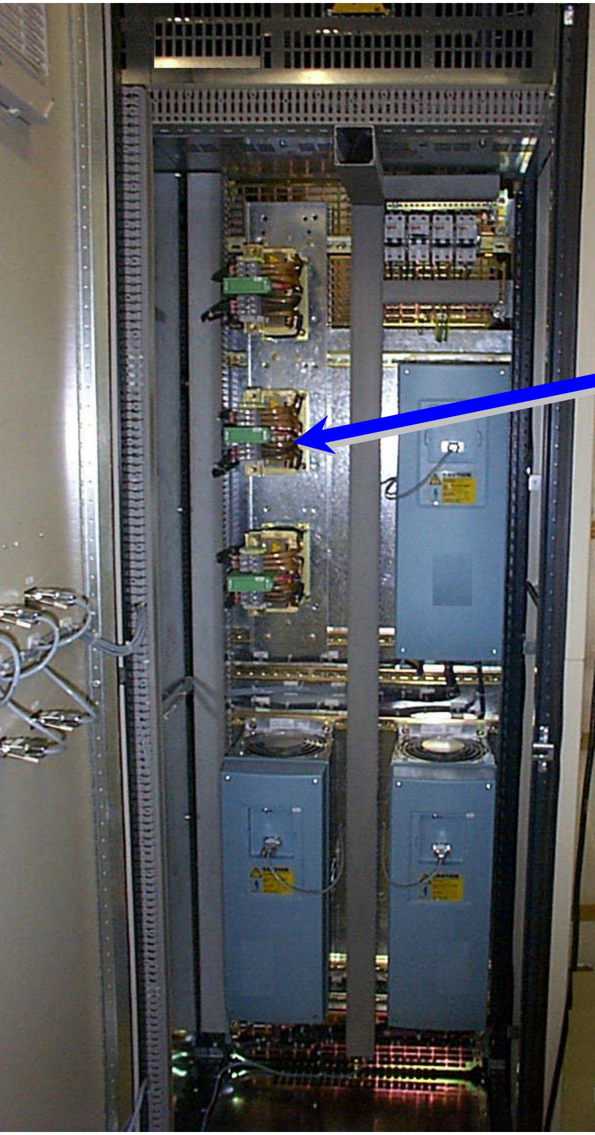
- Relays provide all protection functions
- Relays execute standard automatic transfer functions
- Relays execute no-break reconfiguration
- No additional equipment required
- Same design for high-voltage equipment
  - Easier maintenance
  - Less engineering time
  - More robust



Design of VFD cubicles

- Cabling between VFDs and withdrawable motor-starter units done as internal wiring:
  - Reduces installation time at site
  - Allows complete FAT of VFD circuits
  - Form IV as per IEC 60439-1
- Transport unit comprised of 3 standard MCC cubicles:
  - Central cubicle contains withdrawable motor-starter units
  - Left & right cubicles contain VFDs
    - Back-to-back
    - Connected to withdrawable protection units
    - Including all accessories such as dU/dt filters
  - Shipped & installed as one unit

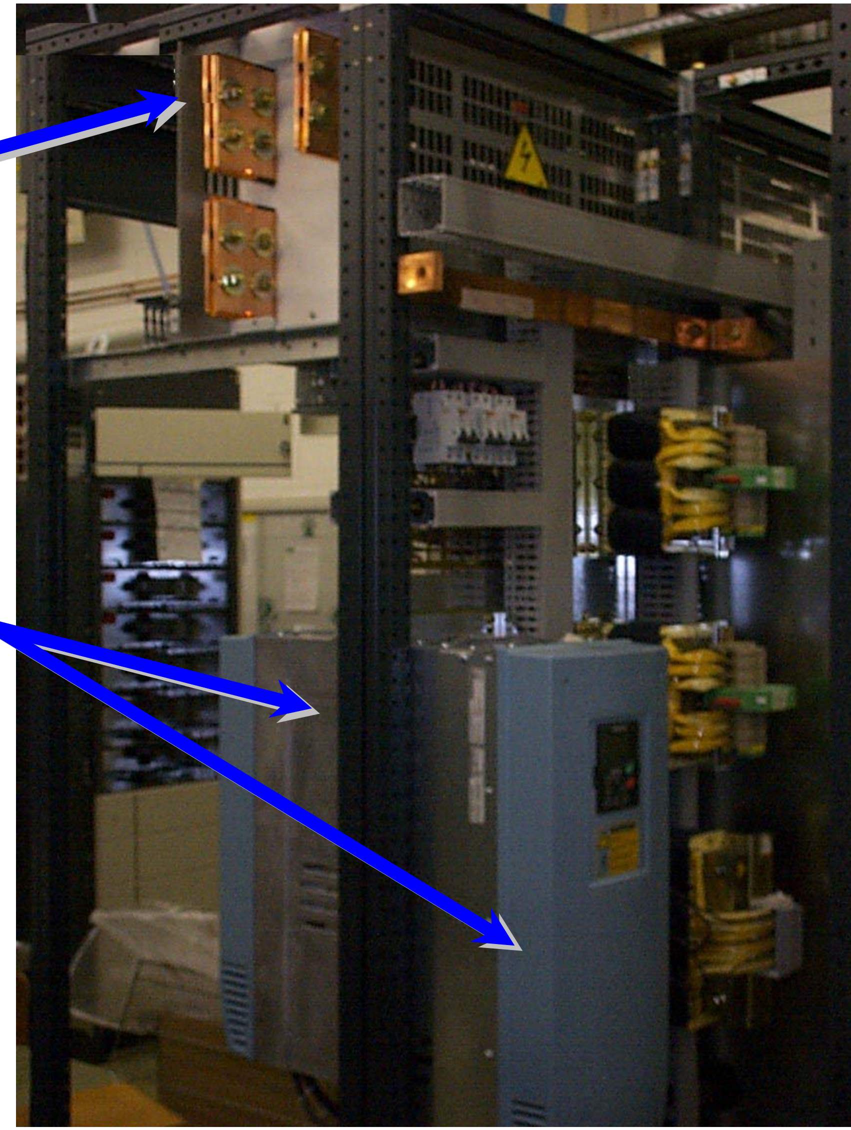
Fixed mounted VFD units, back-to-back



Common busbar,
3-phase 3-wire

VFD dU/dt
filters

Back-to-back
VFD installation



Front & rear views of transportation units

Front view at site

VFD HMI

Motor starte
drawers
(racked in)

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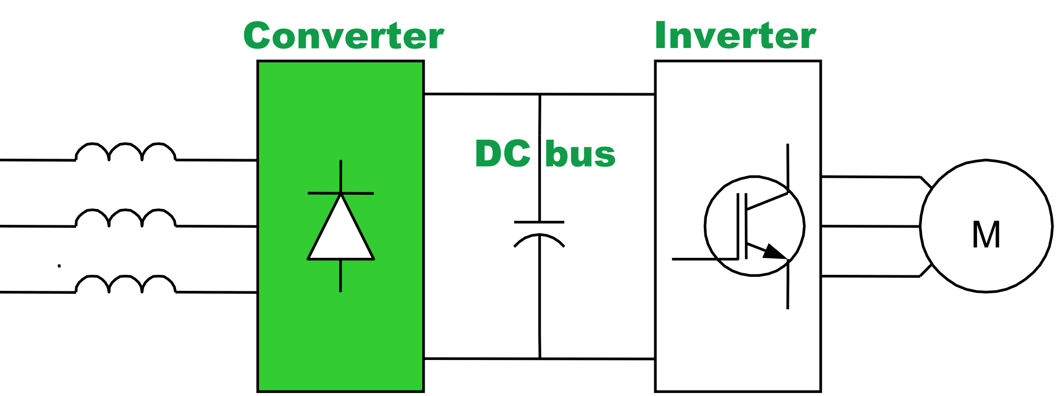
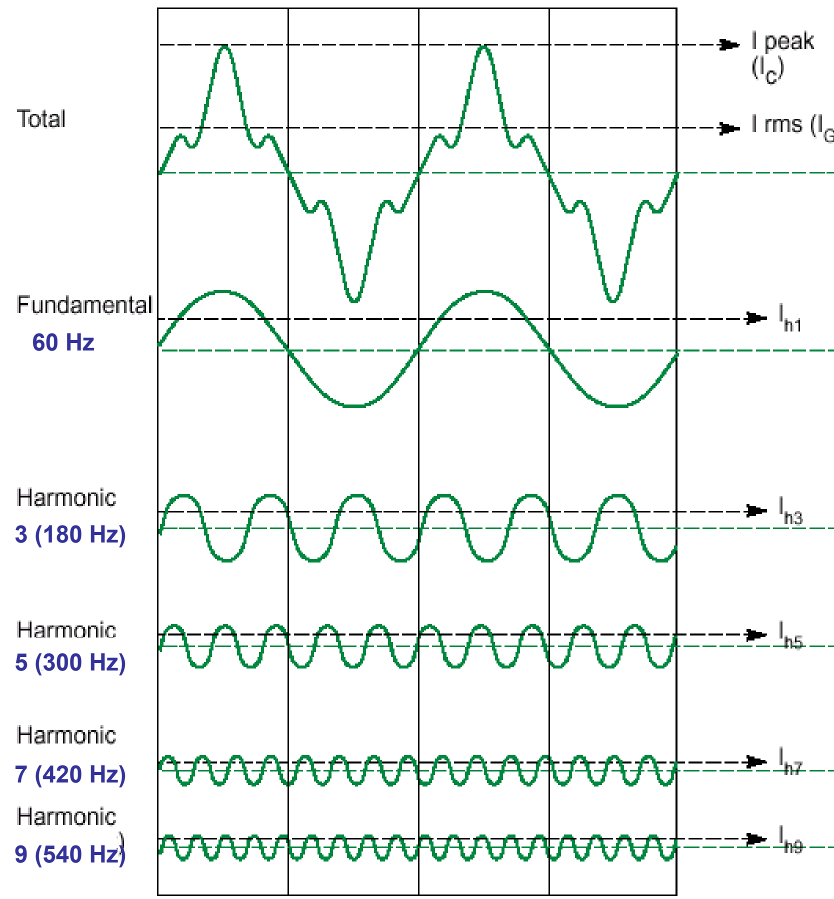
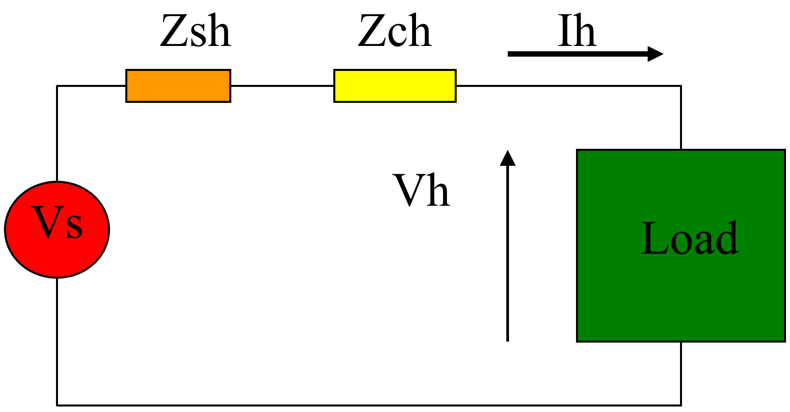
Harmonic currents from VFDs

- Power source supplies current VFDs require for proper operation
- Harmonic current (Ih) is produced by VFD since it consumes current in a non-sinusoidal manner
- The lower the harmonic order the higher the amplitude of the harmonic current





Harmonic voltages Vh



Vh = Harmonic voltage

Ih = Harmonic current

Zsh = Source impedance for harmonic current

Zch = Cable impedance for harmonic current

$$Vh = Ih * (Zsh + Zch)$$

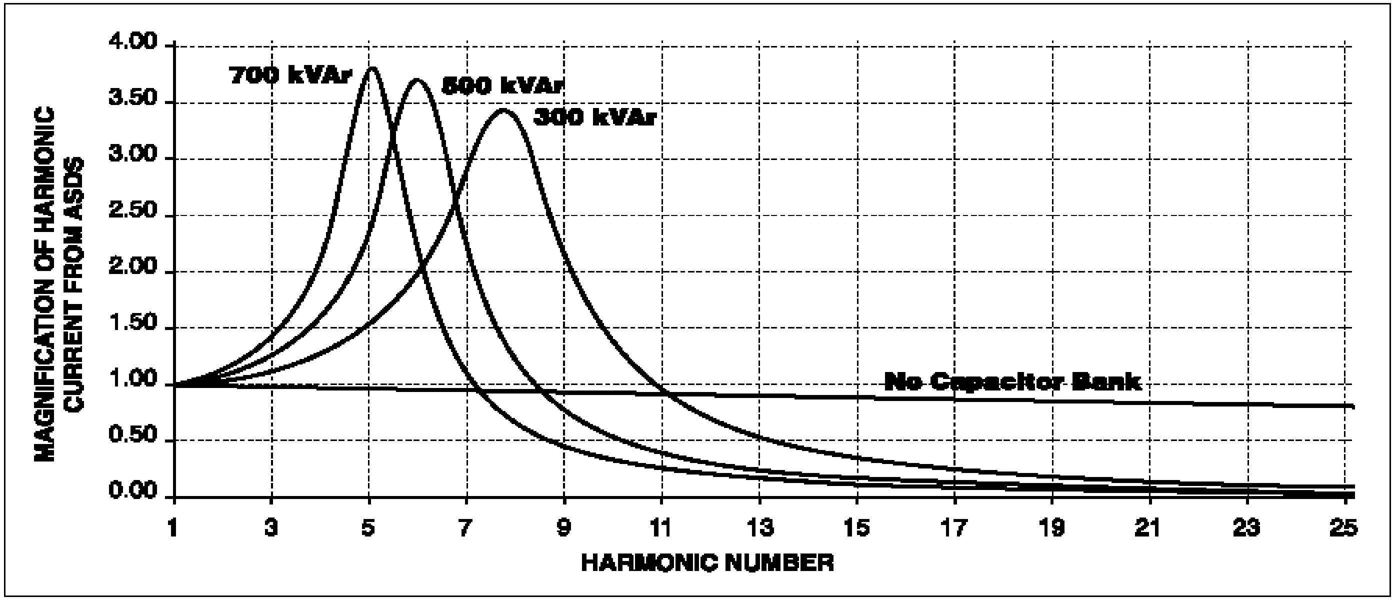
- Result of harmonic currents Ih flowing through power system impedance
- Impedance = f(frequency), so each harmonic current Ih develops specific harmonic voltage Vh
- Harmonic voltages Vh cause disturbances throughout power system & must be kept to low values (e.g. < 5%)
- Reduce Vh by reducing Ih or power system impedance

Solutions to reduce harmonic voltages Vh

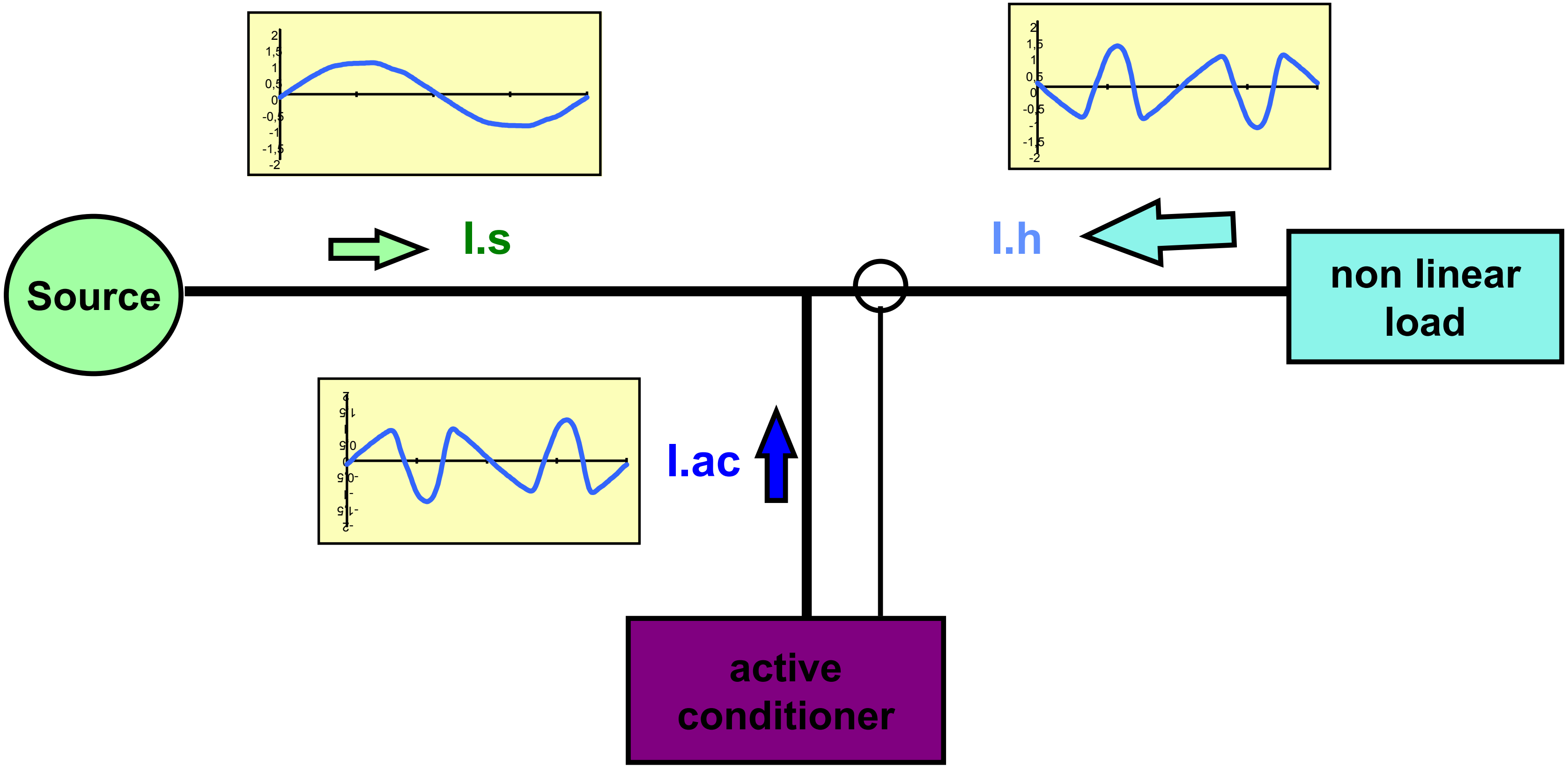
- Reduce power system impedance:
  - Not possible in low-voltage installations due to use of step-down transformers
  - Only applicable for high-voltage installations such as arc furnaces
- Reduction of harmonic currents Ih:
  - Use of passive filters which absorb harmonic currents & supply vars
  - Active filter to cancel harmonic currents flowing into transformer low-voltage winding

Why passive filters were not selected

- Must be switched on & off to avoid over-compensation
- Can cause resonance at certain frequencies:
  - Resonance = high system impedance at certain frequency
  - Harmonic currents Ih generate high harmonic voltages Vh
  - Resonance frequency varies greatly due to use of local generation (number of generators in service varies)

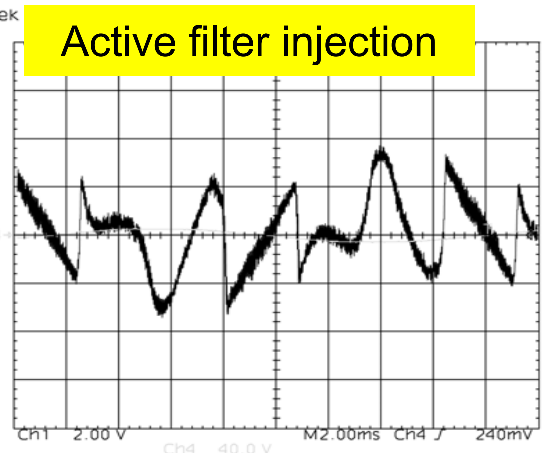


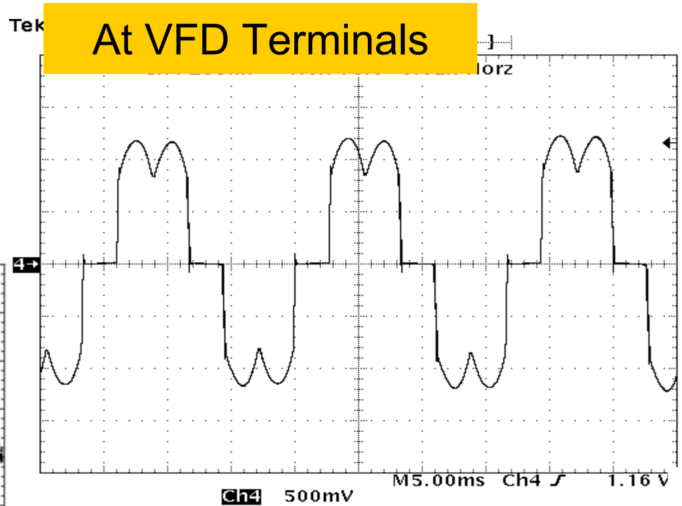
Operation of Active Filters

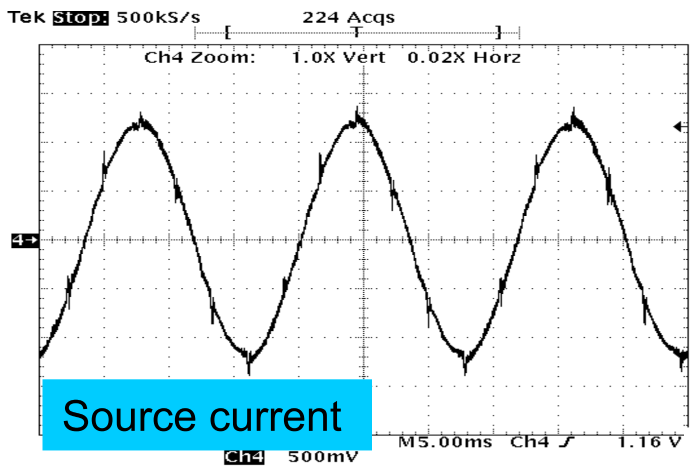


- Harmonic current Ih measured
- Current injected by active filter cancels harmonic current from load
- Result is clean current through source impedance eliminating harmonic voltages

Harmonic Performance



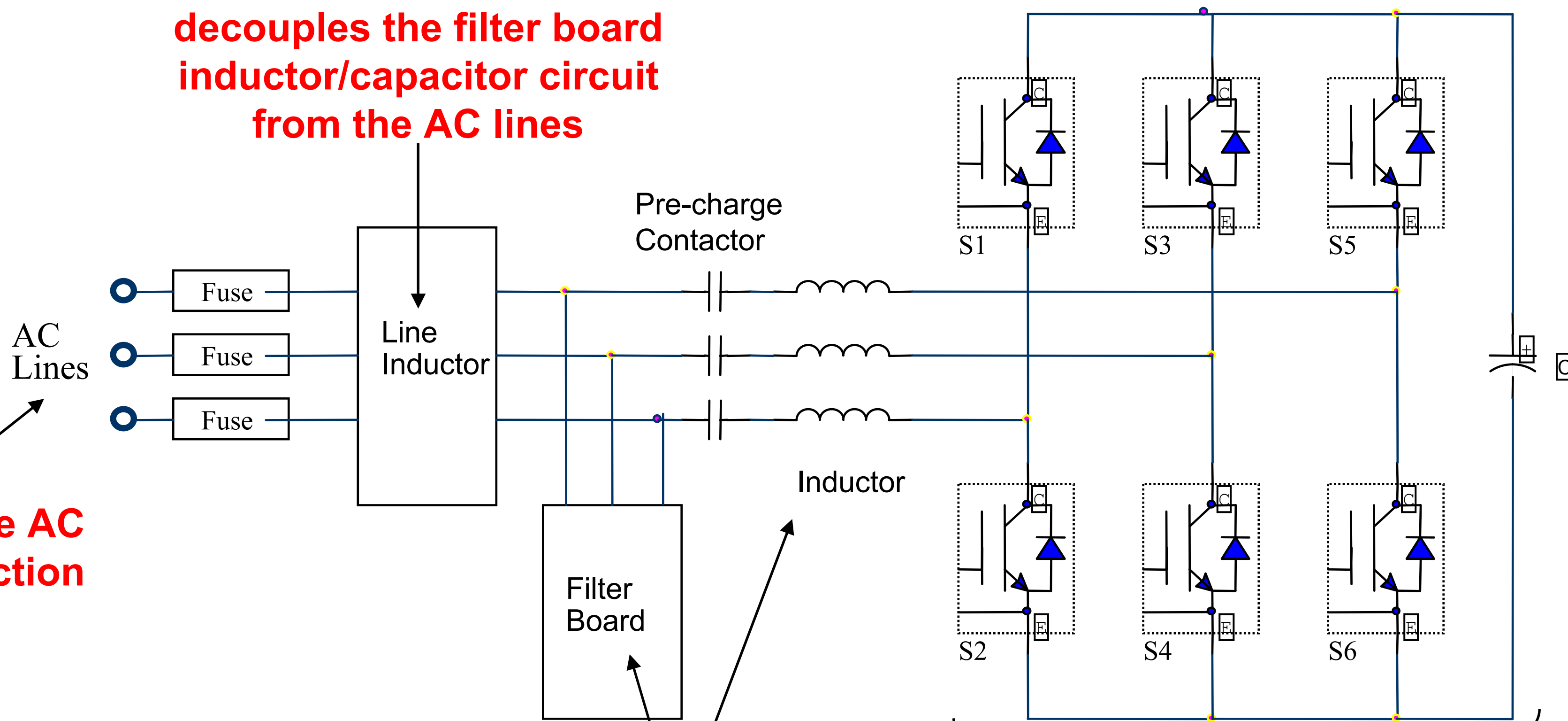




Order	AF off % I fund	AF on % I fund
Fund	100.000%	100.000%
3	0.038%	0.478%
5	31.660%	0.674%
7	11.480%	0.679%
9	0.435%	0.297%
11	7.068%	0.710%
13	4.267%	0.521%
15	0.367%	0.052%
17	3.438%	0.464%
19	2.904%	0.639%
21	0.284%	0.263%
23	2.042%	0.409%
25	2.177%	0.489%
27	0.293%	0.170%
29	1.238%	0.397%
31	1.740%	0.243%
33	0.261%	0.325%
35	0.800%	0.279%
37	1.420%	0.815%
39	0.282%	0.240%
41	0.588%	0.120%
43	1.281%	0.337%
45	0.259%	0.347%
47	0.427%	0.769%
49	1.348%	0.590%
% THD(I)	35.28%	2.67%

Active filter power diagram

decouples the filter board inductor/capacitor circuit from the AC lines



three phase AC line connection

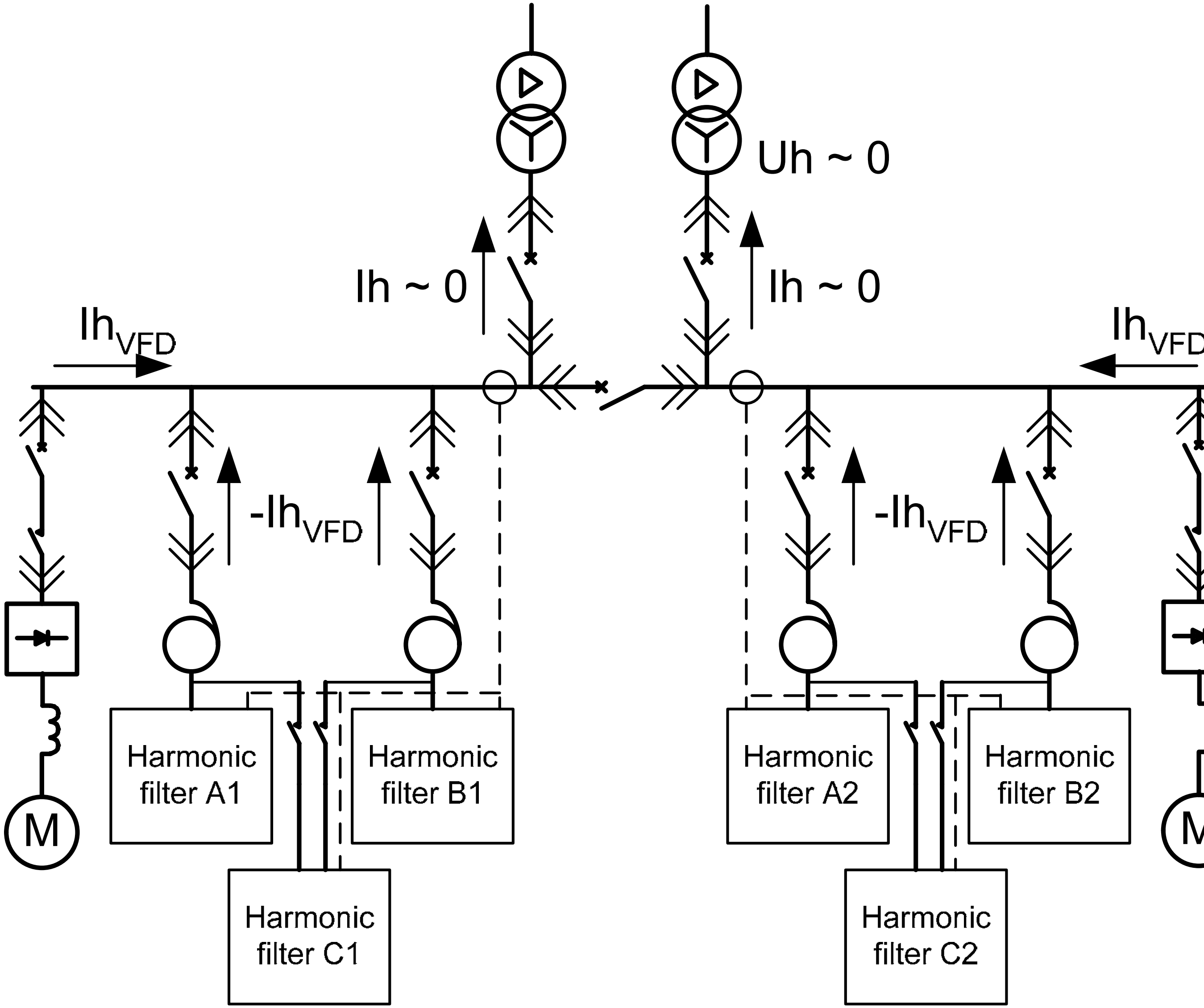
Used also to correct power factor

remove the carrier frequency from the current waveform sent into the AC lines.

IGBTs manage the power flow to/from the *DC bus caps*

Harmonic filter connection

- Used autotransformers due to 690V
- 2 each 300A active filters required per bus section
- Additional 300A unit per bus section for redundancy
- Each active filter set controls harmonic current from its busbar
- ~0 harmonic current flows to transformers
- Harmonic voltages ~0



Installation of active filter

- Stand-alone active filters used for this project due to redundancy requirements
- Can be integrated into switchgear lineup
- Heat dissipation (9 kW per 300A unit) to be included in HVAC design
- Allow free flow of air for ventilation purposes

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Advantages of selected solution

- All VFDs in dedicated switchboards:
  - Reduced quantity of equipment required for harmonic filtering
  - Avoided disturbance to linear loads (normal starters)
  - Provided optimum design to reduce foot print
- Active filters
  - Avoided any resonance problems
  - No over-compensation at light process loads
  - Redundancy achieved in simple, easy-to-maintain manner