Harmonics and Solution for Port Cranes

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Presentation Outline:

1. What are Harmonics?
2. Harmonics in Port System
3. How bad can it get?
4. How to fix it?
What are Harmonics?
Let’s understand using a circle

$n = 7$

harmonic wave  Sine wave

$\omega$

“Omega” (Speed)
No perfect sine wave in reality
\[ \omega = 2\pi f \]

Harmonic Spectrum

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>(Hz)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>f = 60 Hz</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>2f</td>
<td>120</td>
<td>2</td>
</tr>
<tr>
<td>3f</td>
<td>180</td>
<td>3</td>
</tr>
<tr>
<td>5f</td>
<td>300</td>
<td>5</td>
</tr>
<tr>
<td>7f</td>
<td>420</td>
<td>7</td>
</tr>
<tr>
<td>.....</td>
<td>.....</td>
<td>.....</td>
</tr>
<tr>
<td>40f</td>
<td>2400</td>
<td>40</td>
</tr>
</tbody>
</table>

\[
\text{f} \quad \text{2f} \quad \text{3f} \quad \text{4f} \quad \text{5f} \quad \text{6f} \quad \text{7f} \quad \text{.........} \quad \text{40f} \quad \text{41f} \quad \text{42f} \quad \text{...}
\]
Port & Harmonics
Where do Harmonics come from?
Sources of Harmonics on a crane

1. Variable Frequency AC Drives
2. DC Drives
3. UPS
4. Computers
5. Non-Linear Auxiliary loads
Negative Impacts of harmonics
Negative Impacts of harmonics:

1. Heating
   1. Bigger equipment - more cost
   2. Wasted energy
   3. Premature equipment failure

2. Poor power quality and penalties from Utilities.
Negative Impacts of harmonics (cont.):

3. Premature failure of Aux equipment including near by office equipment such as AC, lights, Computers, Printers etc.

4. Interferes with crane control circuits.
How much is too much?

IEEE Standard 519 - 2014
Local Harmonics Limit can be different...

**What about Local Utility?**

<table>
<thead>
<tr>
<th>Harmonic (n)</th>
<th>Voltage Limit (%)</th>
<th>Current Limit (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.100</td>
<td>3.67</td>
</tr>
<tr>
<td>3</td>
<td>0.125</td>
<td>3.07</td>
</tr>
<tr>
<td>4</td>
<td>0.100</td>
<td>1.84</td>
</tr>
<tr>
<td>5</td>
<td>0.529</td>
<td>7.77</td>
</tr>
<tr>
<td>6</td>
<td>0.100</td>
<td>1.22</td>
</tr>
<tr>
<td>7</td>
<td>0.410</td>
<td>4.30</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Comparison: IEEE vs Local Limits

Current Harmonics:

<table>
<thead>
<tr>
<th>Harmonic (n)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>IEEE-519 Limit</td>
</tr>
<tr>
<td>3</td>
<td>Local Utility Limit</td>
</tr>
<tr>
<td>5</td>
<td>IEEE-519 Limit</td>
</tr>
<tr>
<td>7</td>
<td>Local Utility Limit</td>
</tr>
<tr>
<td>11</td>
<td>IEEE-519 Limit</td>
</tr>
<tr>
<td>13</td>
<td>Local Utility Limit</td>
</tr>
<tr>
<td>17</td>
<td>IEEE-519 Limit</td>
</tr>
<tr>
<td>19</td>
<td>Local Utility Limit</td>
</tr>
<tr>
<td>23</td>
<td>IEEE-519 Limit</td>
</tr>
</tbody>
</table>
Voltage distortion - Local Limits

Voltage Harmonics:

Voltage (%)

Harmonics (n)

Voltage distortion - Local Limits

Voltage Harmonics:

Voltage (%)

Harmonics (n)

Local Utility Limit
Solution
Harmonic Filter
Harmonics from Drives …

Current Harmonics & Harmonic Filter

Without Harmonic Filter

IEEE-519 Limits (I_{sc}/I_L < 20)
Harmonic Filter

Utility  \[ \text{Impedance} = \omega L \]  Harmonic Filter  \[ \text{Impedance} = \frac{1}{\omega C} \]  Drive

\[ \text{Impedance} = \frac{1}{\omega C} \]
With Harmonic Filter …

Current Harmonics & Harmonic Filter

With Harmonic Filter

Without Harmonic Filter

IEEE-519 Limits (Isc/I < 20)
Harmonic Filter

Is IEEE Std. 519 filter sufficient?
Case 1:

7 ASC + 4 QC vs 12 ASC + 5 QC

(Scenario 1)    (Scenario 2)

• Impacts of increasing # cranes
• Each crane contributes
Less Cranes v/s More Cranes

Current Harmonics: 7ASC/4QC vs 12ASC/5QC

- 7 ASC + 4 QC
- 12 ASC + 5 QC
- IEEE-519 Limit
- Local Utility Limit
Less Cranes v/s More Cranes

Voltage Harmonics: **7ASC/ 4QC vs 12ASC/ 5QC**

<table>
<thead>
<tr>
<th>Harmonics (n)</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>11</th>
<th>13</th>
<th>17</th>
<th>19</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (%)</td>
<td></td>
<td></td>
<td><strong>0.5</strong></td>
<td><strong>0.5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **7 ASC + 4 QC**
- **12 ASC + 5 QC**
- **Local Utility Limit**
Scenario 3:

Critical # of cranes

(Scenario 3): 22 ASC + 7 QC

- 5\textsuperscript{th}, 7\textsuperscript{th} harmonics exceeded
- Standard v/s Custom Design
More cranes operating at the same time, increase harmonic injection!
**Problem:** 5\textsuperscript{th} and 7\textsuperscript{th} harmonics

Standard filter **fails** to keep 5\textsuperscript{th} and 7\textsuperscript{th} harmonics under limit

- Harmonic Injection
- IEEE-519 Limit
- Local Utility Limit
**Problem:** 5\textsuperscript{th} and 7\textsuperscript{th} harmonics

Standard filter **fails** to keep 5\textsuperscript{th} and 7\textsuperscript{th} harmonics under limit

- **Voltage (%):**
  - 0.5
  - 0.4
  - 0.3
  - 0.2
  - 0.1
  - 0.0

- **Harmonics (n):**
  - 2
  - 3
  - 5
  - 7
  - 11
  - 13
  - 17
  - 19
  - 23

- **Lines:**
  - **Harmonic Injection**
  - **Local Utility Limit**

Confidential
What about Custom Harmonic Filter?
After adding **Custom Filter** ...

**Notch Branches added to Quay Cranes**

22 ASCs

7 QCS

Custom Filter
5th and 7th harmonics are suppressed

Custom Harmonic Filter – Current Harmonics

- Harmonic Injection
- Reduced Harmonics
- IEEE-519 Limit
- Local Utility Limit

Harmonics (n)

Current (A)
5\textsuperscript{th} and 7\textsuperscript{th} harmonics are suppressed

Custom Harmonic Filter – Voltage Harmonics

Voltage (%)

Harmonics (n)

Harmonic Injection

Reduced Harmonics

Local Utility Limit

5\textsuperscript{th} and 7\textsuperscript{th} harmonics are suppressed
Local Utility Limits may be more stringent than IEEE-519.

Harmonic distortion at PCC increases as more cranes are operated.

A custom filter based on the model of entire port including future expansion meets IEEE std. 519 and local utility requirements at PCC.
A custom filter based on the model of entire port including future expansion meets IEEE Std. 519 as well as applicable local utility requirements at PCC.
DC and AC cranes inject harmonics with substantially different spectrums.

Case 1: DC and AC cranes with Filters.
6 Pulse DC Drive Current

Waveform

Spectrum

Low-order harmonics are large
2 Levels IGBT Drive Current

Waveform

Spectrum

High order harmonics have moderate amplitude
DC Cranes Filter

Filters at the MV Bus
AC Cranes Harmonic Filter

Utility

Harmonic Filter

Drive

\[ \text{Impedance} = \frac{1}{\omega C} \]

\[ \text{Impedance} = \omega L \]
Harmonic Spectrum at the PCC

Harmonic Currents

Order (th)

Harmonic Currents (%)

- DC and AC Cranes
- IEEE519

$\frac{I_{sc}}{I_L} > 20$
AC Crane, High Pass Filter Currents

High Pass Filter Currents

Low Order Harmonics injected by DC cranes

High Order Harmonics injected by AC drives
DC drives inject low order harmonic currents with high amplitude.

AC drives inject high order harmonic currents with moderate amplitude.

Cranes with DC drives require Low harmonic order notch filters and a High Pass section, all connected at the MV bus.

Cranes with AC drives require High Pass filter to attenuate high frequency harmonics.

Combination of these filters ensure compliance with IEEE std. 519 at the PCC.
Case 2: DC cranes without MV Filters.

Notch and High Pass filters for DC cranes are disconnected.
Harmonic Spectrum at the PCC

Harmonic Currents

- DC and AC Cranes
- IEEE519

Harmonics (%)

Order (th)

$\frac{I_{SC}}{I_L} > 20$
AC Crane, High Pass Filter Currents

High amplitude of Low Order Harmonics injected by DC cranes
Summary

➢ When DC cranes operate without MV notch and high pass filters, the low frequency harmonics injected by the DC drives exceed the IEEE std 519 limits.

➢ Some of the low frequency harmonics injected by the DC drives are absorbed by the LV High Pass filters installed in the AC Cranes.

➢ In this example, the 11\textsuperscript{th} harmonic current on the AC cranes filters is approximately 6 times higher when the DC cranes filters are disconnected.

➢ Due to high harmonic currents in the AC crane filters, protection devices will trip.
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