



The Need for Harmonic Modeling and Mitigation in Generator Applications: A Conversation and Guide

Michael McGraw, USA National Sales Manager, Mirus International Inc.

Introduction & Structure

It is widely accepted that performing harmonic studies for non-linear applications is important to ensure a workable and energy efficient installation. It is also accepted that these harmonic studies be performed under normal source conditions and maximum operating load. But it is even more critical to perform harmonic modeling and evaluation under unusual or emergency operating conditions, such as when supplied by a backup Generator source.

Generator sources have a much higher source impedance in comparison with Utility Distribution sources, meaning the short circuit ratio of the overall system is lower. A higher source impedance and lower short circuit ratio will result in a weaker or less stiff overall system, making control of source voltage regulation more difficult, and leading to higher associated voltage distortion from any given current harmonic load condition. Based on this, it is imperative that if a normal Generator Source or Emergency Generator system exists within a distribution scheme, a credible harmonic solution must be modeled, designed, and implemented for this operating configuration. Credible should be defined as a harmonic design that resolves the current harmonic and voltage distortion challenges within the system while not creating operational challenges for any potential source or load package within the circuit.

These challenges would include over- or under-excitation, excessive load voltage boost, excessive load voltage drop and potential resonance between the source and the capacitive reactance of any proposed harmonic mitigation solution. So, we must model and design the circuit to resolve the load current harmonic profile without compromising the operational integrity of the Generator Power Source.

This conversation is broken into two sections, the first is the required information and base data to build the harmonic model and enter this information into a computer simulation software package. The second is a case study on how the comparative modeling was used to analyze filtered versus unfiltered scenarios with Utility and Generator Sources with a provision for a future non-linear load expansion. We will utilize Mirus' SOLV computer simulation software since it is simple to use and allows for analysis under 'real world' conditions, including source/background voltage distortion, Vd, and systemic voltage imbalance. These two factors allow for a true determination of harmonic condition and must be considered to fully understand their impact on the circuit. SOLV software is a free download and is available at

<https://www.mirusinternational.com/register.php?reg=1>

Part 1: Determining Required Information and Model Data Input

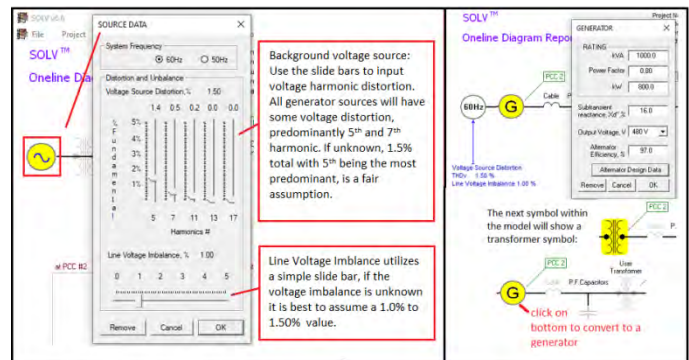
Required Generator Information:

To properly model a source Generator you must know the following data from the Generator specification sheet in order to setup the model:

- kW/kVA rating
- Power Factor
- Unsaturated Sub-transient Reactance ($X''d$)
- Source Voltage Distortion (when available)
- Source Voltage Imbalance (when available)

This information can typically be found from the Generator Data Sheet. Below is a diagram on how to load the data into the Mirus SOLV software package:

Source Data Graphic: By clicking on the source emblem, the window for source data will open.



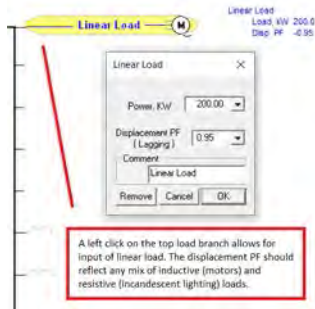
Within the Generator data section, enter the data from the generator specification info. There is a provision for alternator design data, where you can custom load the data. The software is using a "typical" core loss/resistance/reactance model. Care should be exercised when entering custom alternator information.

Required Load Data:

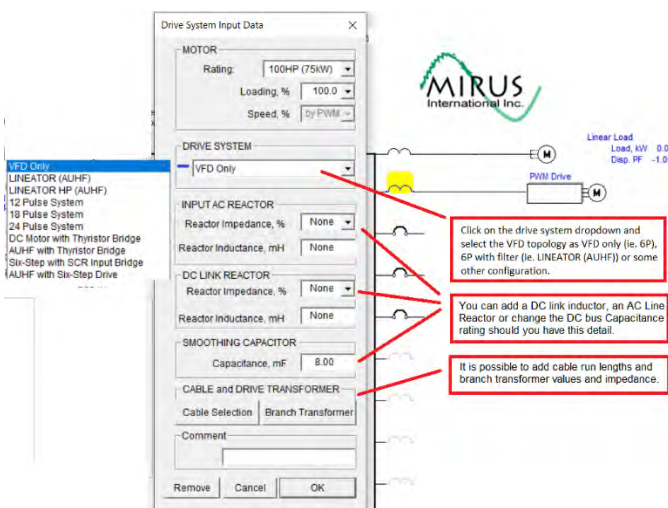
Often there is no load shedding associated with operation on a generator source, but within some Emergency Generator applications, there may be load shedding during transfer. Consult the load schedules and specifications for clarification.

The information below is required for an accurate model:

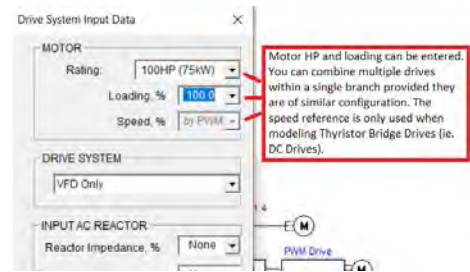
- Linear Load information including an estimate of the Displacement Power Factor. Consult the load schedule if present within the specification and drawings. For retrofit applications, a site survey should be done. Keep in mind that not all branch circuits are fully loaded, so a survey of the breaker current ratings is not appropriate. Linear load data will affect ITHD calculations at the Point of Common Couplings (PCC 1 and PCC 2) but will have minimal, if any, effect on VTHD. Including them is not always necessary for an accurate depiction of the effect of harmonic distortion.



- Non-Linear Load Information includes all existing drive loads and anticipated new drive loads associated with the review. The following data should be collected:
 - Drive Configuration: This would include the types of ASD/VFD equipment present within the system.
 - Drive Topology, such as 6 pulse or phase shifted multi-pulse.
 - Secondary/DC bus impedance structures, such as line reactors and/or DC bus inductors.



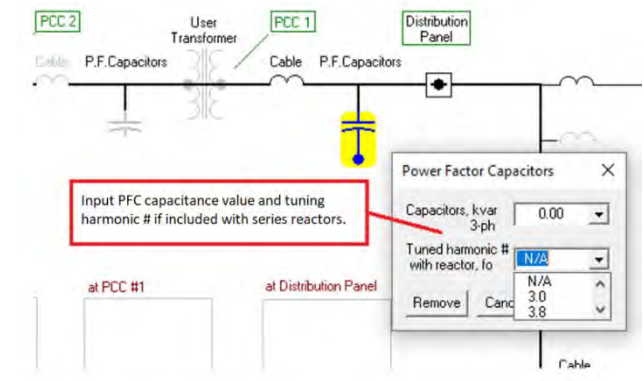
- Anticipated Load Values: Current Harmonic output of a VFD is a function of its relative load level. That is, the actual current load is relative to the rated load. For the SOLV simulation we use a Load %, not a speed reference within the model.



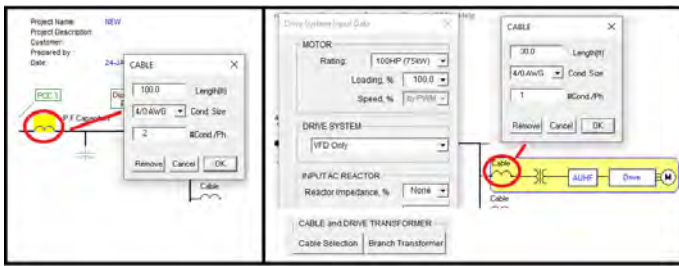
For worst case scenario, it is best to model the most heavily loaded condition anticipated. This may not always be 100% but selecting 100% would result in the highest levels of voltage distortion.

Cable runs and Power Factor Correction:

Within the SOLV Modeling software, you can input individual branch circuit cable runs or primary circuit cable runs for a more accurate representation of overall circuit impedances. This will result in slightly lower ITHD and VTHD values at the PCC's but can be neglected for worst case scenario, if unknown. Another important consideration is any existing or proposed power factor correction that may be within the circuit. If power factor correction capacitors exist, they should be included so that their impact on power system resonance is taken into consideration. Adding Power Factor Corrective equipment to a high harmonic load structure increases the possibilities of triggering harmonic resonance, especially on weak source systems like a generator supply. Within SOLV, you can add PF correction into the model and qualify the construction should it be of a tuned or detuned configuration.



To enter information on cable runs, see the diagram below. Keep in mind, the secondary impedance structure of associated cabling within the distribution system can have an effect. For the highest simulation accuracy, cable details should be included. But, if cable details are not available or if you want the model to be conservative in nature, you can ignore the cables or only include some runs of conductors. If the modeling is done without these secondary impedance structures, actual results will tend to be marginally better than the model itself. See diagram below for two cable run input locations within the SOLV software.



Part 1 Summary: Building the model may seem complicated but it is normally relatively simple. The entire concept and the ease of running these models is best demonstrated via the Case Study in Part 2. Even complicated systems can be reviewed relatively quickly by organizing the data properly and building a good base model. Then variations as to constructions and operating scenarios can be made with simple changes to the model data, including source parameters and future load structures.

When possible, it is important to include the following within the harmonic model:

- Source power quality condition is of an overriding concern when reviewing true harmonic conditions. If data is available relative to source or background voltage distortion or systemic voltage imbalance, it is best to include it within the model. If this information is not available, a good 'rule of thumb' is to assume 1.5% to 2% Background Vd for most commercial applications, 2% to 3% for moderate industrial applications such as Water/Waste-Water installations, and 5% or greater for heavy industrial installations such as Oil & Gas production. Systemic Voltage imbalance should be included based on actual test data or estimated at around 1% if unavailable.

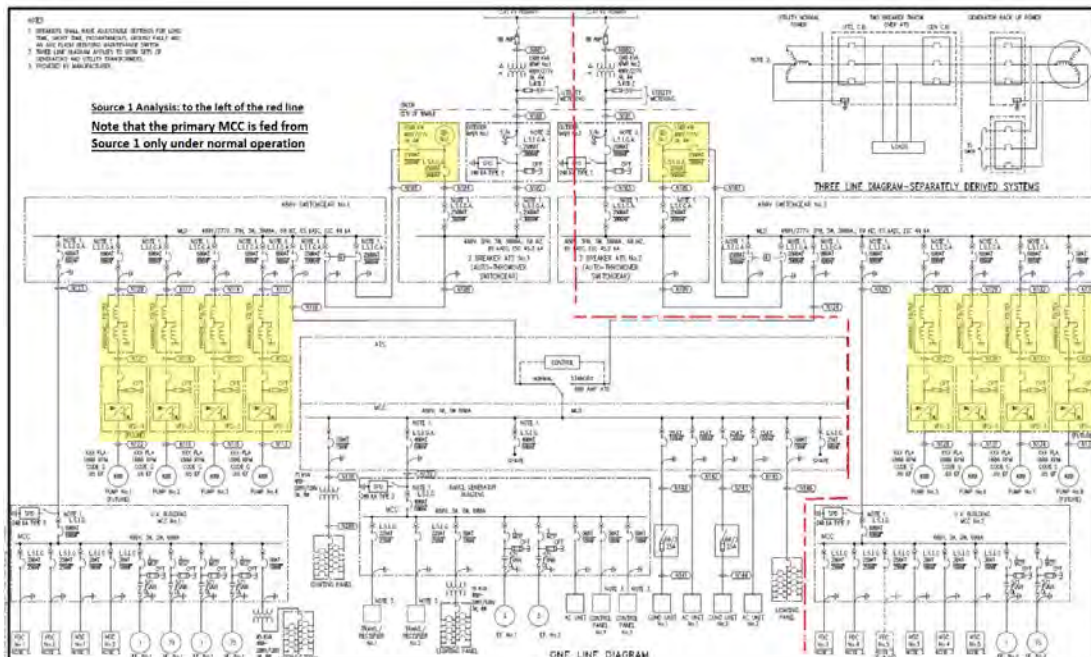
- Of course, non-linear load values should be considered. Software, such as SOLV, that calculates the harmonic spectrums of the loads through discrete components and does not depend upon look up tables structured around full load models, will provide the most accurate simulations. VFD speed and % load are different variables. The relationship between speed and % load is not linear since the motor load torque requirements can and will dictate the drive current draw characteristics.
- If the circuit contains existing power factor correction equipment, it must be reviewed and included within the model. Make sure to determine if the PFC assemblies are tuned, and at what frequency. Non-tuned PFC's can have serious resonance consequences to the voltage distortion within the system.

Part 2: Case Study: Temple TX Membrane Treatment Expansion

To understand the need and format of the harmonic mitigation modeling in relationship to a Generator Back-up (B/U) project, the following case study can be reviewed. For this discussion, we will review one Utility-B/U Gen-Set grouping to simplify an already complex analysis. The site actually has four Utility sources feeding isolated load structures, each having their own back-up generation. These were all analyzed for the project demonstrating the capabilities of this approach to harmonic analysis.

Step 1: One Line Review:

The first step is to review the 1-lines to gain a general sense of the situation. This particular project was complicated since it involved multiple Utility feeds/Backup Gen-set sources, within multiple load sections of the project. One part of the overall 1-Line is shown below:



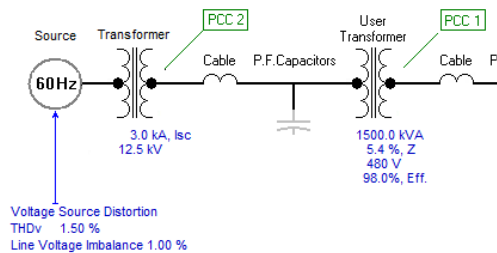
Note that there is no direct tie-breaker between the two Utility services and that the MCC loads are normally fed through the first Utility service, but are also fed from Gen-Set 1 when in standby mode. These types of supply changes must be considered when building your harmonic model. Also of interest is that there is 1200 HP of VFD loads potentially being fed from a 1500 kW generator on each side of the 1-line, with an additional 400 HP to be added at a future date. This needed to be considered within the sizing of the Gen-Sets, and construction specification for the harmonic filters, both existing and future. In this example, Utility source and Gen-set sources were both modeled to allow a complete project prospective.

Step 2: Modeling the Source

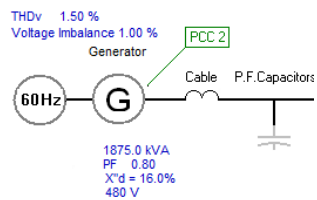
To model the Utility Source, a quick review of the nameplate or specification sheet of the transformer should be your first step. You will need to confirm the kVA, power factor, and % Impedance of the transformer. You should also review the Utility voltage, Available Short Circuit (ASC), Source Voltage imbalance and Source Voltage Distortion.

Utility Supply: 12.47 kV to 480V, 1500 kVA, .80 pf transformer. We were not given the ASC, or source condition. To be conservative, we assumed a 3kA ASC at 12.47 kV, 1% Voltage imbalance, and 1.5% Background Vd for the source.

Generator Supply: 1500 kW, 480V, 0.80 pf, X"d = 16%. No voltage imbalance or background voltage distortion was provided so the same assumptions were made as per the Utility Supply.



Utility Source Model Construction



Backup Generator Source Model Construction

Step 3: Building the Load Profile

For Utility Source – B/U Gen-Set 1, a quick review of the linear versus non-linear loads should be your first step.

Non-linear Load Profiles:

(Qty 3) 400 HP VFD’s with Harmonic Filters – Pump 2, 3 and 4: Since the VFD’s are being used for speed regulation, the actual maximum load current anticipated on each drive will be less than full load. The SOLV software versus other manufacturer and commercial harmonic software products takes this into consideration when calculating the current harmonic injection into the source impedance. Many other software packages will use the full speed spectrum which may not be accurate for a partially loaded VFD structure. For this example, we will use a 70% loading nominal value on all three VFD’s for the evaluation.

(Qty1) 400 HP Future VFD Load: Pump 1. The project calls for a fourth future designated 400 HP pump. Therefore, for a worst case scenario, analysis was done with all four pumps operating.

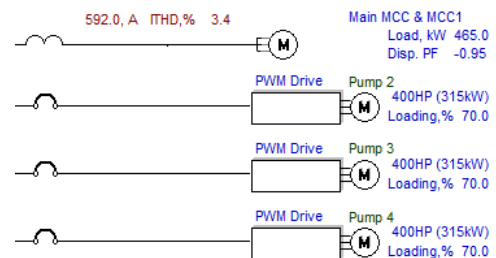
Linear Load Profile: From the 1-Line, Linear Load profiles were estimated as follows:

MCC-1: 600A at a nominal loading of 40% -> 240A @ 480V = 200 kW, pf of .95

Primary MCC: 800A at a nominal loading of 40% -> 320A @ 480V = 265 kW, pf of .95

(Note: there are AC Unit Condensers present in this case they are linear loads)

Total Linear Load for the model: 465 kW



Note: No cable runs and no specific detail on the VFD’s are known since this is a new installation and the drive brand and construction are unknown.

Step 4: Models to Compare Performance to IEEE Std 519 under Different Source Conditions

This step is quite easy. First build a base model using the Utility Source data with the associated loads without any harmonic mitigation or filtration. The model should reflect line reactors and/or DC link inductors should that be the normal installation configuration from the manufacturer. This will act as your base model and help streamline the modeling function moving forward. For this study, I have labeled this as the Utility Source – Unfiltered (Model 1). Then I can simply save this model and as variations are made, the new files can be saved under different file names. SOLV also allows comparative models in one file by establishing a base model as “Scenario A” and then adding a second scenario “Scenario B” for comparison.

It should be noted that the SOLV software only has built-in models for Mirus AUHF and AUHF-HP passive harmonic filters. These models are based on our proprietary inductive /capacitance network and therefore, the use of SOLV is not appropriate for modelling competitive passive filter products. An important difference in the Mirus filter design is our low capacitive reactance ratio to full power rating, which prevents overexciting a generator supplied circuit. At 100 HP and greater power, the kVAR to kW ratio is less than 15%. For competitive

filters, this ratio can be as high as 40%, which can result in higher voltage boost at no load, generator instability and the requirement for a capacitor switching contactor. As stated, the SOLV software is not appropriate for modeling any passive filters other than the Mirus product offering.

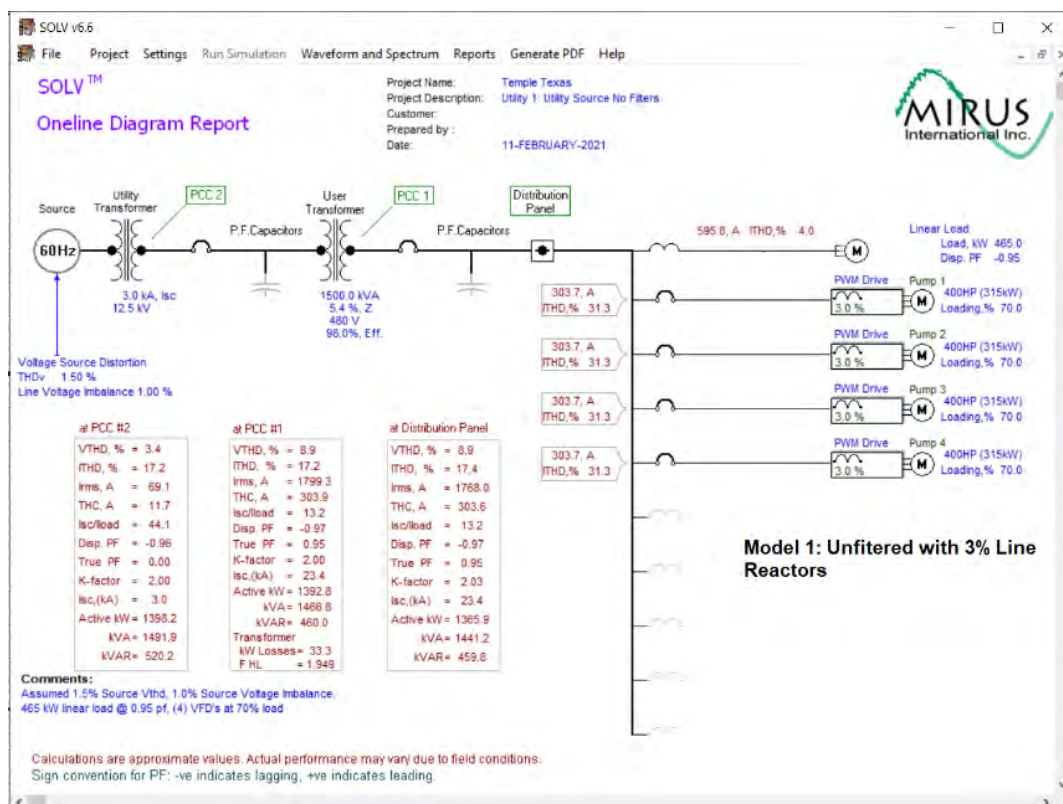
Following are the Model Summaries we will review:

- Model 1: Utility Source with 3% AC Reactors
- Model 2: Utility Source with Mirus AUHF Filters
- Model 3: Generator Source with 3% AC Reactors
- Model 4: Generator Source with AUHF filters
- Model 5: Generator Source with AUHF-HP High Performance filters

It is noted that IEEE519 defines the limits at the Point of Common Coupling (PCC). For reliable equipment operation, we recommend that the analysis consider the Generator terminals to be the PCC when operating on the Generator supply.

Model 1: Utility Source – Unfiltered

Loading the Data as previously discussed, we input the Utility parameters and then input the step-down transformer information as the User Transformer. This allows us to compare the Utility PCC 2 versus the End User PCC 1 within the model:



As can be seen, on Utility supply at PCC 1, the 480V VTHD level is 8.9% and ITHD or ITDD is 17.2%. In this case, ITHD and ITDD are the same value because the analysis was done at what is anticipated to be maximum load level. At the 12 kV Utility bus, PCC 2, VTHD is 3.4%. ITDD is the same as the PCC 1 ITDD since these harmonic currents pass through the transformer. The IEEE 519 compliance schedule, showing both 1992 and 2014 requirements, is below:

Project Name: Temple Texas
Point of Coupling: PCC #2
Bus voltage at PCC: 12 kV
Short-circuit ratio: 44.1
Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

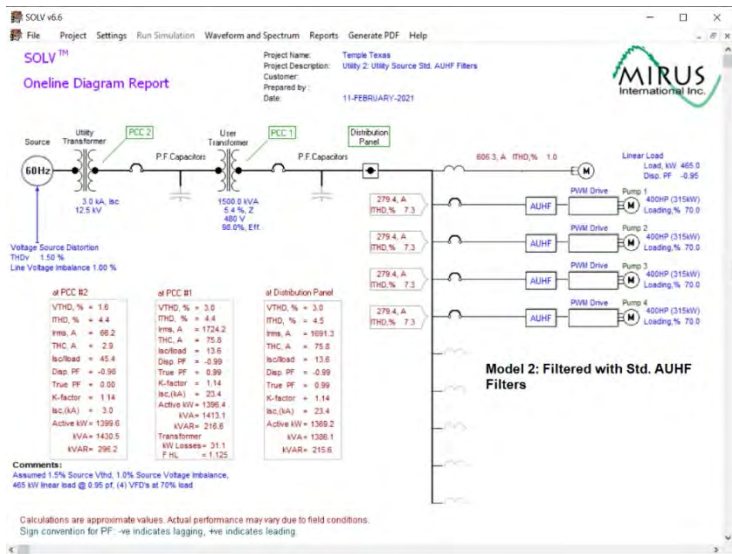
	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	3.4	5.0	PASS
Max. Individual Voltage Harmonic	2.9 {5}	3.0	PASS
Current Total Demand Distortion (ITDD)	17.2	8.0	FAIL
Max. Individual current harmonic	<11	7.0	FAIL
11 to 16	2.5 {11}	3.5	PASS
17 to 22	0.8 {19}	2.5	PASS
23 to 34	0.5 {25}	1.0	PASS
>35	0.2 {37}	0.5	PASS

Point of Coupling: PCC #1
Bus voltage at PCC: 480 V
Short-circuit ratio: 13.2
Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	8.9	5.0	FAIL
Max. Individual Voltage Harmonic	6.8 {5}	3.0	FAIL
Current Total Demand Distortion (ITDD)	17.2	5.0	FAIL
Max. Individual current harmonic	<11	4.0	FAIL
11 to 16	2.5 {11}	2.0	FAIL
17 to 22	0.8 {19}	1.5	PASS
23 to 34	0.5 {25}	0.6	PASS
>35	0.2 {37}	0.3	PASS

Notes: Based on the information provided, this application will NOT meet IEEE Std 519 harmonic limits

Model 2: Utility Source Filtered with Mirus AUHF Filters



Once we filter the VFD's, the associated harmonic distortion is reduced at PCC 1 to 3.0% VTHD and 4.4% ITHD. This indicates that the harmonic filtration limited the net PCC 1 voltage distortion to only 1.5% more than the background Vd from the source (1.5%). As per the following tables, IEEE 519 limits are met at both PCC 1 and PCC 2.

Project Name: Temple Texas
Point of Coupling: PCC #2
Bus voltage at PCC: 12 kV
Short-circuit ratio: 45.4
Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	1.6	5.0	PASS
Max. Individual Voltage Harmonic	1.4 {5}	3.0	PASS
Current Total Demand Distortion (ITDD)	4.4	8.0	PASS
Max. Individual current harmonic	<11	7.0	PASS
11 to 16	1.4 {11}	3.5	PASS
17 to 22	0.6 {17}	2.5	PASS
23 to 34	0.3 {25}	1.0	PASS
>35	0.1 {37}	0.5	PASS

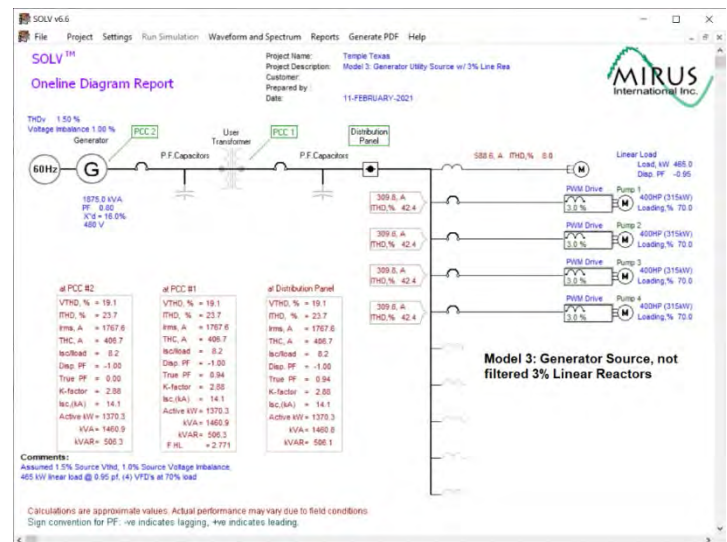
Point of Coupling: PCC #1
Bus voltage at PCC: 480 V
Short-circuit ratio: 13.6
Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	3.0	5.0	PASS
Max. Individual Voltage Harmonic	1.8 {7}	3.0	PASS
Current Total Demand Distortion (ITDD)	4.4	5.0	PASS
Max. Individual current harmonic	<11	4.0	PASS
11 to 16	1.1 {11}	2.0	PASS
17 to 22	0.6 {17}	1.5	PASS
23 to 34	0.3 {25}	0.6	PASS
>35	0.1 {37}	0.3	PASS

Notes: Based on the information provided, this application will meet IEEE Std 519 harmonic limits

The model and results show that there is significant headroom for future non-linear load additions without concern for exceeding harmonic compliance.

Model 3: Generator Source with 3% AC Reactors



As can be seen, the weak Generator Power Source has a significant effect on the harmonic profile of the circuit. At PCC 1, Vthd is projected to be 19.1% and Ithd 23.7%. This dramatically shows the need to run Back-up Generator harmonic modeling. The IEEE 519 compliance schedule is as follows:

Project Name: Temple Texas
 Point of Coupling: PCC #2
 Bus voltage at PCC: 480 V
 Short-circuit ratio: 8.2

Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	19.1	5.0	8.0
Max. Individual Voltage Harmonic	13.5 {5}	3.0	5.0
Current Total Demand Distortion (ITDD)	23.7	5.0	5.0
Max. Individual current harmonic	<11	4.0	4.0
11 to 16	3.6 {11}	2.0	2.0
17 to 22	1.2 {17}	1.5	1.5
23 to 34	0.6 {25}	0.6	0.6
>35	0.3 {39}	0.3	0.3

Point of Coupling: PCC #1
 Bus voltage at PCC: 480 V
 Short-circuit ratio: 8.2

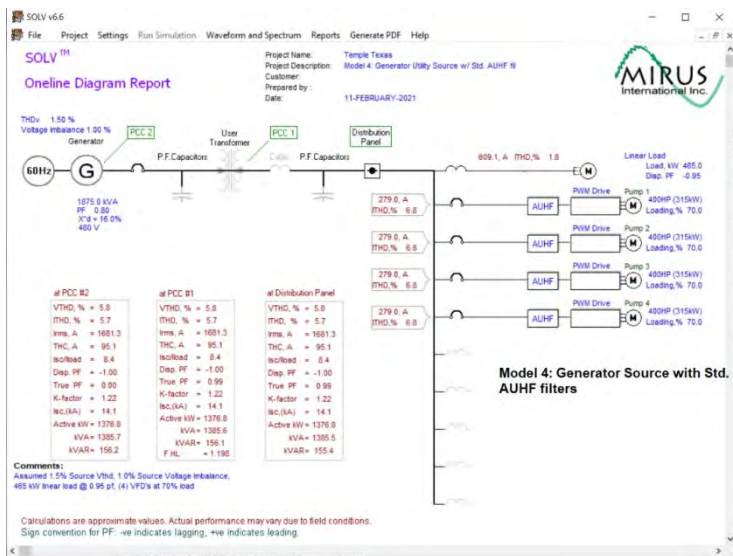
Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	19.1	5.0	8.0
Max. Individual Voltage Harmonic	13.5 {5}	3.0	5.0
Current Total Demand Distortion (ITDD)	23.7	5.0	5.0
Max. Individual current harmonic	<11	4.0	4.0
11 to 16	3.6 {11}	2.0	2.0
17 to 22	1.2 {17}	1.5	1.5
23 to 34	0.6 {25}	0.6	0.6
>35	0.3 {39}	0.3	0.3

Notes: Based on the information provided, this application will NOT meet IEEE Std 519 harmonic limits

It is clear that operating the pumps with only 3% AC reactors exhibits poor harmonic performance, to the point where it is doubtful that the generator would function properly due to voltage regulation challenges and overheating of the alternator windings.

Model 4: Generator Source with AUHF filters



Project Name: Temple Texas
 Point of Coupling: PCC #2
 Bus voltage at PCC: 480 V
 Short-circuit ratio: 8.4

Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	5.8	5.0	8.0
Max. Individual Voltage Harmonic	3.9 {7}	3.0	5.0
Current Total Demand Distortion (ITDD)	5.7	5.0	5.0
Max. Individual current harmonic	<11	4.0	4.0
11 to 16	1.6 {11}	2.0	2.0
17 to 22	0.7 {17}	1.5	1.5
23 to 34	0.4 {23}	0.6	0.6
>35	0.2 {37}	0.3	0.3

Point of Coupling: PCC #1
 Bus voltage at PCC: 480 V
 Short-circuit ratio: 8.4

Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]	IEEE-519:2014 Limit, [%]
Voltage Total Harmonic Distortion (VTHD)	5.8	5.0	8.0
Max. Individual Voltage Harmonic	3.9 {7}	3.0	5.0
Current Total Demand Distortion (ITDD)	5.7	5.0	5.0
Max. Individual current harmonic	<11	4.0	4.0
11 to 16	1.6 {11}	2.0	2.0
17 to 22	0.7 {17}	1.5	1.5
23 to 34	0.4 {23}	0.6	0.6
>35	0.2 {37}	0.3	0.3

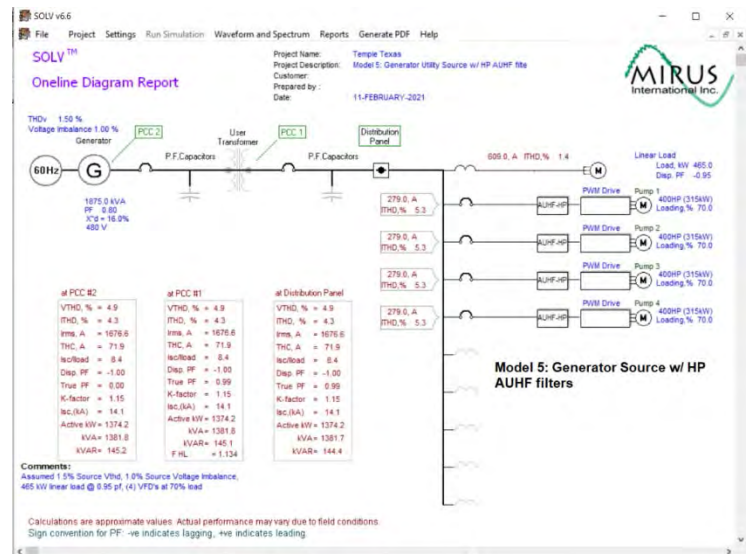
Notes: Based on the information provided, this application will NOT meet IEEE Std 519 harmonic limits

With respect to voltage distortion, the 8% 2014 version limit is met but the previous 1992 version limit of 5% is not. So the question becomes what level of voltage distortion is acceptable for the application. With respect to current distortion, we see that the lower limits defined by the low short circuit ratio are marginally exceeded in both total ITDD and for the largest individual harmonic, which is the 7th harmonic in this case.

Step 5: Additional Mitigation Model with AUHF-HP Filter Option

Since IEEE Std 519 compliance is not fully met when supplied by generator source even when the standard harmonic filter is applied, a final simulation is done using higher performance AUHF-HP harmonic filters.

Model 5: Generator Source with High Performance AUHF-HP filters



With the additional harmonic mitigation capabilities of the HP series AUHF filter, the overall VTHD and ITHD are both reduced to less than 5%. Since this is a conservative analysis, we can safely predict that all requirements of IEEE Std 519 will be met in both Utility and Generator Source configurations even when all four pumps are in operation. IEEE compliance summary is below:

Project Name: Temple Texas
 Point of Coupling: PCC #2
 Bus voltage at PCC: 480 V
 Short-circuit ratio: 8.4

Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]		IEEE-519:2014 Lin	
Voltage Total Harmonic Distortion (VTHD)	4.9	5.0	PASS	8.0	PAS
Max. Individual Voltage Harmonic	2.4 (7)	3.0	PASS	5.0	PAS
Current Total Demand Distortion (ITDD)	4.3	5.0	PASS	5.0	PAS
Max. Individual current harmonic	3.1 (7)	4.0	PASS	4.0	PAS
	1.7 (11)	2.0	PASS	2.0	PAS
	0.7 (17)	1.5	PASS	1.5	PAS
	0.3 (25)	0.6	PASS	0.6	PAS
	0.1 (37)	0.3	PASS	0.3	PAS

Point of Coupling: PCC #1
 Bus voltage at PCC: 480 V
 Short-circuit ratio: 8.4

Summary of Compliance with IEEE Std 519:1992 and IEEE Std 519:2014 Harmonic Limits:

	Calculated Value, [%]	IEEE-519:1992 Limit, [%]		IEEE-519:2014 Lin	
Voltage Total Harmonic Distortion (VTHD)	4.9	5.0	PASS	8.0	PAS
Max. Individual Voltage Harmonic	2.4 (7)	3.0	PASS	5.0	PAS
Current Total Demand Distortion (ITDD)	4.3	5.0	PASS	5.0	PAS
Max. Individual current harmonic	3.1 (7)	4.0	PASS	4.0	PAS
	1.7 (11)	2.0	PASS	2.0	PAS
	0.7 (17)	1.5	PASS	1.5	PAS
	0.3 (25)	0.6	PASS	0.6	PAS
	0.1 (37)	0.3	PASS	0.3	PAS

Notes: Based on the information provided, this application will meet IEEE Std 519 harmonic limits

Final Design Summary and Conclusions:

Below is a summary of the models for this case study:

Model	Configuration	ITHD	VTHD	kVAR	Total pf	IEEE
1	Utility Source with AC reactors	17.2%	8.4%	460	0.95	IEEE 519 Fail
2	Utility Source with Std. AUHF Filters	4.4%	3.0%	216.6	0.99	IEEE 519 Pass
3	Generator Source with AC reactors	23.7%	19.1%	506.3	0.94	IEEE 519 Fail
4	Generator Source with AUHF filters	5.7%	5.8%	156.1	0.99	IEEE 519 Marginally Fail
5	Generator Source with AUHF-HP filters	4.3%	4.9%	145.1	0.99	IEEE 519 Pass

- All measurements shown are at PCC #1
- Note the dramatic reduction in Reactive Power Consumption and Power Factor Improvement when harmonic mitigation is applied to the circuit

- The computer simulations confirmed that IEEE Std 519 requirements would not be met with the application of reactors only, especially under Generator supply.
- With the application of standard Lineator AUHF passive filters, IEEE Std 519 was met under Utility supply but marginally failed under Generator supply. The application passed VTHD limits for the 2014 edition, but slightly failed on current. This could be considered acceptable performance since it is highly unlikely that these levels would cause equipment malfunction.
- A final simulation was performed using higher performance Lineator AUHF-HP filters which guarantee < 5% ITDD. In this simulation, all requirements for both 2014 and 1992 editions of the standard are met.
- An interesting observation is the reduction in Reactive Power Consumption as harmonic mitigation is applied. Reactive power is non-work producing power, meaning that the overall system is becoming more efficient as a result of the harmonic mitigation strategy.
- Once the VFD supplier is determined for the project, a revamp of the harmonic models for the VFD configuration is advisable to help fine tune the evaluation. Variables that should be considered were discussed within Part 1 of the paper. The successful bidder will be required, by specification, to provide a harmonic review of all segments of the project, which include Source Voltage Distortion and Voltage Imbalance as a modeling qualification.
- As part of the specification, the supplier of the equipment will be required to perform verification of harmonic performance and compare these results to the selected harmonic mitigation manufacturer's required harmonic models. The successful manufacturer and contractor must warranty their harmonic performance to IEEE Std 519, through modeling and field verification.

The need to Model Harmonics in relation to the IEEE 519 Std under Generator Supply is paramount to a sound engineering design if a Generator is an available source for the loads.