Developing an Improved Strategy for Valuing PQ

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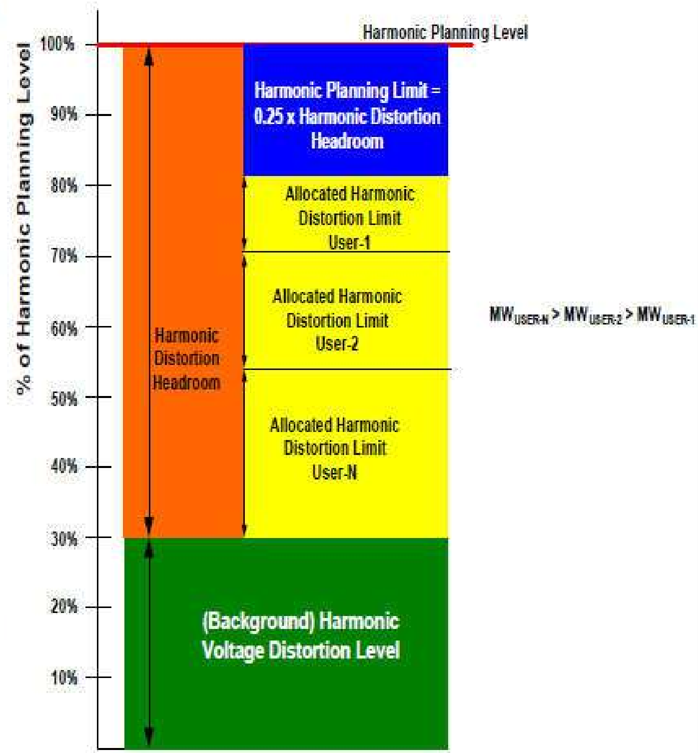
Today’s Approach to “Managing” PQ

- Maximum allowable limits
- Allocation to existing loads

The method adopted by [redacted] for calculating the **Allocated Harmonic Distortion Limits** for each new **User**'s connection is based on Stage 2 of IEC/TR 61000-3-6, with some enhancements aimed to distribute the emission limitation burden as equitably as possible.

The main principles in the allocation method are:

- Carry-out measurements of existing background **Harmonic Voltage Distortion Levels** and **THD**.
- Calculate the **Harmonic Distortion Headroom**.
- Retain 25% of the **Harmonic Distortion Headroom** as **Harmonic Planning Margin**
- Allocate a portion of the remaining distortion capacity (taking into account interactions from neighbouring Transmission Nodes) to the **User**'s connection. The apportioning of distortion capacity is on a MW pro-rata basis between all **Users** connecting at the same Transmission Node.



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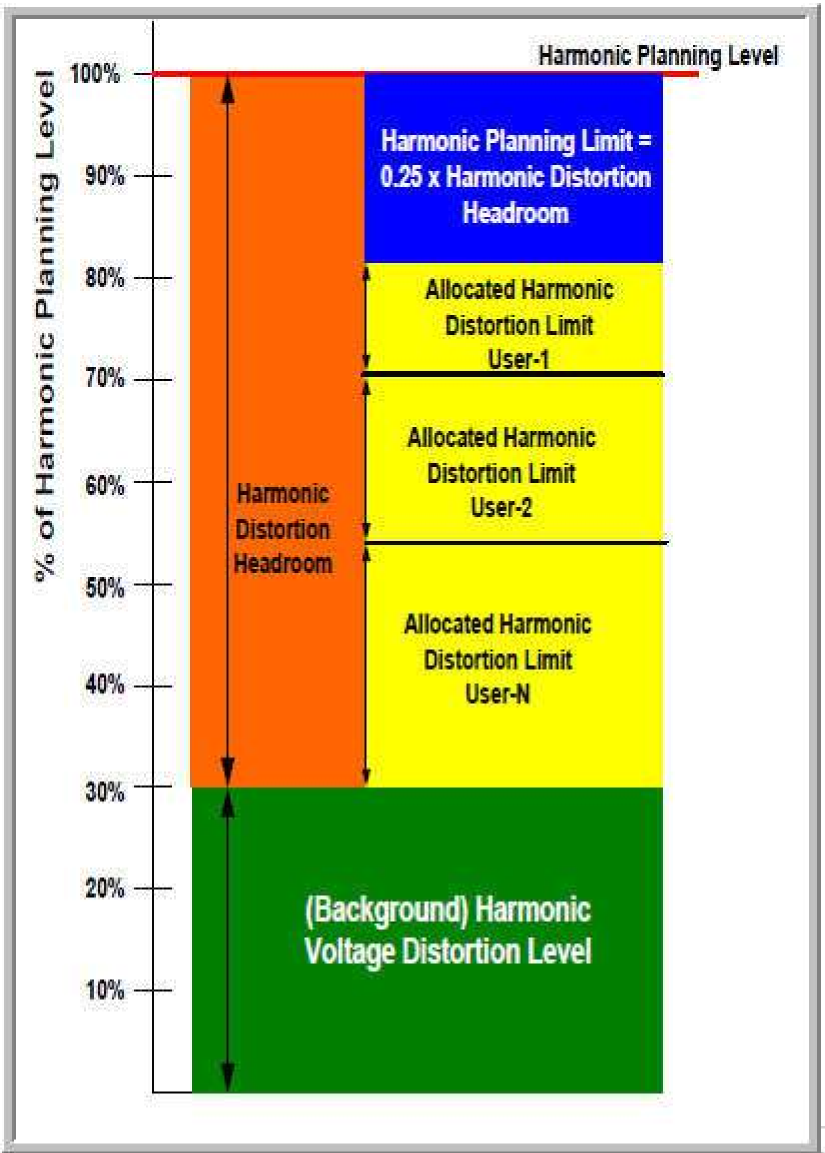
Today's Approach to "Managing" PQ
What's missing from this picture?

- Planning levels for most PQ phenomena are based on avoiding equipment damage and/or customer complaints
- GOAL of the planning process is to *allocate* PQ to existing or planned loads
- Missing:
  – Goal of maintaining near-perfect PQ
  – Opportunity for continuous correction, load-by-load
  – Economic value of good PQ



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Today's Approach to "Managing" PQ
Some PQ thresholds

- Harmonics (IEEE 519-2014)

Table 1—Voltage distortion limits

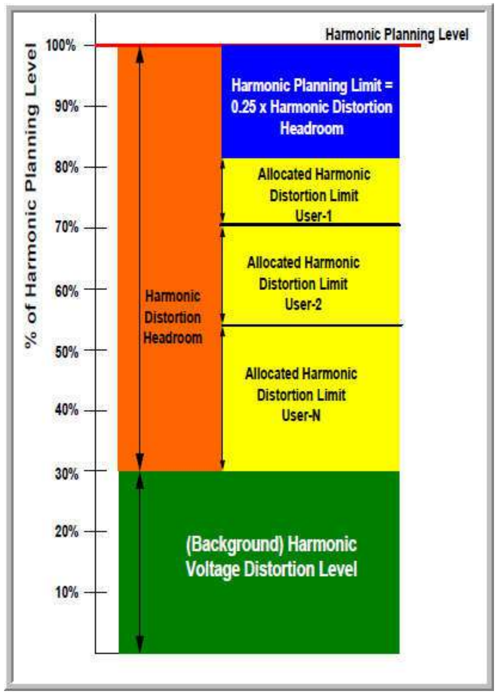
Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq$ 69 kV	3.0	5.0
69 kV $< V \leq$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

[a]High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

- Flicker (IEC 61000-3-7)

Table 2 – Indicative values of planning levels for P_{st} and P_{lt} in MV, HV and EHV power systems

	Planning levels	
	MV	HV-EHV
P_{st}	0,9	0,8
P_{lt}	0,7	0,6



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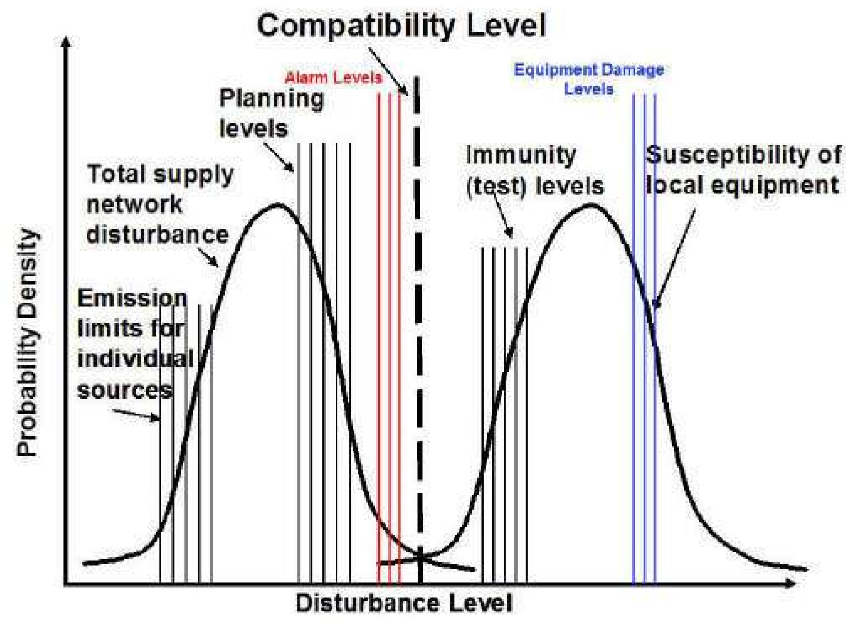
Today's Approach to "Managing" PQ
Illustration of thresholds

- Threshold-based management of PQ can operate at different levels
- Goal is to maximize connected load up to the maximum allowable contamination
- We can -- and must -- do better!



Concept of compatibility levels for the electric supply system and the immunity characteristics of equipment

Source: IEEE 1250

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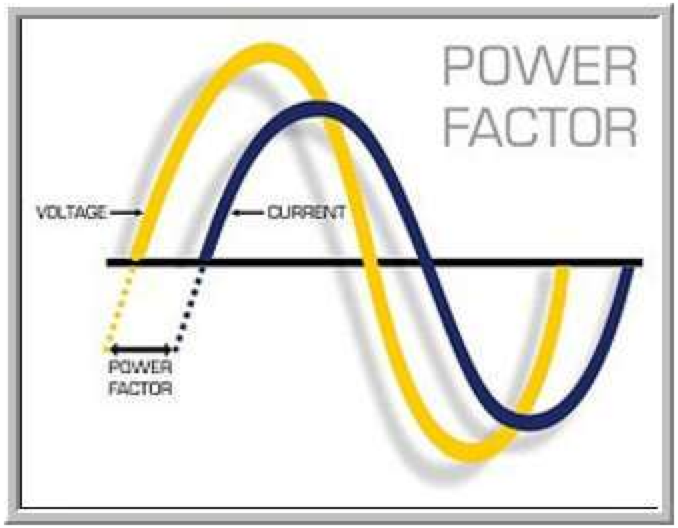
Displacement Power Factor
An example of where we got it right (mostly)

- Recognized Costs Resulting from Less-than-perfect PF
  - Additional generation capacity and operational costs
  - Lost system capacity in transformers, conductors, etc.
  - Additional I^2R losses
  - Costs for utility-side mitigation
- Management Strategy
  - Performance goal of near perfect PF (1.0)
  - Expectation that each connecting load will be responsible for
- Management Implementation
  - Utility-side correction
  - PF penalties and KVA tariffs



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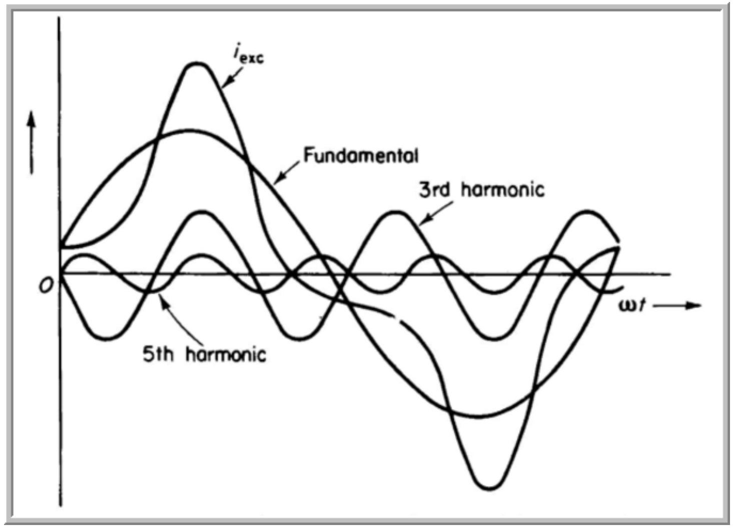
Developing a New Model for Management of PQ
Incorporating Economical Drivers - Harmonics

- Hard costs due to harmonics
  - Additional generation capacity and operational costs
  - Additional I^2R losses in equipment and wiring
  - Damage due to harmonic resonance
- Soft costs due to harmonics
  - Equipment heating / shortened life
  - Increased chance of malfunction
  - Lost system capacity
  - Others



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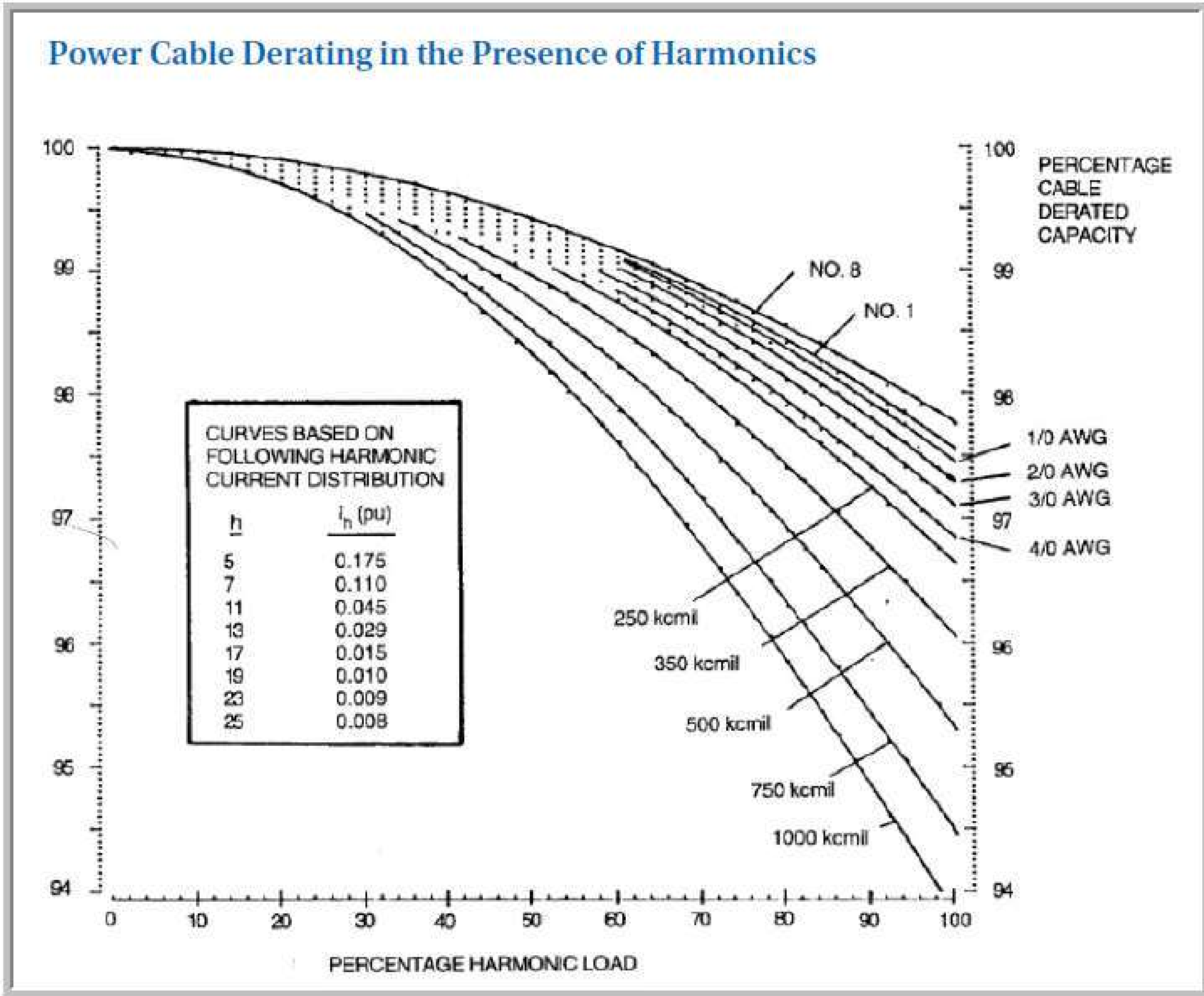
Economic Factors for Harmonics

Lost System Capacity - Conductors



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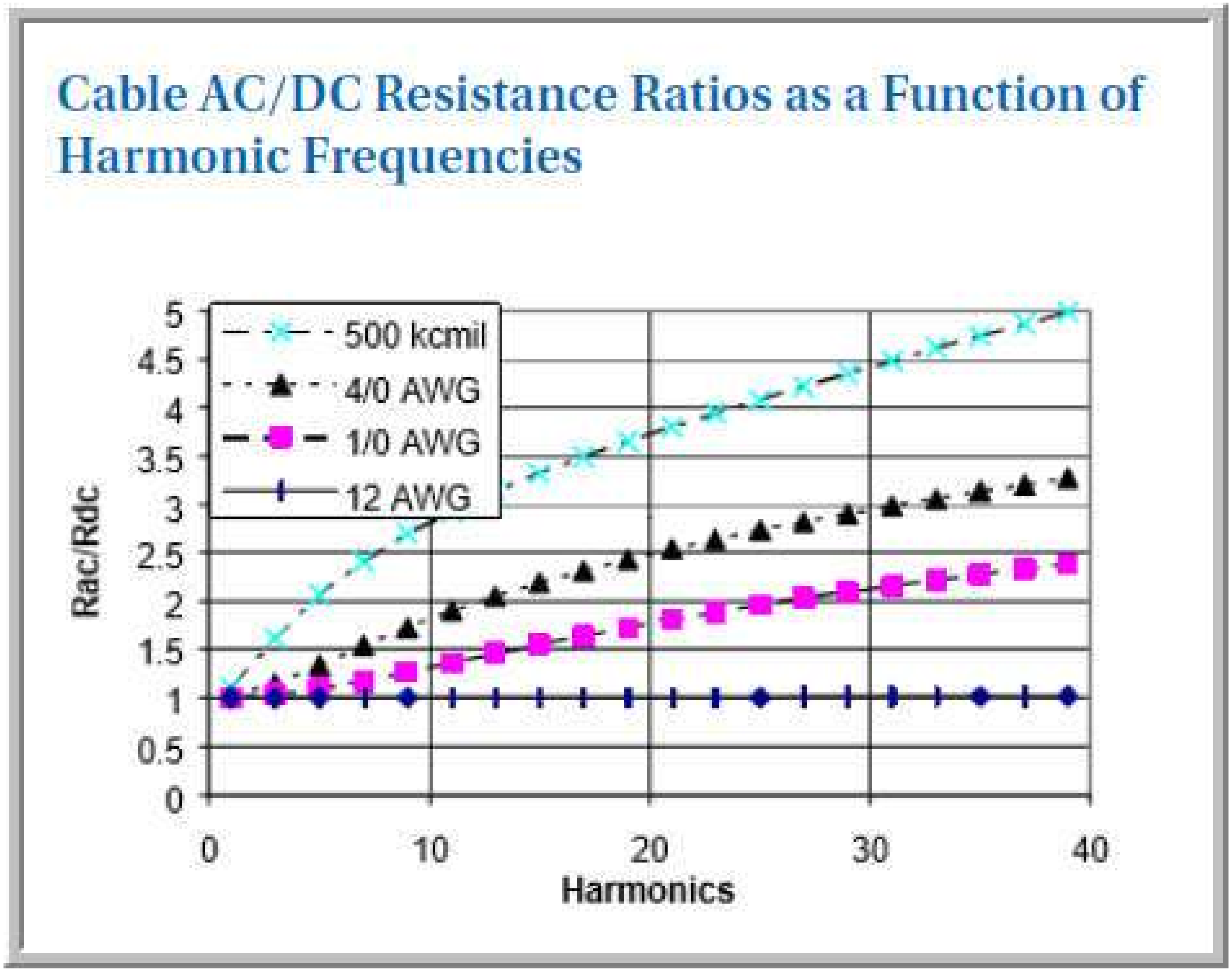
Economic Factors for Harmonics
Energy Losses due to Harmonics - Conductors



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Economic Factors for Harmonics
Hydro Quebec Analysis (2000)

- Grid-wide analysis of harmonics based on IEC levels
- Estimated cost of US$43M per year

Estimated Losses due to Harmonics (kW)

	Harmonic Levels of 50% of IEC Limits	Harmonic Levels of 100% of IEC Limits	Harmonic Levels of 150% of IEC Limits
LV lines	3078	12,311	27,701
MV lines	2330	9320	20,970
Transformers	975	3899	8774
Capacitors	137	548	1233
Total	6491	26,078	58,678

Estimated Annual Cost for Distribution System Power Losses Produced by Harmonics (US$1000)

	Harmonic Levels of 50% of IEC Limits	Harmonic Levels of 100% of IEC Limits	Harmonic Levels of 150% of IEC Limits
LV lines	$2,292K	$9,167K	$20,626K
MV lines	$1,735K	$6,940K	$15,614K
Transformers	$726K	$2,903K	$6,533K
Capacitors	$102K	$408K	$918K
Total	$4,833K	$19,418K	$43,692K

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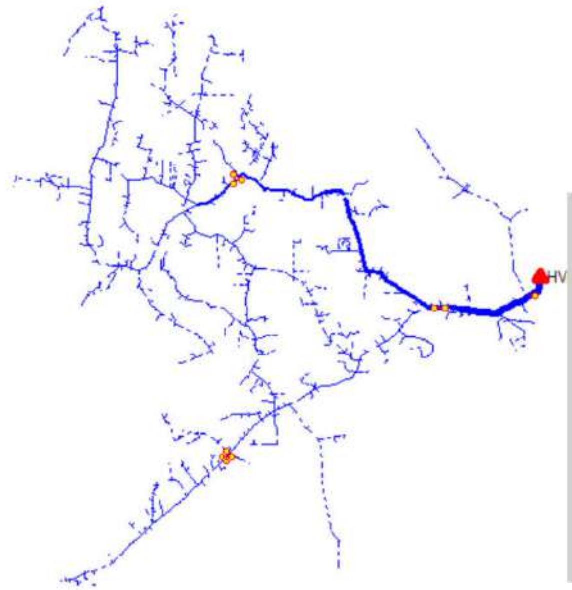
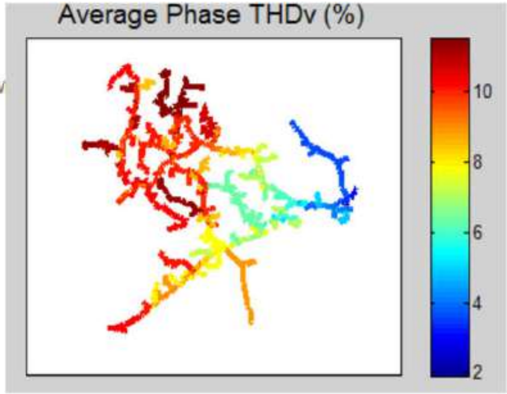
EPRI Scenario Analysis of Cost of Harmonics

- V-thd at the substation: ~2%
- V-thd peaks ~10%





Harmonic Spectrums Used in Analysis

Harmonic Order	Harmonic Magnitude (% of Fundamental)		
	Background Voltage	Base Harmonic Load Current	High Harmonic Load Current
3	1.3	8.6	14
5	1.5	4.7	7.5
7	0.4	2.9	4.5
9	0.2	2.9	4.5
11	0.1	1.1	1.5
13	0.1	0.9	1.4

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EPRI Scenario Analysis of Cost of Harmonics
Base Case – No filters

- Percent increase in losses due to harmonics: 2.6%

Losses for Test Case 1—Base Harmonics

Component	Losses (kW)			Percent Increase due to Harmonics
	Fundamental	Harmonics	Combined	
Peak Hour Analysis				
Lines I^2R losses	1034.4	29.2	1063.6	2.8
Transformers I^2R losses	118.8	1.5	120.3	1.3
Transformers no-load losses	56.8		56.8	
Transformer eddy losses	7.1	0.9	8.0	12.7
Capacitor losses		0.5	0.5	
Total losses	1217.1	32.7	1249.2	**2.64**
Annual Analysis				
Losses (kWh)	3,419,784	84,045	3,503,829	
Cost ($1000)	342	8.4	350.4	
Total losses (% of energy)	11.30	0.3	11.6	

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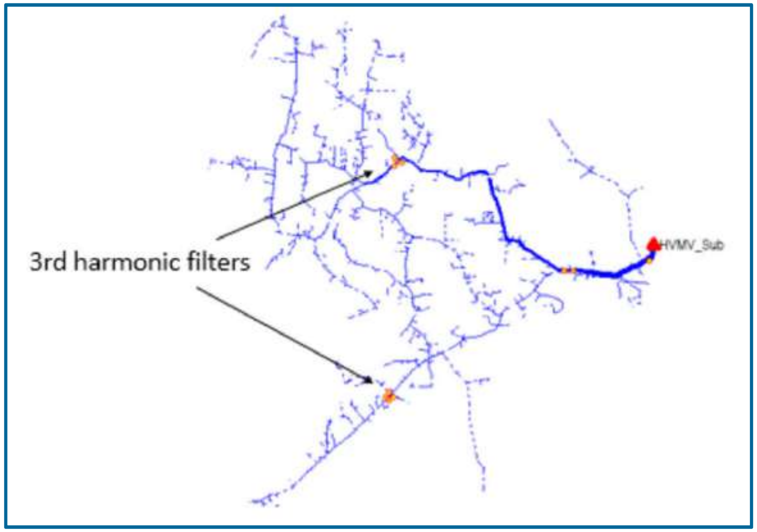
EPRI Scenario Analysis of Cost of Harmonics Base Case – 3rd Harmonic Filters Added

- Losses due to harmonics are 1.1% after vs. 2.6% before
- Economic payback based only on these losses: ~11 years



Losses for Test Case 1—Base Harmonics Scenario with Filter Banks

Component	Losses (kW)			% Increase due to Harmonics
	Fundamental	Harmonics	Combined	
Peak Hour Analysis				
Lines I^2R losses	1034.4	11.4	1045.8	1.1
Transformers I^2R losses	118.8	0.8	119.6	0.7
Transformer no-load losses	56.8		56.8	
Transformer eddy losses	7.1	0.5	7.6	7
Capacitors losses		0.2	0.2	
Total losses	1217.1	12.9	1230	**1.06**
Annual Analysis				
Losses (kWh)	3,419,784	33,794	3,502,472	
Cost ($1000)	342	3.4	345.5	
Total losses (% of energy)	11.3	0.12	11.59	

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Economic Model for PQ
Future Work

- More sophisticated models of the economic impact of harmonics
  - Additional generation capacity and operational costs
  - Lost system capacity in transformers, conductors, etc.

- Incorporation of other PQ phenomena
  - Flicker
  - Voltage Unbalance
  - Transients
  - Etc.

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