Design Criteria
Additions Related To
PJM IPP R02 project
GENERAL DESCRIPTION OF THE PPL ELECTRIC UTILITIES 500 KV SYSTEM

Existing System:

This document describes the design details of the EXISTING 500 kV system. Proposed additions for the Berwick #1 nuclear facility would be on a SIMILAR design basis. There may be some minor changes based on newer technologies and designs.

The existing 500 kV system is composed of several lines and substations:
- Juniata 500/230/69 kV Substation
- Sunbury 500/230/132/69 kV Substation
- Susquehanna 500/230 kV Substation
- Wescosville 500/230/138/69 kV Substation
- Alburtis 500/230 kV Substation
- Hosensack 500 kV Switchyard
- Elroy 500/138/69 kV Substation
- Steel City 500/230 kV Substation
- And the associated lines.

There are several other 500 kV facilities in the immediate electrical vicinity that are not owned by PPL Electric Utilities. These are not described in this document.

JUNIATA 500/230/69 KV SUBSTATION

Juniata 500-230 kV Substation is currently configured with eight line breakers in a breaker and-a-half configuration. Four 500 kV lines from Keystone, Conemaugh, Three Mile Island, and Alburtis are terminated in the breaker-and-a-half bays, and the Sunbury 500 kV line is terminated in a double-breaker double-bus bay. The two 500 kV buses will be operated as true buses, not a part of the 500 kV lines. In addition there are two 500 kV capacitor banks on the South bus, and one (1) 420 MVA 500/230 kV transformer bank on each bus.

SUNBURY 500/230/132/69 KV SUBSTATION

Sunbury 500-230 kV Substation is currently configured with the Susquehanna and Juniata 500 kV lines, connected through a single 500 kV GIS tie circuit breaker. A 500-230 kV, 650 MVA transformer is connected to the Sunbury-Susquehanna 500 kV line through a 500 kV MOD and a 500 kV GIS circuit breaker. A normally open air insulated by-pass switch is provided for the 500 kV tie breaker. Currently the 500 kV portion of this substation is gas insulated. PPL EU has a project to remove the GIS equipment and replace this with air insulated equipment. The proposed arrangement is double breaker double bus, with up to 4 Bays. The existing 500/230 kV transformer would be connected to the proposed North bus.

SUSQUEHANNA 500/230 KV SUBSTATION

Susquehanna 500/230 kV substation is designed for breaker and a half operation and currently consists of two 500 kV buses (North and South) and six (6) 500 kV breakers, arranged in a double breaker double bus configuration. The Sunbury and Wescosville- Alburtis 500 kV lines are terminated in the double-breaker double-bus bays, a 500-230 kV, 650 MVA transformer is connected to the South 500 kV bus through a 500 kV circuit switcher and the Susquehanna SES generator unit #2 is terminated in the double-breaker double-bus bay. In addition there is one 500 kV capacitor bank on the North bus.
WESCOSVILLE 500/230/138/69 KV SUBSTATION

Wescosville 500/230/138/69 kV Substation, consists of a 500-138 kV substation 300 MVA transformer connected to the Susquehanna-Wescosville-Alburtis 500 kV line, through a 500 kV MOD and a GIS 500 kV circuit breaker.

ALBURTIS 500/230/69 KV SUBSTATION

Alburtis 500-230 kV Substation is designed for breaker and a half operation, and consists of seven (7) 500 kV line breakers with Juniata and Hosensack 500 kV lines terminated in a breaker and a half bay, and the Branchburg and Wescosville-Alburtis 500 kV lines terminated in double breaker bays. There is a 500/230 kV transformer on the 500 kV West Bus, and two (2) 500 kV capacitor banks on the East Bus.

HOSENSACK 500 KV SWITCHYARD

Hosensack 500 kV Switchyard is designed for breaker and a half operation, and currently consists of four (4) 500 kV line breakers operated as a four (4) breaker ring bus. The Three Mile Island, Steel City, Elroy and Alburtis 500 kV lines are each terminated between two breakers of the ring.

ELROY 500/138/69 KV SUBSTATION

Elroy 500/138/69 kV substation currently has a single radial 500 kV line to the PECO Elroy 500 kV switchyard. The PECO 500 kV switchyard is currently operated as a three breaker ring bus with lines to Branchburg, Whitpain, and Hosensack. The tap to Elroy is part of the Branchburg 500 kV line. A future second tap is proposed off the Hosensack 500 kV line to a second 500/138 transformer.

STEEL CITY 500/230 KV SUBSTATION

Steel City 500-230 kV Substation is designed for breaker and a half operation, operated as a three breaker ring bus and consists of three (3) 500 kV line breakers with Hosensack and Bethlehem Power (IPP) 500 kV lines terminated in a breaker and a half bay, and the 500/230 kV transformer connected to the other bay.

Detailed description of the existing Susquehanna 500/230 kV substation.

This is a description of the specifications that were applicable to the original 500 kV design. The same specifications were used for all of the 500 kV facilities.

Susquehanna 500/230 kV Substation is located adjacent to the Susquehanna Steam Electric Station along U.S. Route 11 approximately 5 miles northeast of Berwick, PA.

The 500/230 kV Substation is 0.5 mile from generating Units No.1 and No.2, and is 2.0 miles from the 230 kV switchyard which is physically separated from the generating station and 500/230 kV Substation by the Susquehanna River.

The switchyard is of the "breaker and a half" design and currently is arranged with 5 bays. Four bays are breaker and half construction. The fifth bay contains a 500 kV capacitor bank on a single circuit breaker termination.
**Station Equipment Ratings**

All substation equipment will be designed to meet the following minimum values:

1) Frequency 60 Hertz

2) Voltage

   nominal is an archaic term not used in equipment ratings

   o Maximum Continuous 550 kV

3) Continuous Current Rating 3,000 Amperes

4) Short Time (2 seconds) Rating 40,000 Amperes, RMS

5) Peak Current Rating 108,000 amps crest

6) BIL (Lightning Impulse Withstand) 1,550 kV

7) 60 Hz Withstand (Wet, 10 seconds) 620 kV

8) Switching Surge Waveshape 250 ± 50 x 2500 ± 1000 microseconds

9) Switching Surge Withstand (Wet, 2 Standard Deviations below critical flashover).

   o Phase-to-Ground 1,050 kV

10) Creep Distance 305 inches

**Substation Insulation - Surge Arresters**

The coordination of all substation insulation is based on having surge arrestors on each line terminal and at each of the transformers.

500 kV surge arrestor, MOV type, station class

Duty cycle Rating 396 kV, RMS
MCOV 318 kV, RMS

**Electrical Clearances**

Phase-to-phase 18'-0"
Phase-to-ground 12'-2"
Main Bus Live Parts to Grade 40'-0"
Cross Yard Bus Live Parts-to-grade 21'-0"
   (Area restricted from vehicular access - crossing under main Bus).

Cross Yard Bus Live Parts-to-grade (area available for vehicular access). 26'-0"

Switch open gap, single vertical break 13'-6"
Disconnect switches installed on each side of a power circuit breaker are equipped with 125 volt dc motor operated mechanisms to facilitate isolation of faulted lines or equipment.

Initially bus side disconnects not adjacent to circuit breakers may be installed with manual hand operating mechanisms.

**Bus Arrangements**

The substations are typically designed for an ultimate four bay breaker and a half scheme. Initially both buses and portions of two or more bays will be installed. Sufficient power circuit breakers will be installed to provide the necessary protective isolation and breaker failure protection.

**Direct Stroke Protection**

A system of overhead shield wires is installed from transmission terminal structures to the substation dead-end structures. Line terminal surge arresters are installed at each line terminal and at a distance of 28 feet from each transformer high voltage bushing.

**Safety Grounding**

A ground grid containing a 250 KCMIL copper equivalent is required. A system of 19 #7 copperweld wire on a 20’ grid is installed, and includes main runs and taps to structures and equipment, to maintain acceptable step potentials. The substation ground grid is tied to each transmission counterpoise and the generating station ground grid. The ground will extend 2’-6” beyond the station fence.

The following is the design criteria used in the ground grid design:

- Fault current - 50,000 A
- Fault clearing time - 0.2 seconds
- Soil resistivity 150 OHM-meter
- Ground cable maximum temperature - 450°C
- Fault to a structure without an OHGW connection

All below grade connections are made by Cadweld exothermic welding process. Connections to structures and equipment utilize bolted terminal connectors.

**Fire Protection**

The single phase autotransformers are typically installed on 50’ centers, and separated by firewalls. Each transformer foundation is surrounded by a crushed stone filled pit, or suitable oil containment system.

Each oil containment pit is designed to accept a minimum of two-thirds of the oil from one transformer.

The plant fire protection water system is extended to the substation where three fire hydrant hose houses will be installed. The houses are located adjacent to the switchyard roadways, one in bay one south, one south of the 500-230 kV transformers, and one north of the transformers. In addition to the water system, there will be a distribution of 15# CO₂ devices, 20# and 150# dry chemical wheeled extinguishers.

**Transient Suppression in Control Circuits**
Control cables are installed according to PP&L practice established to suppress transients due to electrostatic and electromagnetic coupling and differences in ground potential. All cables are of the shielded type with shields grounded at both ends.

The cables are installed in a prefabricated concrete trench system.

**EQUIPMENT RATINGS**

A. **Autotransformers (existing)**

NOTE: It is expected new autotransformers will comply with the new (2007) PJM specification for 500/230 kV transformers banks.

1. **Nameplate MVA Rating and Design**

   The transformer design was determined by the combined results of several studies and load carrying criteria:

   a. Transient network analyzer studies utilizing duty cycle rating surge arresters and allowing a transformer internal H.V. BIL of 1,300 kV.

   b. Requirement to carry 835 MVA NORMAL SUMMER LOAD at 30°C ambient, and 945 MVA NORMAL WINTER LOAD at 10°C ambient. **Revise to current PJM spec**

   c. Requirement to be compatible with and for use of PJM spare single phase 333 MVA unit. **Revise to current PJM spec**

   The existing transformer bank is comprised of three single phase General Electric 500-230 kV autos with a 13.8 kV tertiary winding brought out for station service purposes. The units are 130/172/217 (55°C) 243 (65°C) MVA OA/FOA/FOA nameplate is 730 MVA total bank. **Revise to current PJM spec**

2. **Insulation Levels**

<table>
<thead>
<tr>
<th></th>
<th>Internal</th>
<th>External</th>
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</thead>
<tbody>
<tr>
<td>HIGH VOLTAGE BIL, kV</td>
<td>1,300</td>
<td>1,550</td>
</tr>
<tr>
<td>LOW VOLTAGE BIL, kV</td>
<td>750</td>
<td>900</td>
</tr>
<tr>
<td>NEUTRAL BIL, kV</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>TERTIARY BIL, kV</td>
<td>110</td>
<td>110</td>
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</table>

   **Revise to current PJM spec**

3. **Voltage Tap Ranges**

   The transformer will have ± 5% de-energized taps, and full capacity LTC taps for ± 10% to give adjustment of the high voltage in sixteen 1 1/4% steps with the low voltage maintained at rated voltage. Total high voltage operating range: 425,000 volts to 575,000 volts. Revise to PJM Spec

4. **Impedance**

   **Positive sequence on a 217 MVA base:**

   - H-L: 12.45%
   - H-Y: 121%
Radio Influence Voltage Level

Each transformer shall be corona tested at the full induced test voltage level. RIV shall not exceed 1000 microvolts.

Excitation Capability

The transformer will be designed to meet ANSI standard over excitation requirements.

Circuit Breakers

500 kV independent pole operated circuit breakers are installed. Various manufacturers are currently suitable. Contact PPL EU for a list of approved manufacturers. The initial installation consisted of live tank breakers. Only Juniata has had live tank CBs replaced by dead tank

Dead tank is the preferred circuit breaker configuration for new designs.

2. Maximum voltage 550 kV
3. Continuous current 3,000 amperes
4. BIL 1,800 kV
5. Short circuit rating 40,000 amperes, RMS
6. Short time rating (2 seconds) 40,000 amperes, RMS
6. Peak current 104kA
7. Interrupting time 2 cycles
8. Closing resistor 400 – 500 ohms 8ms insertion time
9. Out of phase rating 2.5 p.u.
10. capacitance current switching class C2 for line switching

Bus - Insulators – Connectors

Bus Rating

NOTE: design of future 500 kV buses will be to IEEE 605, latest version and PPL EU internal standards if more stringent.

The main and cross yard bus will be 4 inch Schedule 80 aluminum tubing, 6063 T6 alloy. The maximum total temperature for the aluminum tubing will be 110°C.

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
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<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Emergency</td>
</tr>
<tr>
<td>Current Ratings,</td>
<td>4,260</td>
<td>4,780</td>
</tr>
</tbody>
</table>

Bus Connectors

Welded type aluminum bus fittings and connectors will be used throughout, except for bolted type bus support fittings on top of insulator stacks and where future removable connections are required. Compression connectors are being considered for future

Bus Support Insulators
(a) Insulator Stack BIL 1,550 kV
(b) 60 Hertz Withstand (wet) 620 kV
(c) Impulse Withstand 1,550 kV
(d) Impulse Flashover 1,710 kV
(e) Cantilever Strength 1,650 lbs
(f) RIV shall not exceed 200 microvolts at 350 kV test level.
(g) 4 units/stack, tapered 128” high
(h) Bus support insulator strengths will meet the following load conditions:

1. Bus and insulator covered with 1 1/2 inch ice with no wind.
2. 25 psf wind on bare bus.
3. Bus and insulator covered with 1 inch ice with 8 psf wind.

Bus support insulators will also be designed for any one of the above loads simultaneous with forces exerted by a short circuit current of 50,000 amperes, RMS, symmetrical.

**Carrier Current Line Traps**

1. Voltage class 500 kV
2. Rated continuous current 4,000 amperes
3. Thermal current rating (2 sec.) 63,000 amperes, RMS,SYM
4. Mechanical current rating 170,000 amperes, peak
5. Inductance 0.265 mH

**Coupling Capacitor Voltage Transformers**

These are expected to be three winding, metering accuracy, and suitable for carrier applications.

1. Voltage class 500 kV
2. Maximum rated voltage 550 kV
3. BIL 1,800 kV
4. Minimum switching surge withstand, BSL 1,300 kV
5. Minimum 60 Hz withstand
   - Dry, 1 minute 900 kV
   - Wet, 10 seconds 780 kV
6. RIV - per ANSI design tests in C93.1
7. Accuracy - X and Y secondaries
   - Winding 0.3%
8. Burden ratings - X and Y secondaries
   - Winding 200 VA
   - Winding 50 VA

**Current Transformers**

Free standing, 500 kV current transformers are installed on the line side of each 500 kV live tank circuit breaker. Each device contains five 3000/5 ampere multi-ratio, C800 relay accuracy current transformers.

Dead tank circuit breakers (the preferred option) will have 2 current transformers per bushing, 3000/5 multi ratio, C800, relaying accuracy, and a thermal factor of 2.0.

The 500-230 kV autotransformer bank will contain the following bushing type current transformer arrangement:
- **High Voltage Bushings:** Two 3000/5 ampere and two 2000/5 ampere, C800 standard multi-ratio bushing current transformers shall be furnished on each bushing. Placement of the current transformers shall be alternated starting with one 3000/5 nearest the winding, followed by 2000/5, 3000/5 and 2000/5.

- **Low Voltage Bushings:** One 2000/5 ampere single ratio, metering accuracy, and four 3000/5 ampere, C800 standard multi-ratio bushing current transformers shall be furnished on each bushing. The 2000/5 ampere unit shall be nearest the winding. Metering accuracy shall be 0.3B2 and have 10 amp thermal rating for the secondary winding.

- **Delta Tertiary Winding:** One 3000/5 ampere, C800 multi-ratio current transformer shall be furnished inside the delta on each leg of the 13.8 kV delta tertiary winding.

**Disconnect Switches, Single Vertical Break**

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<td>1.</td>
<td>Voltage class</td>
<td>500 kV</td>
</tr>
<tr>
<td>2.</td>
<td>Maximum rated voltage</td>
<td>550 kV</td>
</tr>
<tr>
<td>3.</td>
<td>Rated continuous current</td>
<td>3,000 ampere</td>
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<tr>
<td>4.</td>
<td>Peak current rating</td>
<td>108,000 ampere</td>
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<tr>
<td>5.</td>
<td>Three second current rating</td>
<td>43,000 ampere</td>
</tr>
<tr>
<td>6.</td>
<td>BIL</td>
<td>1,550 kV</td>
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<tr>
<td>7.</td>
<td>BSL</td>
<td>1,240 kV</td>
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<tr>
<td>8.</td>
<td>All switches equipped with manually operated ground switches on the hinge end.</td>
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<tr>
<td>9.</td>
<td>The switches will be suitable for satisfactory service in a 100 MPH wind or 3/4 inch of ice at any temperature down to -40°C.</td>
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<tr>
<td>10.</td>
<td>Open Gap distance</td>
<td>13'-6&quot;</td>
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**Transformer Primary Switch (existing)**

Note: new installations will use a 500 kV circuit breaker.

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<tr>
<td>2.</td>
<td>Maximum rated voltage</td>
<td>550 kV</td>
</tr>
<tr>
<td>3.</td>
<td>Rated continuous current</td>
<td>2,000 amps</td>
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<tr>
<td>4.</td>
<td>Peak current rating</td>
<td>130,000 amps</td>
</tr>
<tr>
<td>5.</td>
<td>Three second rating</td>
<td>50,000 amps</td>
</tr>
<tr>
<td>6.</td>
<td>BIL</td>
<td>1,800 kV *</td>
</tr>
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</table>

* While 1550 kV is the required BIL, this switch is equipped with 1800 kV BIL insulators.

7. The switch is capable of interrupting the exciting current of a 730 MVA, 500/230 kV autotransformer.

8. Minimum 60 Hz withstand
   a. Dry, 1 minute | 810 kV |
   b. Wet, 10 seconds | 710 kV |

9. Minimum switching surge withstand
   a. Minimum, wet, phase-to-ground | 1,120 kV |
   b. Minimum, wet, phase-to-phase | 1,470 kV |

10. RIV - Not to exceed 500 microvolts at 350 kV applied test voltage.
11. The switch is capable of closing or opening when coated with 1-1/2 inch of ice, both manually and motor operated, while maintaining satisfactory mechanical and electrical characteristics, and without damage to any of its parts.

**AC Supply System**

Two independent three phase AC sources are provided to supply the AC load in the 500 kV switchyard. The normal source is from the 13.8 kV tertiary windings of the 500-230 kV autotransformer to a three phase 500 kVA, 13.8 kV ungrounded wye 480 V delta pad mounted transformer protected by 40 amp current limiting fused disconnect switches on the high side. The alternate source is from the 13.8 kV plant switchgear to a three phase 500 kVA, 13.8 kV - 480 volt pad mounted transformer. Each three phase 480V source feeds a 600A 3 phase-3 wire panelboard. In addition to 3phase 480V station load, each 480V panelboard feeds through an automatic throwover switch to supply a 300 kVA, 480V - 120/240V Station service pad mounted dry type transformer located inside the 500 kV control cubicle. This transformer supplies the three phase 240V and single phase 120V load through distribution panelboards. Criteria for circuit loading, overcurrent protection device ratings and voltage drop is in accordance with applicable latest version of the National Electric Code articles.

**DC Supply System**

DC supply system consists of two (2), 125V, 60 cell lead-calcium batteries, three (3) battery chargers with three phase 240V AC input, 125V DC, 75A output equipped with a load sharing circuit. The battery feeds two 250V DC, 200A fusible panelboards in the control cubicle from which all DC load is supplied. One charger is normally connected to the primary DC system, but can be switched to the backup system.

Also, there is the capability to tie the primary and backup DC systems together to allow one of the batteries to be removed from service.

Components of the DC supply system were designed based on being able to supply the station for a period of 24 hours.

**Yard Lighting**

Overall yard lighting is provided by 41 appropriately placed high pressure sodium, 400W floodlights to provide 2 footcandles minimum throughout the yard.

**Control Cubicle**

A 40' x 56' control cubicle with a 16' x 24' attached maintenance workroom is located in the 500 kV switchyard and houses the following equipment:

- AC supply equipment to include 480V-30 power panels, 480V AC automatic throwover switch, 30 power panel, 240/120V 10 lighting panel.
- DC supply equipment to include battery, battery chargers and DC panels.
- All 500 kV and 230 kV relay and control panels
- Supervisory control equipment
- Telephone facilities
Annunciator panel

Control cable access to equipment is facilitated by a raised "computer room" type floor system with removable panels. The building is insulated and provided with heating and air-conditioning to maintain temperature in the range of 40°F-90°F and relative humidity below 65%. General lighting is provided by suitably placed 2L-40W fluorescent fixtures.

A smoke detector fire detection system is installed below the raised floor and at ceiling level. Contacts from this system are connected to alarm through SCADA.

CIVIL STRUCTURAL DESIGN CRITERIA

A. Control House

1. The control house is a 40'-O x 56'-O block building with an auxiliary workroom at one end which is built as an extension to the main building. This workroom is 16'-O x 24'-O.

2. The roof is a 5 ply insulated felt and gravel roof supported on steel joists. The roof is designed for the following loads:
   - Dead load: 7 lbs./sq. ft
   - Live load: 20 lbs./sq. ft
   - Wind load: 6.4 lbs./sq. ft. (9 x .707)

3. The control house foundation is supported on steel piles and has been designed as continuous beams supported at the piles. The following contributory loads were used in the design of the continuous beam foundation:
   - Roof: 876 lbs./ft.
   - Joists: 59
   - Wall: 866 X 1.4 D.L. factor=1925 lbs./ft.
   - Footing: 450

   2801 lbs./ft.

B. Foundations

1. Soil borings and field inspections revealed large boulders and uncertain soil conditions which led to the decision to use piles at all foundations.

2. All single pole structures are supported on single piles. Other foundations depend on their configuration for the number of piles with the exception of the dead end structure foundations (see 3).

3. The dead end structure foundations were designed by Gilbert Associates. They are supported on piles, some of which are battered.

4. The concrete was specified to be made with Type I Portland Cement with a minimum 28 day strength of 3,000 PSI. The reinforcing bars are grade 60.
**Structures**

1. Dead end structures are pole type A-frame structures. The height of the pull-off point is 70’. The height of the shield wire is 95’0. The distance, center to center of A-frames, is 90’-0.

2. All other structures are vertical pole type structures of various diameters depending on the stresses.

3. All structures have been designed in accordance with Pennsylvania Power and Light Co., General Specifications for all Substation Structures, A155939. (Also see Meyer Industries design book 9420.)

   Load Cases are as follows:

   **Case 1.** 1” Radial ice  
   9 lbs. per sq. ft. wind  
   0°F 0° max angle

   **Case 2.** 1” Radial ice  
   9 lbs. per sq. ft. wind  
   0°F 20° max angle

   **Case 3.** 0” Radial ice  
   25 lbs. per sq. ft. wind  
   60°F 0° max angle

   **Case 4.** 0” Radial ice  
   25 lbs. per sq. ft. wind  
   60°F 20° max angle

   **Case 5.** 1-1/2” Radial ice  
   No wind  
   0°F 0° max angle

   **Case 6.** 1-1/2” Radial ice  
   No wind  
   0°F 20° max angle

**D. Drainage**

1. The drainage system utilizes Poroswall (or equal) pipe in an east-west direction of the yard in locations designed to affect the change in the elevation of the yard by a maximum of 1’-0.

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