APPENDIX B - SOUND MONITORING STUDY

Field measurements were taken to quantify sound levels in the area surrounding the Substation. The neighboring residents communicated that noise generated by the Substation reaches their houses and causes discomfort. In an effort to determine how sound generated at the Substation affects the neighboring properties, both near-field and far-field measurements were taken.

Near-field measurements are those taken close to the autotransformers. Near-field measurements reduce the influence of extraneous background sounds. Since the Substation is not operating in a controlled environment, it is nearly impossible to measure only the autotransformers' sound levels without significant isolation techniques that would potentially be unsafe for testing personnel. However, the near-field sound levels are considered generally representative of each piece of equipment's operational sound levels, as most background sounds have little influence this close to the autotransformers.

Far-field measurements are those taken outside the Substation fenceline. Far-field measurements are affected more by extraneous sources of sound than are near-field measurements, but they provide information on how sound potentially propagates outward from the Substation.

Short-Term Measurements

Both near-field and far-field short-term measurements were taken at the facility.

Short-Term Near-Field Measurements

To quantify and qualify the sound of the autotransformers at the Substation, short-term near-field measurements were taken at the facility on January 27 and July 26, 2016. The autotransformers have firewalls installed between the individual units, but they do not have firewalls on the outsides of the autotransformer banks. Sound generated by the autotransformers is allowed to radiate in all directions.

Measurements were taken using an ANSI S1.4 type 1 sound-level meter (Larson-Davis Model 831). The sound-level meter was calibrated before and after each set of measurements. None of the calibration level changes exceeded ± 0.5 dB, which is within the acceptable variance per ANSI guidance. A windscreen was used at all times on the microphone to avoid the influence of wind-induced sound increases.

Short-term near-field measurements around the autotransformers were taken at both one-third and two-thirds of the height of the tanks along the equipment envelope, consistent with Institute of Electrical and Electronics Engineers (IEEE) C57.12.90 – Standard Test Code for Liquid-Immersed Distribution, Power,

and Regulating Transformers. Measurements were taken with the fans off. It is not possible to safely measure sound levels directly above an energized autotransformer. The high-voltage nature of substations requires clearances be maintained from all energized equipment for safety reasons, and the IEEE standard does not prescribe measurements be taken there.

Short-Term Far-Field Measurements

Burns & McDonnell personnel took short-term far-field measurements near the Substation during four time periods on January 26 and 27 and June 22 and 23, 2016. Each set of measurements consisted of eight hours of monitoring over a 24-hour period. Measurements were taken at the property line continuous monitor locations to verify the accuracy of the continuous monitors. All sets of measurements were taken when meteorological conditions were favorable for conducting ambient sound measurements. The measured, A-weighted L_{eq} sound levels from the short-term far-field studies were compared to the continuous monitors to determine accuracy of the continuous monitors. The far-field measurements closely followed the respective continuous monitor location sound levels for the times when the measurements were taken. No exceedances of the applicable regulations were measured during the short-term far-field measurements.

Continuous Long Term Monitoring

Five continuous, long-term sound monitors were installed at various locations in and around the substation to monitor sound during three multi-week time periods. One meter was placed 15 feet from the northern edge of the operational 1x autotransformer (Meter 1). This meter acted as a “control meter” for the 1x autotransformer since it was unlikely to be significantly affected by extraneous sounds. A second control meter was installed 15 feet from the northern edge of the 2x autotransformer (Meter 2). This meter acted as a control meter for the 2x autotransformer. Sound levels at the control meters were used as the basis for comparison to the offsite meters. Three other sound meters (Meter 3, Meter 4, and Meter 5) were installed at various locations along the Substation property line in the directions of the closest neighboring residences. The locations of all five meters can be seen in Figure B-1.

Figure B-1: Continuous Monitoring Points

The meters placed along the property line would potentially quantify any spikes in sound emitted by the Substation in the direction of neighboring houses. The meters were installed at an elevation of approximately 7 to 8 feet above the ground surface. Simultaneous measurements at the property line and the control meters could potentially demonstrate cause-and-effect relationships of the sound propagating from the Substation towards the neighboring residences (i.e., discernible trends measured at one noise meter location should correspond to trends at the other noise meter location if both noise meter locations are affected by the same sources).

January to February 2016 Noise Monitoring

Continuous sound monitoring for the Substation was conducted from January 26 to February 16, 2016, to establish operating sound levels of the Substation and determine sound levels at the property line of the Substation during winter months. Both the 1X and the 2X autotransformers were in service. The anti-vibration pads had not yet been installed under the 1X autotransformer.

Onsite Control Meters

Two control meters were placed onsite, Meter 1 and Meter 2. Due to the proximity of the control meters to their respective autotransformers, the meters were not significantly affected by extraneous sources and represent operational sound levels of the autotransformers. The average, minimum, and maximum sound levels measured at the control meters are shown below in Table 1.

Table 1: Control Meter Sound Levels (Winter 2016)

1-Minute Leq	Meter 1 (1x)	Meter 2 (2x)
Minimum sound level	41.9 dBA	47.4 dBA
Three-week average sound level	56.5 dBA	61.6 dBA
Maximum sound level	77.0 dBA	81.3 dBA

The measurement data shows how sound levels fluctuated throughout the 3-week period. The average sound levels for the autotransformers are consistent with the rated sound levels. However, the data confirms that there are spikes in sound and significant variations in operating sound levels of the autotransformers.

The autotransformer sound levels were generally dominant in the 125- and 400-Hz octave bands. At times throughout the measurements, autotransformer sound levels spiked by as much as 20 to 25 dBA. The sound level spikes remained elevated for various amounts of time, generally around 15 minutes, before

eventually falling back to normal levels. The loudest hourly-average sound level at Meter 2 reached 75.3 dBA on January 31, 2016, at 11:06 P.M. At that same time, Meter 1 recorded an hourly-average sound level of 63.3 dBA. During this hour, the sound levels peaked in the 400-Hz octave band. The overall sound levels during this time continually oscillated in amplitude by as much as 20 dB at Meter 2, and reached an overall 1-minute maximum of 81.3 dBA at Meter 2. During this time, period Meter 1 reached a peak 1-minute maximum of 69.1 dBA. Similar pulses in sound were measured at both control meters on February 8 and 16, 2016.

Property Line Meters

Three sound level meters were placed along the Substation property line: Meter 3, Meter 4 and Meter 5. The average, minimum, and maximum sound levels measured at the meters over the 3-week period are shown below in Table 2. It should be noted that the maximum sound levels recorded at each meter were attributed to offsite sound sources and were not consistent with Substation operation.

Table 2: Property Line Meter Sound Levels (Winter 2016)

1-Minute Leq	Meter 3	Meter 4	Meter 5
Minimum sound level	26.9 dBA	25.1 dBA	25.9 dBA
Average sound level	41.4 dBA	47.9 dBA	46.6 dBA
Maximum sound level[a]	71.5 dBA	80.3 dBA	87.1 dBA

(a) Maximum sound levels of property line meters were attributed to extraneous sources.

The property line meters fluctuated constantly due to extraneous sources. However, review of the data shows there were time periods where background sounds were low and the property line meters appeared to clearly follow changes in Substation sound measured at the control meters. During these times, the meters' peak frequencies were consistent with Substation operation (i.e., peak contribution to sound levels from the 125- and 400-Hz octave bands).

The maximum hourly nighttime sound levels at the property line meters that could be attributed to Substation operation were measured on February 8, 2016, at 2:25 AM for Meter 3, and on February 16, 2016, at 5:02 AM for Meter 5. Meter 4 provided additional data, but due to the meter's location, much of the data was heavily influenced by traffic sounds. During each of these time periods, all of the property line meters measured prominent discrete tones in the 400-Hz octave band, consistent with Substation operation. The tone was less readily apparent at Meter 4 due to traffic. As stated in Chapter 3, the overall

sound level limit is reduced to 46 dBA at night in the presence of measured prominent discrete tones. Table 3 and Table 4 show the two measured peak time periods.

Table 3: Sound Levels on February 8, 2016, at 2:25 AM

Meter	Date	Time	1-Min Leq (dBA)	Hourly Leq[a] (dBA)
Meter 1 Control meter (1x Auto)	2/8/2016	2:25 AM	63.9	60.7
Meter 2 Control meter (2x Auto)	2/8/2016	2:25 AM	74.4	71.1
Meter 3 South at Property Line	2/8/2016	2:25 AM	50.1	47.8 (limit 46 dBA)

(a) Hourly sound level measured from 1:55 AM to 2:55 AM

Table 4: Sound Levels on February 16, 2016, at 5:02 AM

Meter	Date	Time	1-Min Leq (dBA)	Hourly Leq[a] (dBA)
Meter 1 Control meter (1x Auto)	2/16/2016	5:02 AM	63.6	59.2
Meter 2 Control meter (2x Auto)	2/16/2016	5:02 AM	74.0	67.2
Meter 5 North at Property Line	2/16/2016	5:02 AM	52.4	48.5 (limit 46 dBA)

(a) Hourly sound level measured from 4:32 AM to 5:32 AM

June to August 2016 Noise Monitoring

Continuous sound monitoring for the Substation was conducted from June 21 to August 22, 2016, to establish operating sound levels of the fully energized Substation and determine sound levels at the property line of the Substation during the summer months, which typically represent peak levels of demand. Both the 1X and 2X were in-service and both had the anti-vibration pads installed. This data has been collected to determine if there are significant changes in operation during different seasons of the year.

It should be noted that a berm was constructed south of the Substation between the fence and the property line. This berm was constructed after the January and February measurements, but before the June, July, and August measurements. Meter 3 was placed near the south property line approximately 75 feet south of the base of the berm. This berm helps block Substation-generated sound south of the Substation.

Onsite Control Meters

Two control meters were placed onsite at the same locations used in January and February 2016, Meter 1 and Meter 2. Due to the proximity of the control meters to their respective autotransformers, the meters were not significantly affected by extraneous sources and represent operational sound levels of the autotransformers themselves. The average, minimum, and maximum sound levels measured at the control meters are shown below in Table 5.

Table 5: Control Meter Sound Levels (Summer 2016)

1-Minute Leq	Control Meter 1 (1x)	Control Meter 2 (2x)
Minimum Sound Level	43.2	48.4
Two-Month Average Sound Level	56.4	58.4
Maximum Sound Level[a]	74.2	80.0

(a) A maximum sound level of 91 dBA at both meters was measured during the study. However, this maximum was attributed to extraneous sources because the property line meters showed the same overall sound levels as the control meters and a frequency analysis showed the sound was not the Substation. The maximum sound levels attributable to the autotransformers were measured on August 11 at 11:05 PM.

The measurement data shows how sound levels fluctuated throughout the 2-month period. The average sound levels for the autotransformers are similar to what was measured in January and February. This set of data confirms that there continue to be frequent spikes in sound and significant variations in operating sound levels of the autotransformers.

The autotransformer sound levels were generally dominant in the 125- and 400-Hz octave bands. At times throughout the measurements, autotransformer sound levels spiked by as much as 20 to 25 dBA. The sound level spikes remained elevated for various amounts of time, generally around 15 minutes, before eventually falling back to normal levels. The loudest hourly-average sound level at Meter 2 reached 75.4 dBA on July 14, 2016, at 2:36 A.M. At that same time, Meter 1 recorded an hourly-average sound level of 65.4 dBA. During this hour, the sound levels peaked in the 400-Hz octave band. The overall sound levels during this time continually oscillated in amplitude by as much as 25 dBA. During this peak hour, the sound level meters reached an overall 1-minute maximum of 79.0 dBA at Meter 2 and 69.0 dBA at Meter 1. Similar pulses in sound were measured at both control meters throughout the study.

Property Line Meters

Three sound level meters were placed along the Substation property line in the same locations used in January and February 2016. The average, minimum, and maximum sound levels measured at the meters over the 2-month period are shown below in Table 6. It should be noted that the maximum sound levels

recorded at each meter were attributed to offsite sound sources, and were not consistent with substation operation.

Table 6: Property Line Meter Sound Levels (Summer 2016)

1-Minute Leq	Meter 3	Meter 4[a]	Meter 5
Minimum Sound Level	28.3	27.7	29.6
Average Sound Level	49.8	50.9	51.2
Maximum Sound Level[b]	87.3	75.0	91.8

(a) Meter 4 data after July 26, 2016, was corrupted. Average sound levels provided are from June 21 to July 26, 2016, only.
(b) Maximum sound levels of property line meters were attributed to extraneous sources.

The property line meters fluctuated constantly due to extraneous sources. Similar to the January and February measurements, there were time periods where background sounds were low and the property line meters appeared to clearly follow changes in Substation sound measured at the control meters. Peak contribution to sound levels from the 125- and 400-Hz octave bands were measured during these times as well.

The maximum hourly nighttime sound levels at the property line meters that could be attributed to Substation operation were measured on July 12, 2016, at 12:24 AM for Meter 4 and Meter 5, and on July 14, 2016, at 2:36 AM for Meter 3. The property line meters measured prominent discrete tones in the 400-Hz octave band, consistent with Substation operation, during each of these time periods. Table 7 and Table 8 show the two measured peak time periods.

Table 7: Sound Levels on July 12, 2016, at 12:24 AM

Meter	Date	Time	1-Min Leq (dBA)	Hourly Leq[a] (dBA)
Meter 1 Control meter (1x Auto)	7/12/2016	12:24 AM	70.2	66.8
Meter 2 Control meter (2x Auto)	7/12/2016	12:24 AM	76.9	74.2
Meter 3 South at Property Line	7/12/2016	12:24 AM	52.2	45.9 (limit 46 dBA)
Meter 4 Northwest at Property Line	7/12/2016	12:24 AM	56.0	50.0 (limit 46 dBA)
Meter 5 North at Property Line	7/12/2016	12:24 AM	56.4	52.3 (limit 46 dBA)

(a) Hourly sound level measured from 11:54 AM to 12:54 AM

Table 8: Sound Levels on July 14, 2016, at 2:36 AM

Meter	Date	Time	1-Min Leq (dBA)	Hourly Leq[a] (dBA)
Meter 1 Control meter (1x Auto)	7/14/2016	2:36 AM	69.7	65.4
Meter 2 Control meter (2x Auto)	7/14/2016	2:36 AM	79.0	75.4
Meter 3 South at Property Line	7/14/2016	2:36 AM	49.5	46.0 (limit 46 dBA)
Meter 4 Northwest at Property Line	7/14/2016	2:36 AM	52.9	47.4 (limit 46 dBA)
Meter 5 North at Property Line	7/14/2016	2:36 AM	53.1	49.5 (limit 46 dBA)

(a) Hourly sound level measured from 2:06 AM to 3:06 AM

Individual Unit Noise Monitoring

An individual unit sound study was performed, consisting of near-field continuous sound monitoring for each autotransformer while the other autotransformer was out of service. This set of measurements was collected to determine how the individual autotransformers operate when the other is taken out of service. Measurements for the 2x unit were taken from May 10 through June 6, 2016. The monitor was moved to the 1x unit on June 7, 2016, and measured sound levels of that autotransformer until June 21, 2016. Each set of measurements established the operating sound levels of the respective autotransformer operating alone.

The measurement data shows that sound levels fluctuated throughout the two measurement periods. The average sound levels for the autotransformers are consistent with expected operational sound levels and each autotransformer's rated sound level. However, the sets of data confirm that there are frequent spikes in sound and significant variations in operating sound levels of the autotransformers, similarly to what was measured during the other sets of continuous monitoring.

Complaint Time Period Analysis

One of the neighboring residents indicated specific times when the Substation appeared to be louder than normal during the course of the continuous long-term monitoring period. One specific instance occurred on August 4, 2016, around 1:00 A.M. Burns & McDonnell analyzed this specific time period to try to identify what the residents were experiencing.

On August 4, 2016, the Substation was operating at normal sound levels until approximately 12:50 A.M. At this point in time, the control meters showed that the autotransformers began gradually getting louder until approximately 1:15 A.M. when the autotransformers reached their peak sound levels. The collected data shows that the control meter for each autotransformer measured approximately 72 dBA. Sound levels measured at Meter 3 (on the south property line) and Meter 5 (on the north property line) exceeded the hourly average L_{eq} limit of 46 dBA during this time period. The peak sound levels at each property line meter were in the dominant frequencies of the autotransformers. The data collected on Meter 4 during this time period was corrupted and could not be recovered. Therefore, only Meter 3 and Meter 5 were analyzed. During this time there were extraneous sound sources influencing the property line meters, but at 1:15 A.M. the meters showed significant influence from the autotransformers.

Noise Monitoring Summary

According to the IEEE Standards C57.12.90 and C57.136, the principal sources of sound in transformers and autotransformers are the core sound and sound from cooling equipment. The core sound is caused by magnetostriction effects and inter-laminar magnetic forces. It is influenced by the flux density, core material, core geometry, and excitation voltage waveform. The sound from cooling equipment is generally caused by the cooling fans. The fan noise is influenced by the blade-tip speed, blade design, and number of fans. Pump noise is typically insignificant when fans are running. According to the autotransformer manufacturer sound level guarantee, the autotransformers are guaranteed to 62 dBA at 120 mega-volt amperes (MVA), 64 dBA at 160 MVA, and 65 dBA at 200 MVA. Therefore, the units should meet a spatially averaged sound level of 65 dBA at 3 feet at any load. This sound level includes the effects of both the core and the cooling equipment.

The autotransformers are rated to a maximum sound level of 65 dBA at 3 feet, but the sound measurements demonstrate that the units are capable of operating well above that level. At times, the sound meters located 15 feet from the units measured autotransformer-generated sound up to 80 dBA in short sound excursions. These increases are measurable at the property line.

The autotransformers vary in loudness throughout the day and night. Control Meter 1 measured sound levels between 43 and 74 dBA, and Control Meter 2 measured sound levels between 48 and 80 dBA. The control meter locations are close enough to the units that common extraneous sounds would not have a significant effect on measured sound levels.

The autotransformers' sound levels were generally dominant in the 125- and 400-Hz 1/3 octave band frequencies. At times throughout the measurements, autotransformer sound levels spiked by as much as 25 dBA. The sound level spikes remained elevated for various amounts of time before eventually falling back to normal levels. Some of the spikes in sound lasted for extended periods of time.

The control meters measured sound levels that fluctuated from day to day. The data shows the autotransformers can ramp up and down in sound over 15- to 30-minute periods. The Substation is audible offsite when background sounds subside and at times when the autotransformer sound levels ramp up. Substation sound is periodically measureable as a pure tone at the property line. Based on the far-field data collected, the Substation periodically exceeds the State of Connecticut noise regulations.

These exceedances are not common and happen at irregular intervals. When the autotransformers are operating at their specified levels, the Substation is well below the State limits. However, there appears to be something acting on the system that is causing the autotransformers to ramp up in sound for short periods of time. During these short-lived sound excursions, State sound level limits have the potential to be exceeded.