Electrical Harmonics 102

A Further Review of Electrical Harmonics and Discussion of Mitigation Strategies with Discussion of VFD Secondary Circuit Design Considerations.

Michael A. McGraw

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- A Quick Review of Harmonic Relationships
- Expanded Discussions of Harmonic Mitigation Strategies
- Discussion of Critical Information Required for Accurate Harmonic Modeling and Design
- Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise
- Questions & Answers

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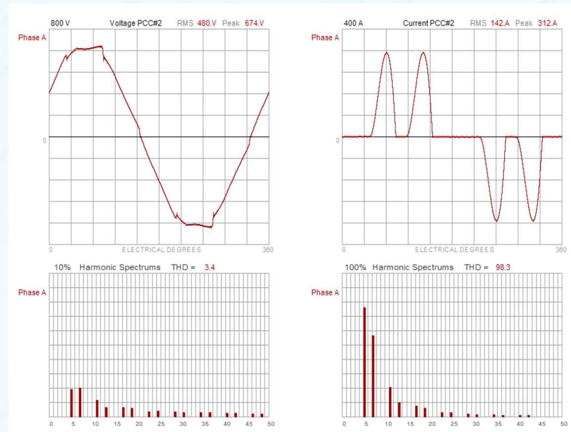
Fundamentals of Electrical Harmonics

Stiff System Waveform Trace- 6 Pulse Rectification

The greater the Available Short Circuit of the Source:

- ~ The tighter the regulation of the source, i.e., the stiffer the source.
- ~ Any given current harmonic injection will have a higher calculated Ithd but a lower impact on the associated Vthd.



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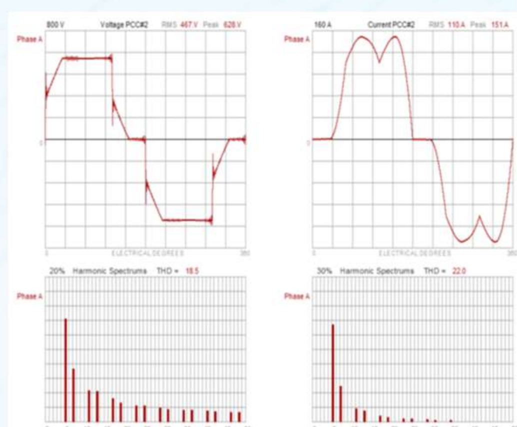
Fundamentals of Electrical Harmonics

Weak System Waveform Trace

The Lower the Available Short Circuit Current of the Source:

- ~ The lower the regulation of the source, i.e., the weaker the source.
- ~ Any given current harmonic injection will have a lower calculated Ithd but a greater impact on the associated Vthd.



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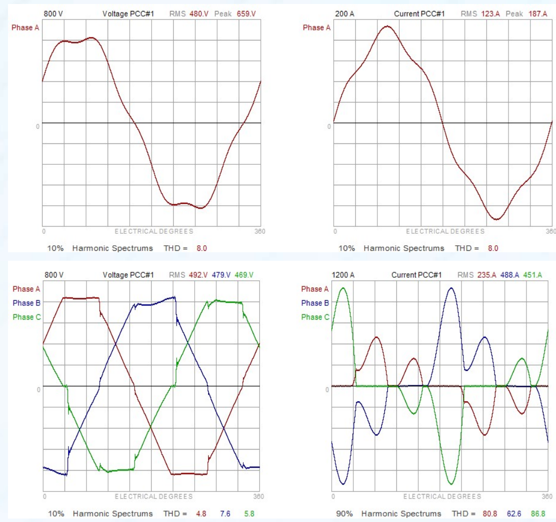
Fundamentals of Electrical Harmonics

- **Key Relationships to Understand:**

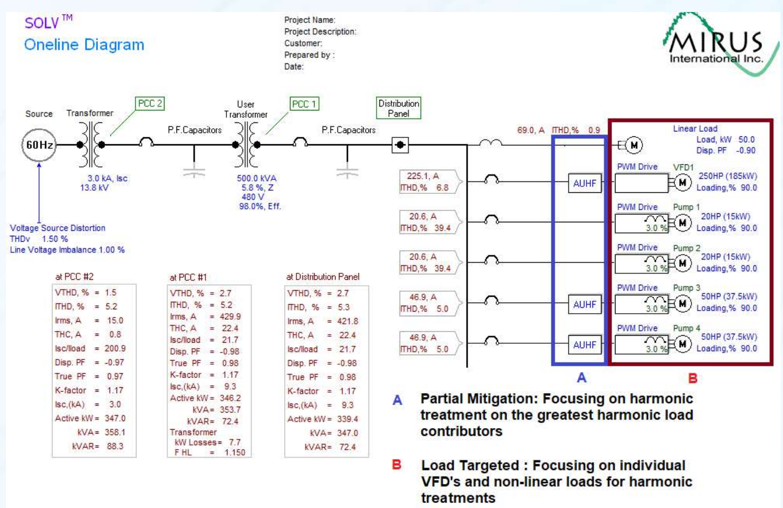
  Any Linear Load Structure fed by a Distorted Source Voltage will run less efficiently and draw current in a non-linear fashion, i.e., will now behave electrically as a non-linear load.

  The greater the source voltage imbalance being provided to a non-linear load, the greater the impact to Current Harmonic (Ithd) and associated Voltage Distortion (Vthd) experienced.

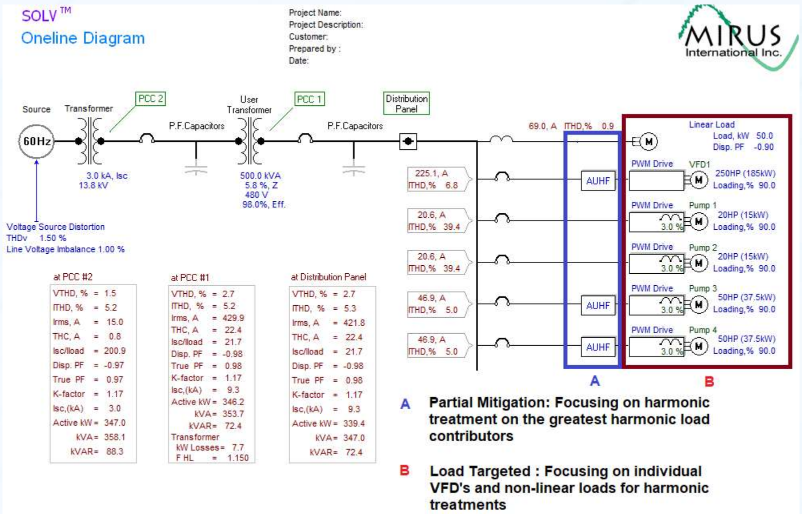


Discussion of Load-targeted, Partial, Systemic, and Staged Harmonic Mitigation Strategies

- **Partial Mitigation is a key element. It is based on the concept that you do not have to treat all the harmonic sources within the circuit, but instead treat/eliminate enough harmonic contribution from those loads to meet the objectives of IEEE Std 519-2022**



Discussion of Load-targeted, Systemic, Partial and Staged Harmonic Mitigation Strategies



- **Load Target Harmonic Mitigation:**

  Focus Harmonic Mitigation Strategies at the individual load locations, via some form of harmonic cancellation or blocking strategy.

  Concentrate on the largest non-linear loads for developing your strategy, following the concept of partial mitigation principals as was discussed previously.

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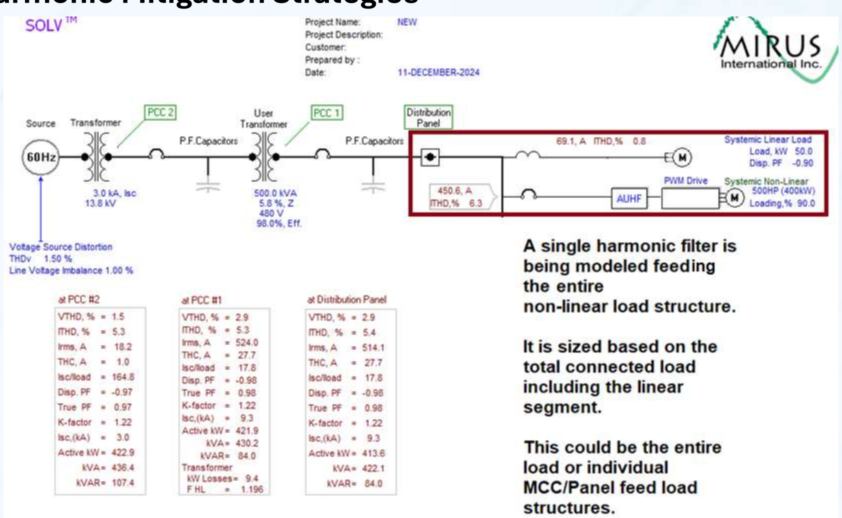
Discussion of Load-targeted, Systemic, Partial and Staged Harmonic Mitigation Strategies



- **Systemic Harmonic Mitigation: in lieu of targeting individual loads within a circuit for treatment, a viable strategy is to isolate a system harmonic mitigation at the service entrance of the project.**
- **The system strategy can help overcome the cumulative effect of smaller non-linear.**

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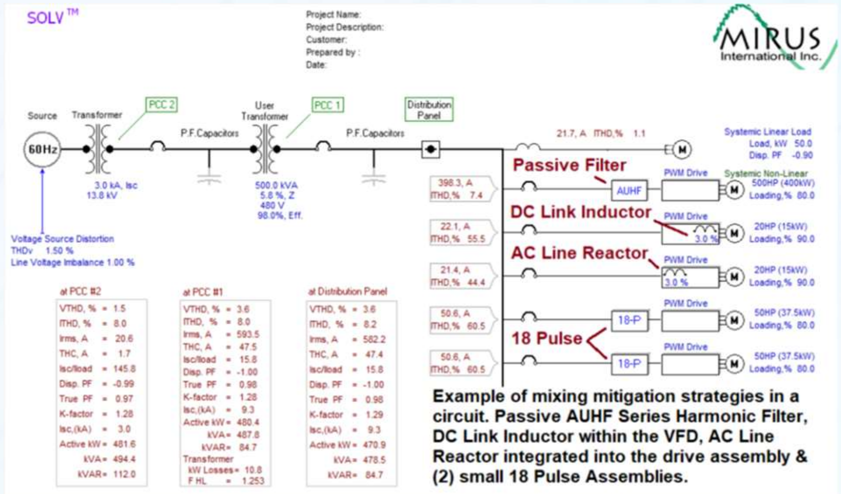
Discussion of Load-targeted, Systemic, Partial and Staged Harmonic Mitigation Strategies

- **Multiple Strategies may be successfully deployed with caution to understand the effectiveness and limitations of each strategy as it relates to true circuit condition. Examples would include Harmonic Filtration (LCL – topologies), Phase Shifting and Multi-pulse Drive deployment, and Active Harmonic Solutions.**



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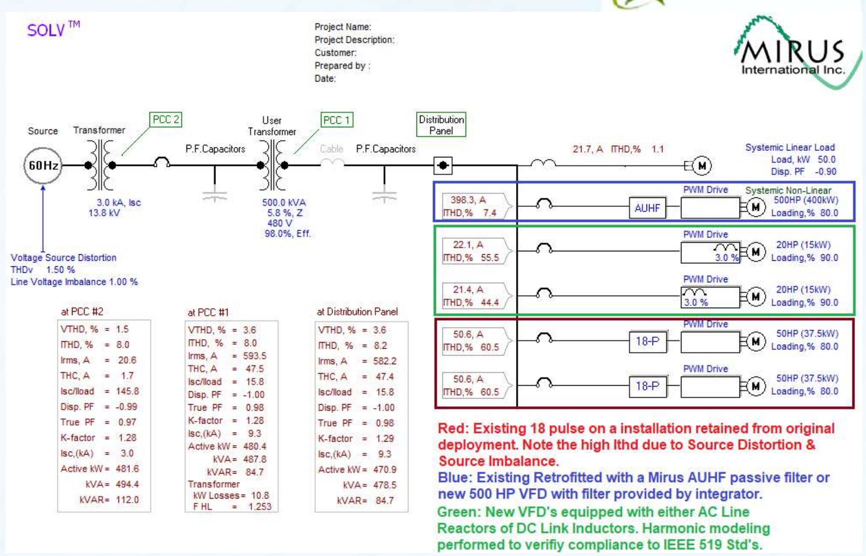
Discussion of Load-targeted, Systemic, Partial and Staged Harmonic Mitigation Strategies

- **Staged Harmonic Mitigation is more relevant to retrofit applications where project restrictions on funding and/or outage impact must be considered. It can be used for new build installations where the construction project is a staged schedule.**



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Discussion of Critical Information Required for Accurate Harmonic Modeling

Source/Systemic Background Voltage Distortion:

- **Table 1 of the IEEE519 Std. Highlights the acceptable Vthd level within a circuit at the PCC. Basically, the level of source background Vthd limits the contributive voltage distortion allowed from the circuit load structure. So, the higher the Vthd-bg the less Vthd from the non-linear loads within the subject circuit is allowed. I refer to this as the "Vthd Headroom".**
- **The higher the source Vthd feeding into the circuit, the greater the current harmonic associated with the linear loads within the circuit. Remember, if you feed a linear load with a distorted voltage, the linear load will now draw current in a non-linear fashion. I refer to this as "Garbage In – Garbage Out". (See Screen 5 for reference graphic)**
- **High Source Vthd can and will impact on phase shift and multi-pulse harmonic mitigation strategies within the circuit. A 2% Vthd from the source will negate an 18 pulse VFD effectiveness. (See FSE:AS7CP Series Five Star Electric Clean Power Drive versus Autotransformer 18 Pulse Drive - "Real World" Water Applications, https://vfd.com/wp-content/uploads/FSE-AS7-CP-TD001.pdf**
- **The presence of a Background/Source Voltage Distortion can trigger resonance within the associated circuit, which can complicate compliance with IEEE 519 Std. requirements since it can add additional voltage distortion and current harmonic within the system.**

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Discussion of Critical Information Required for Accurate Harmonic Modeling

Available Short Circuit from the Source:

- **To properly model and anticipate the current harmonic and associated voltage distortion contribution of the load circuit, you must understand the relative regulation factor of the source.**
- **The lower the Available Short Circuit Current of the Source, the lower the regulation of the source, i.e., the weaker the source. Any given current harmonic injection will have a lower calculated Ithd but a greater impact on the associated Vthd.**
- **The greater the Available Short Circuit of the Source, the tighter the regulation of the source, i.e., the stiffer the source. Any given current harmonic injection will have a higher calculated Ithd but a lower impact on the associated Vthd.**
- **Where a Generator Source is utilized as an emergency back-up, you must model and design for both potential sources to properly anticipate all operating scenarios. Here a Harmonic Modeling Software package that allows for the creation of Scenarios for comparative analysis is critical.**

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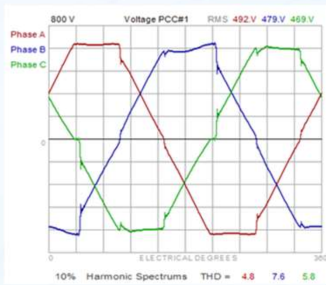
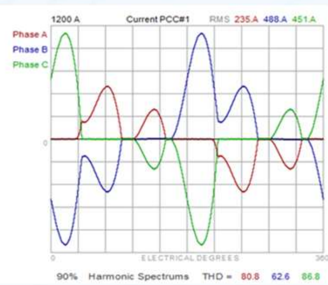
Discussion of Critical Information Required for Accurate Harmonic Modeling

Source/Systemic Voltage Imbalance:

- **Source or load generated voltage imbalance will trigger imbalanced non-linear load current draw characteristics which will increase the current harmonics within the load profile.**
- **The imbalanced current harmonic profile can show-up as a greater overall Ithd level and as higher non-typical harmonic frequency content as compared to a standard 6-pulse 5th and 7th spectrum composition.**
- **The associated spectrum changes from this imbalanced current harmonic pattern can add to the voltage distortion within the circuit profile.**





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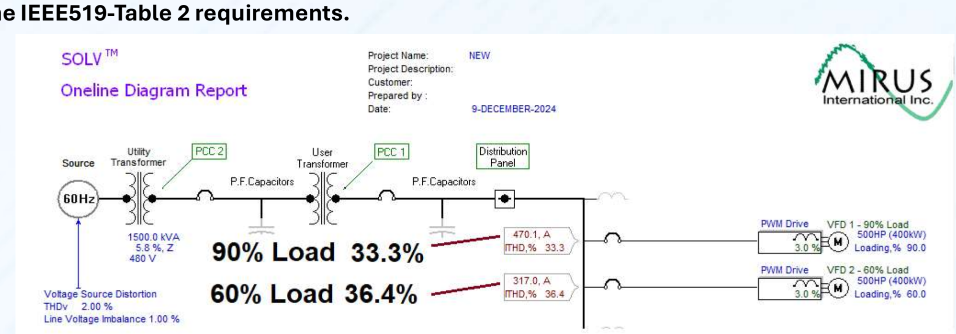
Discussion of Critical Information Required for Accurate Harmonic Modeling

VFD Load Profiles:

- **The harmonic profile and Ithd% changes as the associated non-linear load profiles of the circuit changes. The higher the load on the VFD/ASD/NLL the lower the current harmonic as a measure of the %Ithd as compared to the fundamental.**
- **Any modeling or design must strongly review the nominal loading structure of the subject non-linear devices to fully qualify the associated systemic current harmonic levels for compliance with the IEEE519-Table 2 requirements.**



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Discussion of Critical Information Required for Accurate Harmonic Modeling

VFD Assembly Equipment Topology:

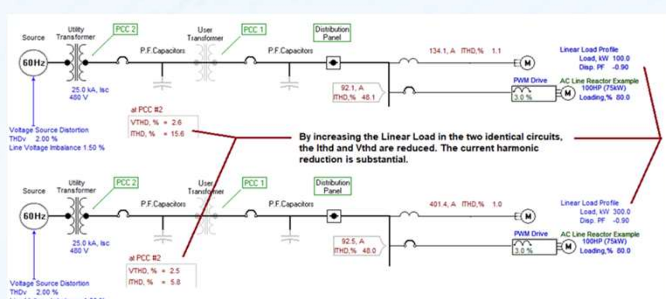
- **Not all VFD's are the same. How the component VFD is engineered or how the integrated VFD is designed can have a significant impact on the harmonic injection of each of the non-linear load components. You must model and engineer your harmonic mitigation design based on the VFD and Non-linear Load characteristic in order to maximize the accuracy of the intended harmonic mitigation.**

  ~ Key elements include:
  - **° Does the VFD of non-linear load have an integrated AC line reactor or DC choke inductor and what is the impedance of the device.**
  - **° Many VFD's now feature a smaller DC bus capacitor to save space or cost. These are often referred to as pumping duty or commercial grade VFD's. Regardless of the designation, all models for harmonic performance must have the correct DC bus capacitor sizing within the VFD model. The sizing of the DC bus capacitor can have a significant effect on the harmonic profile of the VFD load.**
  - **° The Harmonic Modeling Software must allow for addition of transformer front end options, including a phase shift variable should that be present within the design, a provision for adding either or both an AC line reactor of DC link with a range of impedance factors available, and the option to accurately input the DC bus capacitance should that value be known.**

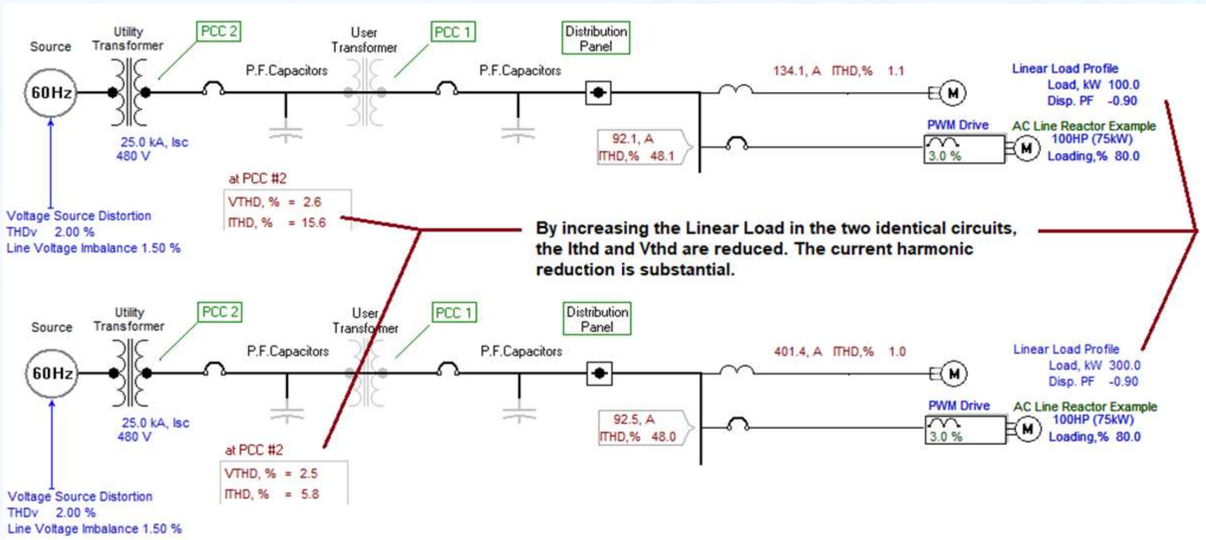
Discussion of Critical Information Required for Accurate Harmonic Modeling

Linear versus Non-Linear Load profile:

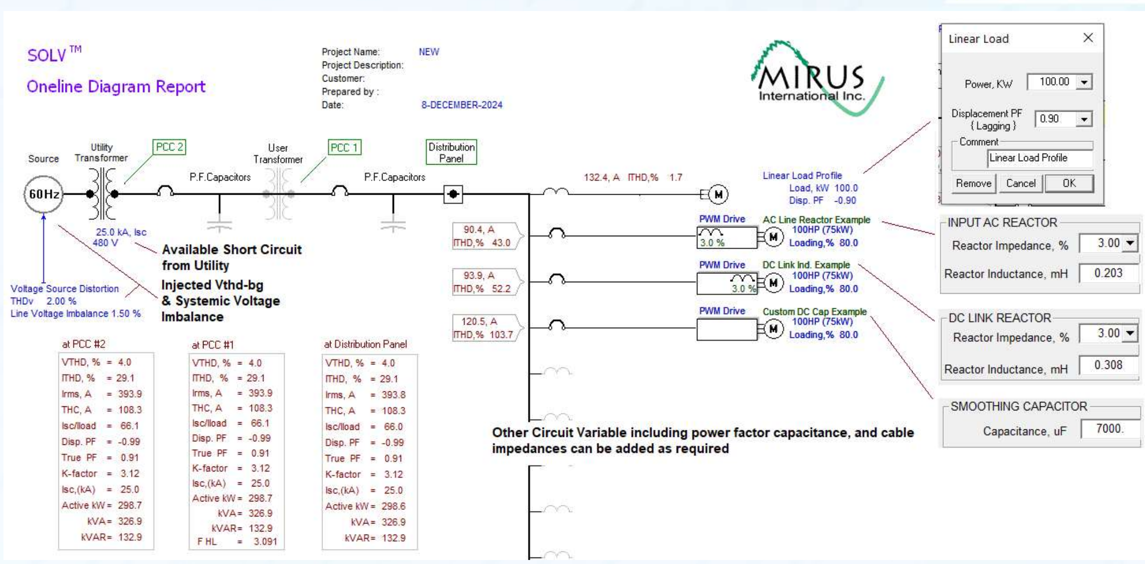
- **From either the one-line of the project or an inventory of the Linear Load Structures, you can approximate the Linear Loads that must be considered when designing the harmonic strategy.**
- **The greater the Linear Load content within the circuit, the lower the current harmonic at the Point of Common Coupling based on any given Non-Linear Load within the circuit. I refer to this as the "Dilution Factor". In other words, the higher the content of the Linear Load versus non-linear load the more the current harmonic is diluted before it reaches the PCC (Point of Common Coupling), i.e., the point within the circuit where the current harmonic and voltage distortion is to be qualified.**
- **To assist in an accurate True/Total Power Factor understanding, your Linear Load structure should include a displacement power factor value as a projected average of the linear loads within the circuit.**
- **The final calculated harmonic model must both the modeled Displacement Power Factor and Total/True Power Factor which can then be utilized to determine suitability for Utility power quality compliance.**



Discussion of Critical Information Required for Accurate Harmonic Modeling



Discussion of Critical Information Required for Accurate Harmonic Modeling



Discussion of Critical Information Required for Accurate Harmonic Modeling

- **Key Harmonic Modeling Specificational Points**
  - All Harmonic Models shall include a source background voltage distortion and systemic voltage imbalance factor within their calculations. The Vthd-bg and Vimb shall be determined by Utility report, site test data, or specified values as detailed within the specification. If not specified or data is not available, for industrial applications a minimum of 2% Source Vthd and 1-1/2% Vimb shall be assumed and utilized.
  - A Utility or Generator Source Impedance shall be factored into the model, an infinite bus assumption is not acceptable. This information must be derived from the Utility provider, generator data sheet (X"d % unsat.), a recent certified short circuit study, or other means acceptable to the reviewing engineer. The source impedance can be as specified within the specification if provided. If not provided or available, an assumption of 3kA or greater @ the known medium voltage level of the distribution voltage must be utilized or if the source is a generator 16% X"d.
  - The harmonic modeling software shall have a linear load component factored into the software and this value must be determined based on a specificational linear load detail from the one-line drawings. An associated displacement power factor must be assigned to the linear load based on an analysis of these loads or assumed to be 0.90 Lagging for the analysis.
  - The VFD harmonic contribution and spectrum algorithm must have the capacity to detail a DC link inductor, AC line reactor, VFD loading factor and DC Bus capacitance and calculate the harmonic contribution of the VFD within the program. Utilization of standard harmonic spectrum reference data is not acceptable.
  - For applications where a Backup Generator is to be provided, the Harmonic Model must detail both potential sources and provide a comparative analysis based on calculated performance for any given mitigation design. The harmonic deisgn must be shown to comply with IEEE519-2022 Std's for Table 1 (Voltage Distortion Limits) and Table 2 (Current Harmonic Limits) under their respective Short Circuit Ratios determine from their respective Source impedance factors.
  - The Harmonic Modeling Software utilized for the analysis must be the latest published SOLV TM Mirus International package or approved equal prior to bid.

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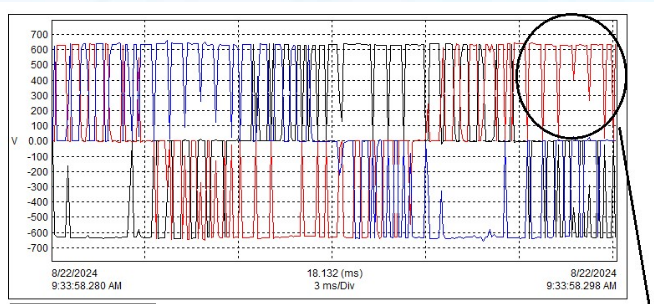
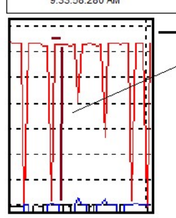
Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

This is a wave-trace of a typical VFD output PWM waveform, as can be seen there is a repetitive zero to peak voltage sequence exposing the secondary circuit components cabling and motor to high dv/dt stress. This is typically referred to as differential noise and will lower the life cycle of the load structures unless the load components are built to an "Inverter Duty" specification. So, Inverter Duty rated motors and Shielded Inverter Duty rated cables will be required. These enhancements are very expensive compared to standard cable and standard induction motors





The change in voltage as compared to time OV to peak voltage negative and positive sequence, dV/dT slope of the change creates significant dielectric stress on the entire secondary circuit and all electrical components within.

Secondary Inductors and dv/dt filters do not change this waveform, not addressing the dielectric stress created by the PWM output voltage waveform.

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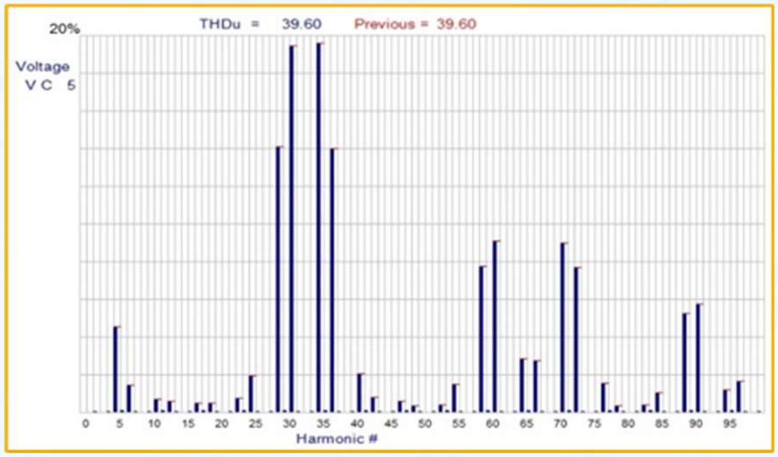
Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

The associated voltage distortion of a PWM waveform can be as high as 40% and will be centered around the switching of the inverter.

This harmonic source will generate elevated levels of eddy current loses and significant di-electric stress on components of the secondary circuit including the cable insulation systems and motors, as well as incremental heating due to harmonic injection.



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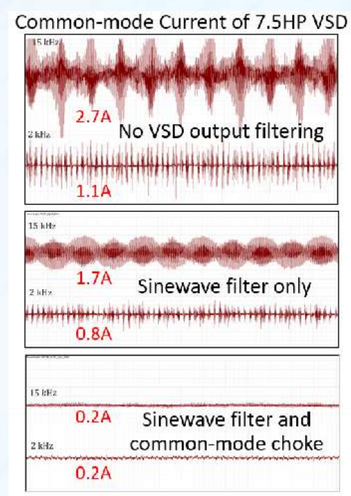
Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

Common Mode Noise Challenge:

The damage from common mode noise within the secondary circuit is created by partial discharge across the motor bearings and associated mechanical load structures, and parasitic capacitance compromising cable insulation to the system ground.

The graphic to the right highlight's common mode levels on a 7.5 HP VFD/VSD highlighting the substantial high frequency currents associated with common mode noise within the secondary circuit. It also shows that a Sinewave filter is not a viable solution for the common mode challenge. As the motor HP/load increases, the associated CM noise current levels will increase in a non-linear growth rate.

The remedy to avoid premature motor and cable failures is to eliminate potentially destructive dielectric stress (dv/dt) by converting the PWM waveform to a sinusoidal and the use of a Common Mode Choke is required.



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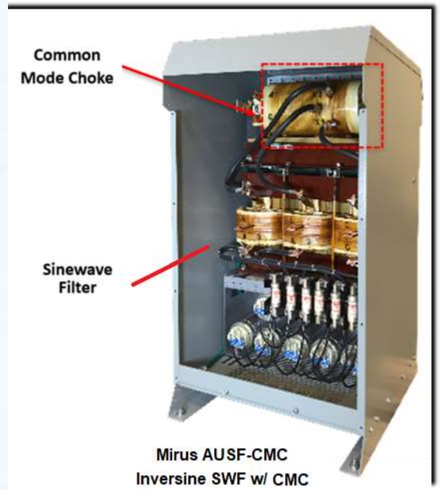
Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

Common Mode Noise Challenge:

In most cases, the addition of the Sinewave filter and Common Mode Choke is more than offset by cost saving by the ability to utilize standard unshielded cable and standard induction motors versus Inverter Duty components.

In addition, adding a Mirus AUSF Sine wave filter can increase the efficiency of the output circuit from 2% - 5% due to the elimination of eddy currents and secondary PWM losses associated with the mitigation of the voltage distortion of the PWM waveform harmonic spectrum.



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Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

	Shielded Inverter Duty Cable: 3C 350 MCM w/Ground					XHHW: 1C 350 MCM with single #3 Ground per conduit run					
Distance from Drive to Motor	Associated Cable Length	Typical Minimum Cable Purchase	$/Foot	Cable Cost without a minimum purchase Requirement	Cable Cost based on 1000' reel minimum	Associated Cable Length	No Minumum Cable Purchase Typ.	$/Foot 1C 350 MCM with Ground Conductor avg.	XHHW Cable Cost	Cable Cost Savings 1000"/reel minimum using XHHW versus Inverter Duty	Cable Cost Savings w/o minimum reel purchase using XHHW versus
50'	50	1000	$ 72.90	$ 3,645.00	$ 72,900.00	150	150	$ 10.75	$ 1,612.50	$ 71,287.50	$ 2,032.50
100'	100	1000	$ 72.90	$ 7,290.00	$ 72,900.00	300	300	$ 10.75	$ 3,225.00	$ 69,675.00	$ 4,065.00
150'	150	1000	$ 72.90	$ 10,935.00	$ 72,900.00	450	450	$ 10.75	$ 4,837.50	$ 68,062.50	$ 6,097.50
200'	200	1000	$ 72.90	$ 14,580.00	$ 72,900.00	600	600	$ 10.75	$ 6,450.00	$ 66,450.00	$ 8,130.00
300'	300	1000	$ 72.90	$ 21,870.00	$ 72,900.00	900	900	$ 10.75	$ 9,675.00	$ 63,225.00	$ 12,195.00
500'	500	1000	$ 72.90	$ 36,450.00	$ 72,900.00	1500	1500	$ 10.75	$ 16,125.00	$ 56,775.00	$ 20,325.00
750'	750	1000	$ 72.90	$ 54,675.00	$ 72,900.00	2250	2250	$ 10.75	$ 24,187.50	$ 48,712.50	$ 30,487.50
1000'	1000	1000	$ 72.90	$ 72,900.00	$ 72,900.00	3000	3000	$ 10.75	$ 32,250.00	$ 40,650.00	$ 40,650.00

Typical Cost of Mirus Inversine Sinewave Filter with Common Mode Choke @ 200HP/480V = $10,670 w/o freight Designation: AUSF-CMC

The difference in motor cost between non inverter duty rated and inverter duty rating is $1,200.00 for a 200 hp vertical motor. $57997.00 for a Std. Induction Motor vs. $59214.00 for an Inverter Duty Rated Motor

Beldon 29534 350-3C-2000V UL, 1000V C (UL) cost $72.90/foot, Minimum purchase by most distributor outlets, 1000' per reel

Single conductor 350 MCM XHHW-2 cost $10.11 per foot. A #3 ground is needed at $1.92 per foot. So the comparison for cable costs per foot so averaging the ground would result in a $10.75/ft average with the ground

Assumed same labor and conduit Cost for both installations

Distance from Drive to Motor	Inverter Duty Motor Cost	Induction Motor Cost	Motor Cost Savings	1000'/reel minimum Cable Cost Saving	No Minimum/Reel Cable Cost Saving	Less AUSF-CMC Inversine Sinewave Filter Cost	Cable & Motor Cost Saving based on using XHHW versus Inverter Duty Rated Cable - 1000" Reel	Cable & Motor Cost Saving based on using XHHW versus Inverter Duty Rated Cable - no Minimum Reel Length	Output Reactor Saving: $2063.00 Estimated	Output DV/DT savings: $2675.00 Estimated
50'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 71,287.50	$ 2,032.50	$ 10,670.00	$ 61,817.50	$ (7,437.50)	$ (5,374.50)	$ (4,762.50)
100'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 69,675.00	$ 4,065.00	$ 10,670.00	$ 60,205.00	$ (5,405.00)	$ (3,342.00)	$ (2,730.00)
150'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 68,062.50	$ 6,097.50	$ 10,670.00	$ 58,592.50	$ (3,372.50)	$ (1,309.50)	$ (697.50)
200'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 66,450.00	$ 8,130.00	$ 10,670.00	$ 56,980.00	$ (1,340.00)	$ 723.00	$ 1,335.00
300'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 63,225.00	$ 12,195.00	$ 10,670.00	$ 53,755.00	$ 2,725.00	$ 4,788.00	$ 5,400.00
500'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 56,775.00	$ 20,325.00	$ 10,670.00	$ 47,305.00	$ 10,855.00	$ 12,918.00	$ 13,530.00
750'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 48,712.50	$ 30,487.50	$ 10,670.00	$ 39,242.50	$ 21,017.50	$ 23,080.50	$ 23,692.50
1000'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 40,650.00	$ 40,650.00	$ 10,670.00	$ 31,180.00	$ 31,180.00	$ 33,243.00	$ 33,855.00

- **The typical minimum cable length purchase for Beldon Shielded Inverter Cable is 1000 foot. When considering a minimum cable reel length, under all distance considerations there is an immediate payback utilizing a Mirus AUSF-CMC filter saving significant project costs even up to 1000 cable lengths.**
- **If the AUSF-CMC filter is being utilized versus an inductor or dv/dt filter the immediate breakeven is just above 150' distance between the VFD and motor.**

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Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

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300'	300	1000	$ 72.90	$ 21,870.00	$ 72,900.00	900	900	$ 10.75	$ 9,675.00	$ 63,225.00	$ 12,195.00
500'	500	1000	$ 72.90	$ 36,450.00	$ 72,900.00	1500	1500	$ 10.75	$ 16,125.00	$ 56,775.00	$ 20,325.00
750'	750	1000	$ 72.90	$ 54,675.00	$ 72,900.00	2250	2250	$ 10.75	$ 24,187.50	$ 48,712.50	$ 30,487.50
1000'	1000	1000	$ 72.90	$ 72,900.00	$ 72,900.00	3000	3000	$ 10.75	$ 32,250.00	$ 40,650.00	$ 40,650.00

Typical Cost of Mirus Inversine Sinewave Filter with Common Mode Choke @ 200HP/480V = $10,670 w/o freight Designation: AUSF-CMC

The difference in motor cost between non inverter duty rated and inverter duty rating is $1,200.00 for a 200 hp vertical motor. $57997.00 for a Std. Induction Motor vs. $59214.00 for an Inverter Duty Rated Motor

Beldon 29534 350-3C-2000V UL, 1000V C (UL) cost $72.90/foot, Minimum purchase by most distributor outlets, 1000' per reel

Single conductor 350 MCM XHHW-2 cost $10.11 per foot. A #3 ground is needed at $1.92 per foot. So the comparison for cable costs per foot so averaging the ground would result in a $10.75/ft average with the ground

Assumed same labor and conduit Cost for both installations

Distance from Drive to Motor	Inverter Duty Motor Cost	Induction Motor Cost	Motor Cost Savings	1000'/reel minimum Cable Cost Saving	No Minimum/Reel Cable Cost Saving	Less AUSF-CMC Inversine Sinewave Filter Cost	Cable & Motor Cost Saving based on using XHHW versus Inverter Duty Rated Cable - 1000" Reel	Cable & Motor Cost Saving based on using XHHW versus Inverter Duty Rated Cable - no Minimum Reel Length	Output Reactor Saving: $2063.00 Estimated	Output DV/DT savings: $2675.00 Estimated
50'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 71,287.50	$ 2,032.50	$ 10,670.00	$ 61,817.50	$ (7,437.50)	$ (5,374.50)	$ (4,762.50)
100'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 69,675.00	$ 4,065.00	$ 10,670.00	$ 60,205.00	$ (5,405.00)	$ (3,342.00)	$ (2,730.00)
150'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 68,062.50	$ 6,097.50	$ 10,670.00	$ 58,592.50	$ (3,372.50)	$ (1,309.50)	$ (697.50)
200'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 66,450.00	$ 8,130.00	$ 10,670.00	$ 56,980.00	$ (1,340.00)	$ 723.00	$ 1,335.00
300'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 63,225.00	$ 12,195.00	$ 10,670.00	$ 53,755.00	$ 2,725.00	$ 4,788.00	$ 5,400.00
500'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 56,775.00	$ 20,325.00	$ 10,670.00	$ 47,305.00	$ 10,855.00	$ 12,918.00	$ 13,530.00
750'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 48,712.50	$ 30,487.50	$ 10,670.00	$ 39,242.50	$ 21,017.50	$ 23,080.50	$ 23,692.50
1000'	$ 59,214.00	$ 57,997.00	$ 1,200.00	$ 40,650.00	$ 40,650.00	$ 10,670.00	$ 31,180.00	$ 31,180.00	$ 33,243.00	$ 33,855.00

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Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

kWh Energy Charge Rate	Operating hours 24hr/day x 30 days/month	kW based on 200HP motor operated at 90% Load (kW)	kWH	Potential Monthly Energy Operating Cost	Potenital Annual Energy Operating Cost	2% Energy Improvement /Month	5% Energy Improvement /Month	Potential 2% Annualized Savings	Potential 5% Annualized Savings
$0.08	720	135	97200	$7,776.00	$93,312.00	$155.52	$ 388.80	$ 1,866.24	$ 4,665.60
$0.10	720	135	97200	$9,720.00	$116,640.00	$194.40	$ 486.00	$ 2,332.80	$ 5,832.00
$0.12	720	135	97200	$11,664.00	$139,968.00	$233.28	$ 583.20	$ 2,799.36	$ 6,998.40
$0.14	720	135	97200	$13,608.00	$163,296.00	$272.16	$ 680.40	$ 3,265.92	$ 8,164.80

Notes:

We have assumed an average 90% loading on the load, changes to this utilization level will imnpact on the actual savings.

The 2% - 5% range is provided for reference only, the actual circuit impedance and other load circuit factors will determine the actual savings.

The range of the kWh energy rates is typical in most applications but can change based on overall peak demand charges and other rate scaled factors.

With considerations of additional efficiencies from the Sinusoidal waveform feeding the secondary circuit and motor load, there could be a efficiency improvement within the operation of the loads and an associated energy savings which can result in a 2% - 5% improvement. The schedule below highlights the additional energy savings payback on top of the payback noted above…

The potential energy saving enhances the payback of adding a Sinewave Filter w/ Common Mode Choke and additional future energy cost savings making this circuit design a prudent engineering requirement.

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Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

Key Specificational Points: Clean Power VFD's w/ Sinewave Filter & Common Mode Choke Assembly

- **Output voltage waveform dV/dT stress and voltage overshoots characteristic for PWM inverter must be eliminated and suppressed without the need for snubber resistors, or auxiliary power electronic circuits.**
- **The Sinewave Filter shall have efficiency of no less than 99% and shall be suitable for application with PWM inverters that have carrier frequencies between 1.5 kHz to 8 kHz and motor leads up to 15,000 feet.**
- **The Sinewave Filter shall be tuned to 180 Hz versus 600Hz for differential noise mitigation of the 5th and 7th voltage distortion frequencies to enhance efficiency of the secondary circuit. Total Voltage Distortion shall be < 3% Vthd. The capacitive reactance of the Sinewave Filter at the load shall compensate for motor inductive reactive power such that power factor at the PWM inverter output is improved to 0.97 or better and will lower overall filter insertion loss (i.e. voltage drop) to < 3%.**
- **The Sinewave Filter cut-off frequency shall be set approximately three (3) times the max allowed fundamental frequency of the PWM inverter to attenuate the carrier components at the rate of >40db per decade while minimizing the absorption of fundamental current by the filter.**
- **The Sinewave Filter shall eliminate the effects of reflected wave phenomenon. The need for VFD-rated cables and Inverter Duty Motors will be eliminated when the common-mode option is included.**

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Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise

Key Specificational Points: Clean Power VFD's w/ Sinewave Filter & Common Mode Choke Assembly

- **Inductors shall be air-gapped to control magnetic saturation. The inductance shall remain above 50% of its nominal value for any overload not exceeding 200% of rated current.**
- **Include common-mode choke option (CMC) to reduce the effects of common-mode currents on motor bearings and cable insulation.**
- **Option: Coordinated Surge Suppression (CSP) with a minimum 100 kA withstand. The CSP option, when ordered, will provide a drive assembly 5 Year Warranty Standard.**
- **Integrated Drive Manufacturer Reference: Five Star Electric AS7 or AS100 CP-AUSF-CMC or equal approved prior to bid.**

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Questions ?

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Technical References:

- *IEEE/PCIC Paper PCIC-2010-15, Design Consideration When Applying Various ASD Topologies to Meet Harmonic Compliance .*
- *A Practical Guide to Partial and Staged Harmonic Mitigation Strategies, MIRUS-TP006-A, Michael A McGraw, 05/12/2020*
- *The Need for Harmonic Modeling and Mitigation in Generator Applications Mike McGraw USA National Sales Manager, Mirus International Inc. Dated 06/24/2021*
- *An 'Intuitive Understanding' of Electrical Harmonics: A Conversation, Mike McGraw USA National Sales Manager, Mirus International Inc. Dated 03/08/2021*
- *Tutorial - Harmonic Challenges for Distribution Grid Design, 3 Hour IEEE Tutorial, IEEE/PES WNC Chapter, 03/05/2024*
- *FSE:AS7CP Series Five Star Electric Clean Power Drive versus Autotransformer 18 Pulse Drive - "Real World" Water Applications*
- *Specificational Notes for VFD Secondary Circuit Design to Prevent Resonance & Common Mode Noise FSE Output-TD001 2024/11/29*
- *Mirus Series AUSF Inversine Sinewave Filter versus dV/dT Filter Discussion: Michael McGraw – Mirus International and Aron Sekula - Five Star Electric, San Antonio*

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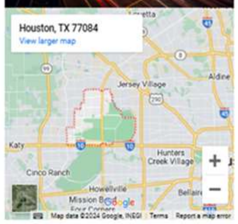

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