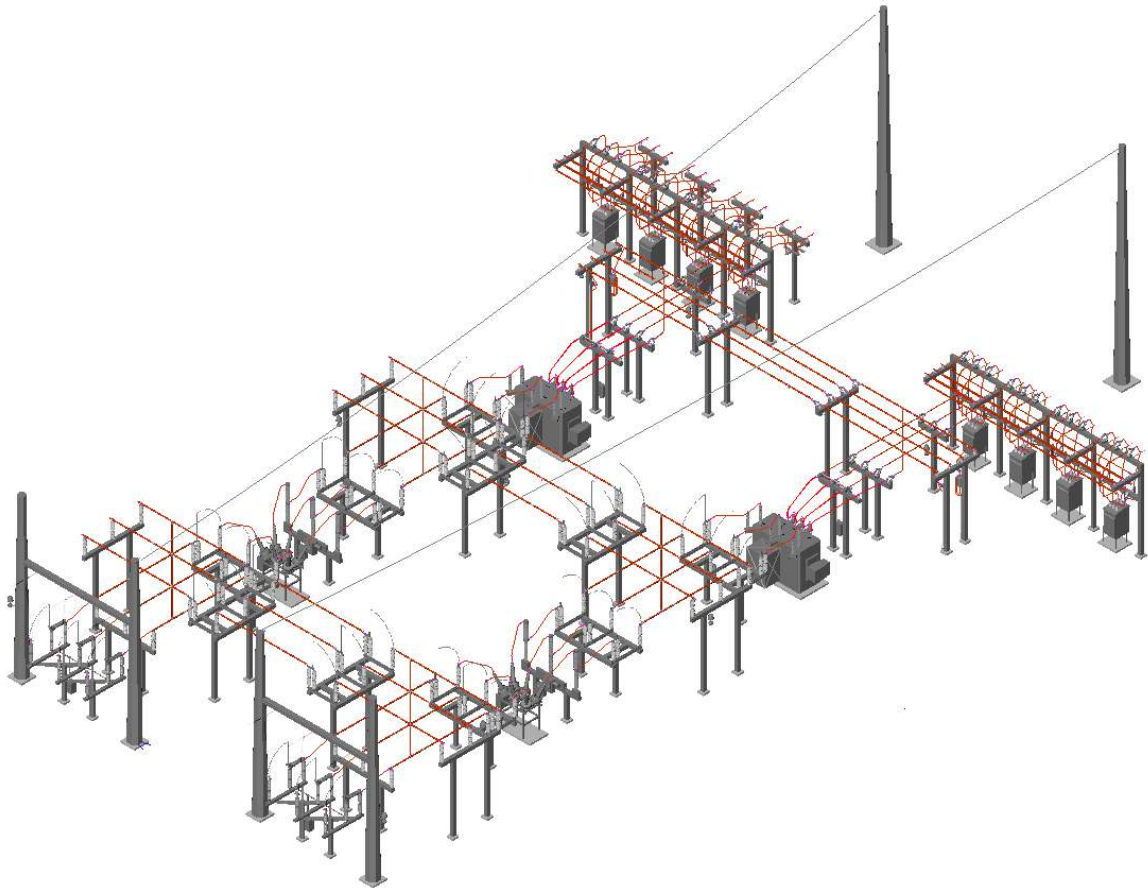### The 3DToolBox
User's Manual
A Toolbox for the Design of
3D Substations
Utilizing AutoCAD

the3DUtility.com

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1.   Background

Since Thomas Edison designed his Pearl Street station in 1882, engineers have had to contend with the presentation of their design on paper . . . in 2D space. His answer to the need for a 3D presentation was to prepare an artistic rendition of the space.

Today, we have one advantage that Edison lacked - the computer. Engineers are now free to let their visions soar, to investigate options that make facilities more economic, more dependable and safer to operate. This can be achieved utilizing the power of 3D design. But to do this efficiently, a Toolbox of building blocks and software is essential. The following describes the functions of such a **3DToolBox**.

2.   A Brief History of AutoCAD 3D

The use of CAD in the preparation of substation design drawings goes back to the late 70s and early 80s. These early systems generally utilized main-frame computers and dedicated workstations putting the cost out of reach for the average distribution utility system. **Autodesk, Inc.**, based in San Rafael, CA, released PC-based **AutoCAD®** software in 1982 finally making CAD accessible to everyone. One of the earliest known adopters of AutoCAD for substation design was Allen & Hoshall, Inc., in 1982.

AutoCAD introduced 3D Level 1 in Version 2.1 in 1985. This level provided for 3D wireframe visualization. Version 2.6 added 3D Level 2 with 3D Line, 3D Face and 3D Plot capabilities. With the release of AutoCAD 2007, AutoCAD introduced the **SectionPlane** command which added Sections and with AutoCAD 2010 added **SectionPlanetoBlock** which allowed for the generation of Elevation views from the Sections. With this, all of the necessary drawing tools were finally available.

3.   Substation Design

A complete substation design project consists of the following three general tasks:
- **Structural design** which includes the physical layout of all structures and appurtenances. This consists of a **Plan View** and a number of **Elevation Views** that convey the arrangement of the substation to the substation contractor/packager. It should also include a number of plan drawings including a **Foundation Plan** and a **Cable & Conduit Plan**. From these drawings the material required to construct the substation can be determined.
- **Relaying and Control design** which includes all conductors required to interconnect the various equipment. This includes physical drawings as well as circuit, schematic and wiring diagrams.

- **Specifications and Contract Documents** required for procuring the material and employing a contractor to construct the substation.

The Structural design task consumes 30-50% of the design process and cost. The 3DToolbox addresses this task providing an efficient and straight forward tool to minimize this cost.

4. 2D vs 3D

In a traditional **2D CAD design**, there are five major steps that must be taken to develop the Plan and Elevation drawings.
- First is the development of the layout of the **Plan View**. This is accomplished by dropping 2D CAD blocks onto the drawing. Connections are then made between equipment and busses.
- Next various **Elevations** necessary to convey the design to the material provider and contractor must be defined.
- The various **Elevation** drawings and **Plan** drawings (e.g. Foundation and Cable & Conduit drawings) must then be individually developed. The connections will again have to be drawn.
- Then the drawings must be checked for conflicts. This can be very laborious given that the designer must cross reference multiple 2D Plan and Elevation drawings. Once discovered, resolutions must be determined and modifications made to both the Plan and Elevations drawings affected by the conflicts. This will often go through several iterations as the design is refined and finalized.
- Lastly, a detailed **Bill of Materials** must be prepared. This again requires cross referencing multiple drawings to make a detailed and accurate count of the material.

If any changes are made to the Plan View, one or more of the Elevations must be checked and possibly modified. Likewise, changes to the Elevations may result in modifications to the Plan View. And in all cases, conflicts must again be reviewed and resolved. And the BOM may need to be recompiled.

In **3D design**, the final product, the design drawings, remain the goal. Though the steps are similar, there are some major differences.
1. Again, initially the Plan View is prepared. However, for 3D design, this is accomplished by dropping **3D** blocks onto the drawing. The bus and connections are added using various apps to simplify the process. Conflict determination and resolution is conducted as the design unfolds.
2. The Elevation views are determined and then generated by the CAD software from the 3D model utilizing the **SectionPlane** and **SectionPlanetoBlock** commands.
3. Elevations and Plan views are arranged in **Paper Space** and dimensioned. If changes are made, they are made in the Plan View and the revised Elevations regenerated. The dimensions of the Elevations may need to be adjusted.
4. From the 3D Plan View, a detailed **Bill of Materials** can be automatically generated. This is possible because, unlike the 2D plan, the 3D plan contains every structure, bus, device, connector and fitting.

Subsequent changes made to the 3D Plan View can easily be reflected in the Elevation views using the AutoCAD **SectionPlane** and **SectionPlanetoBlock** commands.

5.   Benefits of 3D over 2D Design

So what are the benefits of utilizing a 3D approach to design?
- **First the design cycle is reduced.** This is crucial to justifying use of staff personnel for this task. The substation design is prepared completely in the Plan View using a Toolbox of 3D parts and software applications. All Elevation views are then generated from the Plan View. Changes to the design on the plan level are easily reflected in the Elevations with minimal time expended. The results are reduced design time and fewer design errors encountered during construction.
- **Construction costs are reduced.** The more accurate design inherent in the 3D process results in fewer conflicts, fewer errors during construction and reduced Change Orders in the construction process.
- **Total project cycle cost is reduced.** Overall project cost is reduced as a result of the reduced design cycle and reduced construction cost. The 3D rendition allows the Contractor to better visualize the project.
- **And operational safety is increased.** 3D design allows the engineer to check for adequate clearances for the operation of equipment such as switches and fuses as the design progresses.

The development of 3D blocks and their manipulation in the 3D space can be very tedious. The **3DToolbox** presented here solves those problems.

6.   The 3DToolbox

The 3DToolbox consists of two complementary units – a collection of over 600 blocks (**Units** and **Assemblies**) in the **Hardware Toolbox** and over a dozen applications written in **Microsoft Visual Basic for Applications (VBA)** and **AutoCAD AutoLisp™** referred to as the **Software Toolbox**.

7.   The Hardware Toolbox

The Toolbox contains over 600 3D Blocks covering voltages from 15kV through 230kV. They are arranged in the following folders:
- **Condulet** – Used for control conduits and low voltage circuits.
- **Connectors** – Bus supports, couplers, studs, tees and terminals for tube and conductor bus.
- **Equipment** – Lightning Arrestors, Bushings, CTs, VTs, Lighting, etc.
- **Insulators** – Standard TR insulators as well as High Strength and Extra High Strength insulators.
- **Major Equipment** – Breakers, Circuit Switchers, Power Transformers and Switchgear Houses.
- **Structures** – Switch and bus supports, Breaker and Terminal structures.

- **Switches** – Single, three and four pole switches.
- **Transmission** – Pole line hardware including fittings, insulators, and conductor clamps, etc.
- **Distribution** – Pole line hardware including fittings, insulators, crossarms, and conductor deadends, etc.

7.1. Entities, Blocks, Units and Assemblies

The basic graphic object of AutoCAD is the **Entity**. Examples of entities are points, lines, polylines, circles, 2D surfaces, 3D solids, etc.

A **Block** is a named collection of one or more AutoCAD drawing entities that act as a single object. A block can contain other blocks nested within it. A block includes an **insertion point** which defines the point at which the block is inserted into the drawing.

A Toolbox **Unit**, see Figure 1, is fundamentally a Block. A Unit is the only block that is accumulated in a **Bill of Materials** (BOM). A Unit not only contains an insertion point, but may also contain one or more **Node** points to facilitate a bus connection or another Unit insertion. The Unit name consists of a three character prefix that identifies the type of Unit and a string of descriptors that completely define the Unit.

A Unit can contain other Blocks and Units; however, a Unit nested within a Unit will not be included in the BOM. For example, a Switch Unit contains two or more Insulator

Figure 1 - A Connector Unit

Units. When the BOM is produced, the Insulator Units will not be enumerated individually since they are included in the Switch Unit and are actually purchased as part of the complete Switch Unit.

Figure 2 - A Breaker Assembly

Assemblies are Blocks that include multiple nested Units. An example is a **Breaker Structure Assembly** (see Figure 2) that contains one or more Structures, Insulators, Switches, Connectors and Busses. When a BOM is created, the Assembly is broken down into its component Units and then accumulated by Unit. Assembly names are the same as Block names with the prefix **Ass**. An Assembly should **never** include other Assemblies.

It is important to understand the concept of **Unit** vs. **Assembly**. For instance, as stated above, a Switch Unit should also include Insulator Units since they are purchased as a single package. Likewise, a three pole Switch Unit, containing three single poles Switches, should also be considered a Unit rather than an Assembly. A three pole switch is generally purchased as a single package that also contains connecting pipe and fittings. On the other hand, a three pole Switch sitting on a Structure should be considered as an Assembly since the Switch and Structure would be enumerated as distinctive items in the BOM

The following are the Toolbox folders. A detailed description of the Unit names can be found in the Appendices

7.2. Condulet

A **Condulet** (Figure 3) is a metal fitting that connects to one or more conduits. It includes a removable metal plate that allows access to the conductors inside. Condulets are manufactured in various sizes and styles. The styles define the number and location of the conduit connections.
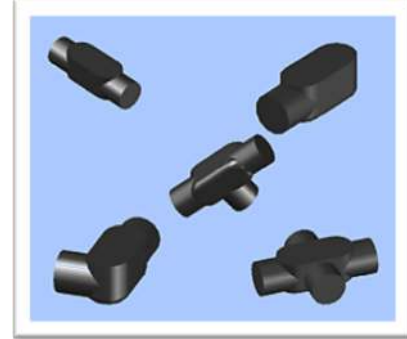
Figure 3 - Condulet Units

7.3. Connector

Connectors (Figure 4) include supports, couplers, studs, tees and terminals for pipe and conductor bus. The Toolbox includes connectors for pipe bus sizes from 1" to 6".

Examples:
- **CnnTeTTAl4** – Connector,Tee, Tube to Tube, Aluminum 4"
- **CnnCpTTAl4@90** – Connector, Coupler, Tube to Tube 4" @90°
- **CnnBSCu2-550-750** – Connector, Bus Support, Cu, 2 550MCM-750MCM

Figure 4 – Connector Units

7.4. Equipment

Equipment (Figure 5) includes smaller items such as Lightning Arrestors, Bushings, CTs, VTs, Lighting, etc.

Examples:
- **EquBu350-2000(ABB)** – Equipment, Bushing, 350kVBIL, 2000A, ABB
- **EquCT110(GE-JCW)** – Equipment, Current Transformer, 110kVBIL, GE model JCW
- **EquLu(Holophane)** – Equipment, Luminaire, Holophane

Figure 5 - Equipment Units

7.5. Insulators

Insulators (Figure 6) include standard TR as well as High Strength and Extra High Strength, 15kV thru 230k.

Examples:
- **InsSPPmSS550** – Insulator, Station Post, Polymer, Standard Strength, 55kVBIL
- **InsSPPrTR210** – Insulator, Station Post, Porcelain, ANSI TR210

Figure 6 - Insulator Units

7.6. Major Equipment

Major Equipment (Figure 7) includes Breakers, Circuit Switchers, Power Transformers and Switchgear Houses, 15kV thru 161kV.

Examples:
- **MjrBrSF750-2000(ABB-PMI)** – Major Equipment, Breaker, SF_6, 750kVBIL, 2000A, ABB model PMI
- **MjrXfOl250-18mVA** – Major Equipment, Transformer, Oil, 250kVBIL, 18mVA

7.7. Structures

Structures (Figure 8) include Bus and Switch supports, Breaker sand Terminal structures and Fence.
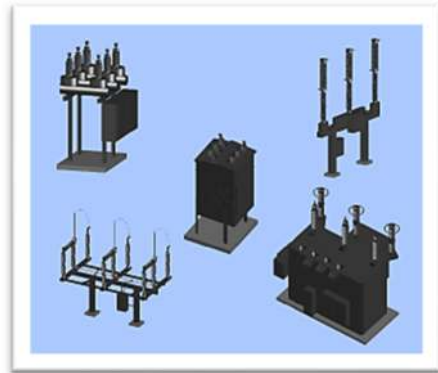
Figure 7 - Major Equipment

Examples:
- **StrBrT1101** – Structure, Breaker ,Type 11, 15kV
- **StrDeHh06-25** – Structure, Deadend, H-Structure, 69kV, 25'
- **StrLM-65** – Structure, Lightning Mast, 65'
- StrSw3PVB16-20 – Structure, Switch, 3 Pole, Vertical Break, 161kV, 20'
- **FncCk-5x9** – Fence, Chain Link, 5' wide x 9' high

Figure 8 - Structure Units

7.8. Switches

Switches (Figure 9) include Vertical Break, Side Break, Center Break, Vee, Hook Stick and Regulator By-Pass.

Examples:

Figure 9 - Switch Units

- **SwtVB3P350-1200(USCO)** – Switch, Vertical Break, Three Pole, 350kVBIL, 1200A, USCO
- **SwtHV1P110-1200(USCO)** – Switch, Hook Stick Vee, Single Pole, 110kVBIL, 1200A, USCO
- **SwtRB1P150-1200(SS)** – Switch, Regulator By-Pass, Single Pole, 150kVBIL, 1200A, Southern States
- **SwtOpWG** – Switch, Operator, Worm Gear
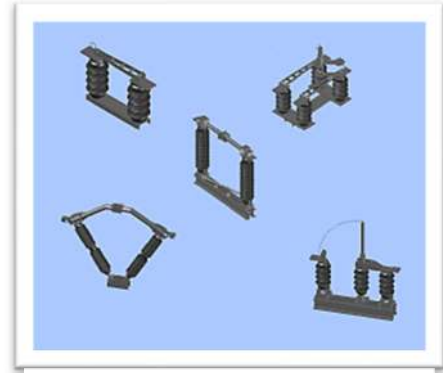
7.9. Unit Physical Design Considerations

All **Units** contained in the **Toolbox** have been developed from information available on the manufacturer's web sites and, as such, are subject to the accuracy stated in their respective sources. For example, the critical dimensions of a Switch are the height and separation distance of the connector pads. These are easily obtained from the manufacturer's catalog data which includes the caveat that the "Dimensions are not for Construction Purposes". However, non-manufacturer specific Units, such as connectors, while based on common manufacturers' data, do not adhere to any physical standards. Therefore, there is no consistency guaranteed between manufacturers. For that reason it is strongly suggested that all dimensions and physical designs be verified with the manufacturer's equipment submittals. It is intended that the Hardware Toolbox be used to develop substation designs that will then be submitted to a substation packager to develop detailed construction drawings based upon the actual equipment they propose for the project. The Units are sufficiently detailed to develop an overall design that meets regulatory and construction standards.

7.9.1. Object Snaps

Object Snaps (referred to as **Osnaps**) are used with graphic commands as aids to create accurate drawings. They provide a means to locate the cursor at a precise point on the drawing, relative to other graphic Entities. For example, to find the exact endpoint of a line, use the ENDpoint Osnap. Similarly, to find the exact center of a circle, use the CENter Osnap. Multiple Osnaps can be in effect at any one time. The Osnaps can be enabled and disabled individually by executing the OSNAP command. This will bring up a form and the specific Osnaps can be selected by clicking the associated check box.

The Osnaps in effect are stored in the **OSMODE** system variable. They are stored as a bitcode which is the sum of the values of the individual Osnaps. The following is a list of the valid Osnaps and their bit values.

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- 1 ENDpoint
- 2 MIDpoint
- 4 CENter
- 8 NODe
- 16 QUAdrant
- 32 INTersection
- 64 INSertion

- 128 PERpendicular
- 256 TANgent
- 512 NEArest
- 1024 0 NONe
- 2048 APParent Intersection
- 4096 EXTension
- 8192 PARallel

If the ENDpoint, CENter and INSertion Osnaps are enabled, the value of OSMODE is 69 (1 + 4 + 64). The object snaps can also be set by typing the **Osmode** command and entering the sum of the bit values of the desired object snap.

Osnaps can also be invoked dynamically when AutoCAD prompts for a point input. For instance at the prompt "Start of line or [Follow] <Last point>:" an Osnap can be typed which will invoke it for the next point selection. To enter the Osnap value, type the first three letters of the Osnap as shown above. This will override the current OSMODE for the subsequent click only.

The Toolbox makes extensive use of three of the Osnaps – INSertion, INTersection and NODe. The INSertion Osnap will locate the coordinates of the point at which a Block, Unit or Assembly is inserted into the drawing. The INTersection Osnap will find the intersection of two lines. This is particularly useful in the initial layout using construction lines. The NODe Osnap will snap to only three entities – a Point, Dimension definition point, or Dimension text origin. Because of this unique feature, the NODe Osnap is used extensively by the Toolbox for two primary purposes – 1) Point entities at which Units are inserted and 2) Point entities to anchor Bus geometry. Because of the use of the NODe Osnap, these points are referred to in the Toolbox simply as Nodes.
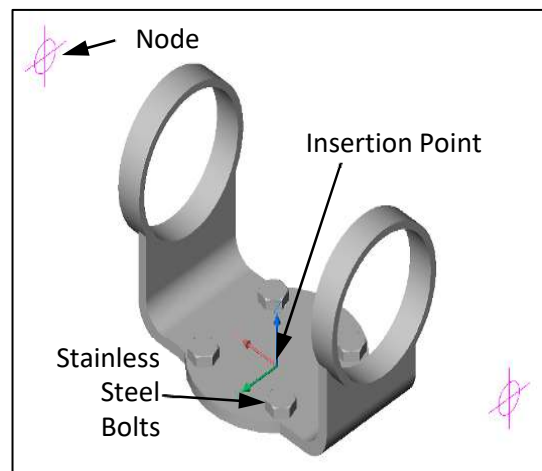
Figure 10 - CnnBSBlAl4 - Connector, Base, Bolted, Aluminum, 4"

7.9.2.   Insertion Point

Figure 10 shows a typical Unit, in this case a Base Connector. This Unit includes several features.

The **Insertion Point** is the point at which the Unit will be inserted into the drawing. It is designated by the Red, Green and Blue arrows. In this instance, the Insertion Point is located at the center of the bottom of the Unit.

It is common to insert a Unit at a Node conveniently located on another Unit.

7.9.3. Nodes

This Unit also contains two **Nodes**. As stated above, these Nodes are AutoCAD Point entities. The 3D coordinate of a Node can be found by using the NODe Osnap mode.

Figure 11 shows an Insulator Unit with an Insertion Point at the center of the base of the Unit and a Node point at the center of the top of the Unit. To insert the CnnBSBlAl4 Unit into the drawing, it should be snapped to the Node point on the Insulator Unit. Figure 12 shows the Connector snapped to the Insulator.
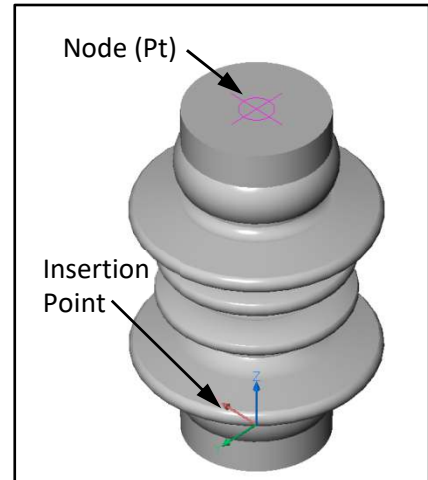
Figure 11 - InSPPrTR205 - Insulator, Station Post, Porcelain, ANSI TR205

7.9.4. Stainless Steel Bolts
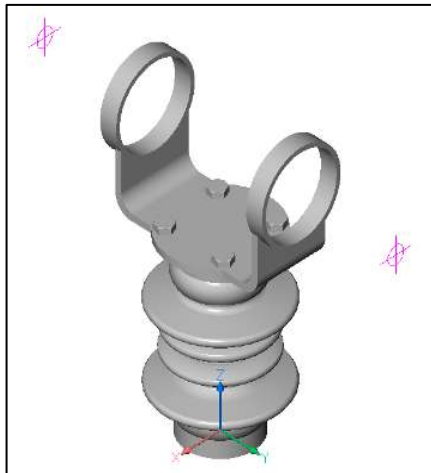
Figure 12 - The Insulator Block with the Connector Block inserted at the Node.

Stainless Steel bolts are used to bolt Insulators to the Structure and Connectors to the Insulator. Since bolts are not included with the physical insulator or connector, they must be accounted for as part of the units. Thus, base connectors and conductor connectors include bolts as part of the Unit to be enumerated on the BOM.

8. The Software Toolbox

The **Toolbar** provides shortcuts to the Software Toolbox apps. The **Software Toolbox** consists of dozens of Major and Minor applications written in AutoCAD AutoLisp and Microsoft VBA for AutoCAD. The Major apps are presented in a Toolbar menu. This menu presents three items. The first is a dropdown menu (Figure 13) that present apps built in VBA and presented as forms.

8.1. The Substation Units & Assemblies Tool

Since Units are AutoCAD Blocks, they could be inserted into a drawing using the AutoCAD Insert command. However, the **Substation Units & Assemblies Tool**, shown in Figure 14, is a VBA app that was created to simplify this operation. The tool expedites the selection and insertion of the Units. The following are the functions of the various parts of the tool. They make several references to the **UCS**, the **Universal Coordinate System**. See Section 10 for more detail on the UCS command.

Figure 13 – The 3DUtility Toolbar

8.1.1. Folders

Selection of one of the options in the **Folders** frame will populate the Units list with the Units in that folder.

8.1.2. Filter

The **Filter** filters the Units list. The list can be filtered by typing a partial description in the Filter. The search assumes leading and trailing wild cards ("*") and the user can include as many additional wild card characters as necessary (e.g. cnn*sl*4 will filter for a CnnBsSl4Al or Connector, Base, Slip, 4" Al).

8.1.3. Units

The **Units** displays the Units in the selected Folder in alphabetical order. To insert a Unit, it must be selected and highlighted. When the Unit is selected, a detailed description will display in the window just below the list box and a thumbnail will display in the image box below the description showing the insertion point an and node points.

8.1.4. Object Snaps

Clicking the **Osnap** boxes will select the snap mode(s) that will be in effect when the Insert Button is clicked. The boxes MUST be selected before clicking the Insert Button. To change the snap mode after clicking Insert, first cancel the current operation by pressing the Esc (Escape) key.

In some drawing modes, the Osnap boxes can also be used to change the snap modes on the fly. If clicking the box does not result in checking the box, then the snap mode must be changed via either the AutoCAD Osnap or Osmode command.

8.1.5. Insert Button

Clicking the **Insert** button will invoke the Insert command and the selected Unit can then be dragged and placed on the drawing. The Osnap buttons checked will determine the Osmode when the Unit is inserted.

8.1.6. 3Pt

The **3Pt** button will insert a Unit using a 3 point orientation procedure. It will request 3 points – first for the Insertion Point (the default snap is Node), then for a point in the X-Axis (the default snap is Perp) and then for the Y-Axis (again a Perp snap). This is normally used
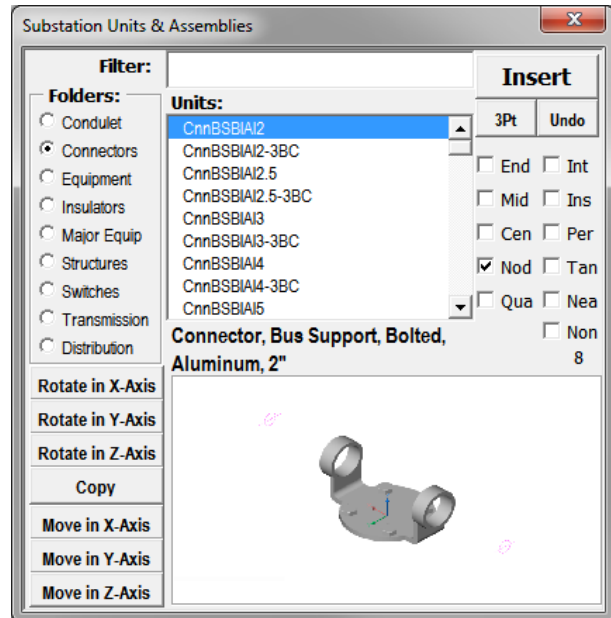
to insert a connector on a pad that does not lie in the X-Y plane. A typical example is a high voltage breaker bushing.

8.1.7. Undo

Clicking the **Undo** button will invoke the AutoCAD Undo command to undo the **last** operation above. Consecutive clicks of the button will undo additional commands.

8.1.8. Rotate Buttons

The **Rotate in X, Y and Z-Axis** Buttons will rotate one or more Units in its **respective** UCS axis. The most common use of the Rotate button is to rotate the **last** Unit inserted. This is the default operation.

However, if one or more Units are selected prior to clicking the Rotate button, they will all be rotated in their respective axes. The Units will remain selected for successive rotations. Press the Esc key to cancel the selected Unit(s). Clicking the Rotate button after cancelling the selected Units will result in rotating the last Unit inserted.

Unit Insertion pt & UCS orientation

Figure 15 - Base Unit

The Unit(s) will be rotated about the respective UCS axis of the Unit, NOT the current UCS as indicated by the UCS icon. (For additional discussion of the UCS and UCS icon, see section 10.) Referring to Figure 15, the X-Axis (the red arrow) is along the direction of the bus. This is typical for connectors. And the Y-Axis (the green arrow) is perpendicular to the X-Axis and lies in the plane of the Unit base. The Z-Axis (the blue arrow) points "UP" from the base. If this Unit is rotated in the Z-Axis, it will always spin about the base. On the other hand, the AutoCAD Rotate3d command rotates about the current UCS axis and NOT the Unit axis.
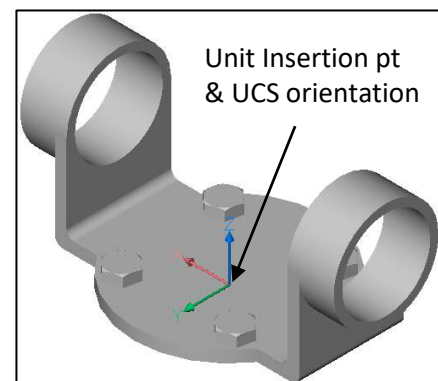
Clicking the Rotate button(s) once will rotate the object(s) 90° clockwise. Holding down the Shift or Ctrl key will clicking the button will cause the object(s) to rotate counterclockwise. Holding the Alt key will result in rotating the object(s) 180°.

8.1.9. Copy

The default operation of the **Copy** button is to copy the **last** Unit inserted. It will make multiple copies of the Unit referenced to its insert point. If one or more Units are selected prior to clicking the Copy button, it will copy those Units as a group based relative to the insertion point of the last Unit selected. If, after copying, the selected Units are canceled with the Esc key, subsequent clicks of the Copy button will copy the last Unit copied.

If the last item drawn is a Line or LWPolyline, clicking Copy will copy this entity multiple times using the Startpoint of the entity. This not only makes adding pipe bus simpler but assures that subsequent lines will start from the same relative end.

8.1.10. Move

Clicking the **Move** buttons will, by default, move the **last** entity inserted. The distance of the move will be entered into a popup input box. Note that, unlike the Rotate and Copy commands, the Move will be made relative to the **current UCS**.

Selecting one or more entities prior to clicking one of the Move buttons will result in the moving all of the selected entities.

8.2.   The Sections Tool

The **Sections Tool** (see Figure 16) provides the user with a simpler method of inserting Section entities into the drawing and generating Elevation drawings. It incorporates both the **SectionPlane** and **SectionPlaneToBlock** commands.

8.2.1.   The AutoCad SectionPlane Command

Before delving into the tool, we should first look at the AutoCAD command **SectionPlane**. To quote AutoCAD, the SectionPlane command "Creates a section object that acts as a cutting plane through 3D objects". In our Substation drawing, these cutting planes result in vertical **Elevations** through the **Plan View**.
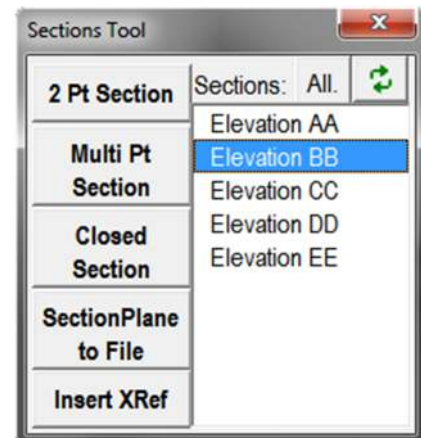
Figure 16 - The Sections Tool

The first step in this process is to define the Sections of the Plan to be displayed as Elevations. These Sections are determined by the designer and the CAD sections are defined by the **SectionPlane** command. Figure 17 shows a Substation Plan View with the Section Layout Lines defining the locations of the SectionPlanes.
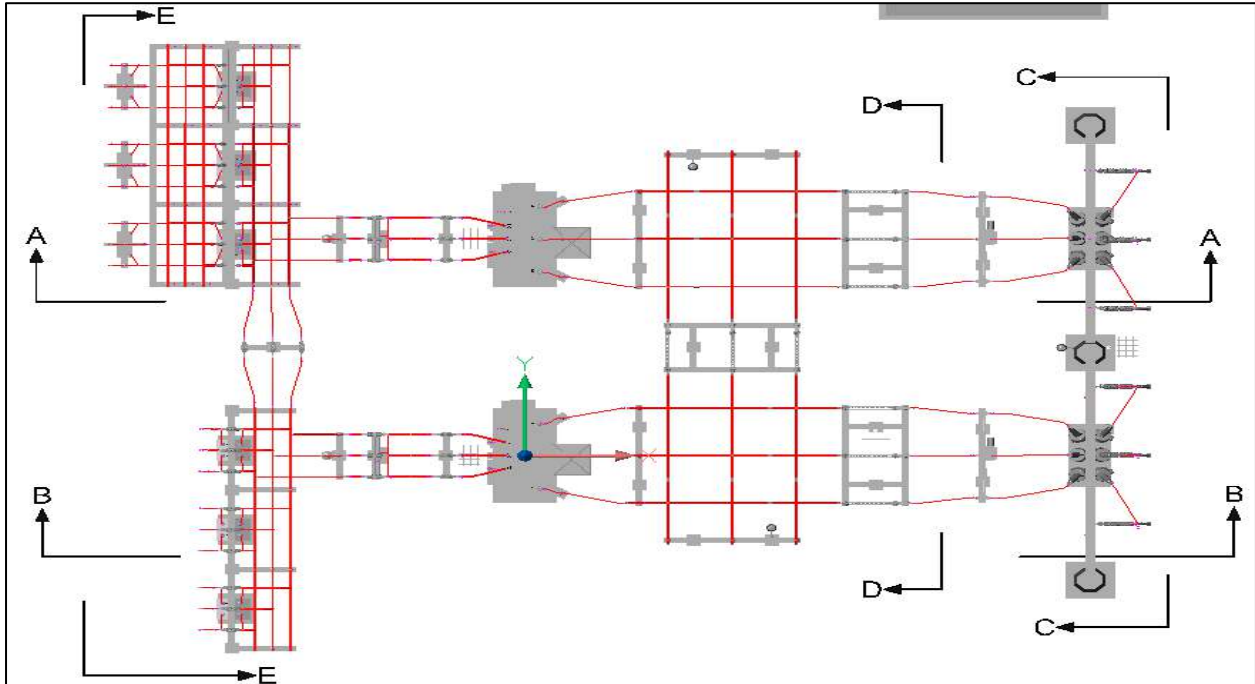
Figure 17- A Substation Plan View with Elevation Section Lines

The SectionPlane command creates a **Section Object** that acts as a cutting plane through the 3D Substation. The allowed responses to the SectionPlane command are as follows:

- **Face** – Specifies a face to establish the plane of the section object.
- **Any Point to Locate Section Line** (default) – Select any point on the screen that is not on a face to create a section object independent of the solid or surface. Select a second point to define the plane of the section object.
- **Draw Section** – Defines the section object with multiple points to create a section line with jogs.
- **Orthographic** – Aligns the section object to an orthographic orientation relative to the UCS. Options are Front, Back, Top, Bottom, Left or Right. The default is Front.

The simplest option is to take the default response and click a point that is the beginning of the SectionPlane and then a second point that is the end. The line should span the structures to be displayed in the Elevation. The SectionPlane has four States – Plane, Slice, Boundary and Volume. By default, the State is Plane. This should be changed to Boundary, easily accomplished via the Properties window. The Boundary State has both a front boundary which corresponds to the Section Line and a rear boundary defining the limit of the Elevation. The rear boundary should be deep enough to present a valid elevation but shallow enough to limit the items shown in the Elevation.

8.2.2.   2 Pt Section

Referring to the **Sections Tool** in Figure 16, the **2 Pt Section** button will create a Section entity by selecting two points (Figure 18). Unlike the SectionPlane command, this will recognize the Ortho setting and easily create orthogonal Section lines. The line can be

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oriented either horizontally or vertically. The user is then queried for a **Section Name** which is added to the **Sections Listbox**. The Section is automatically converted to a non-

clipping Section and the State of the Section is changed from Plane to Boundary. This allows the user to set the "depth" of the section to exclude distant objects. And finally, the app modifies the following settings for the Section:
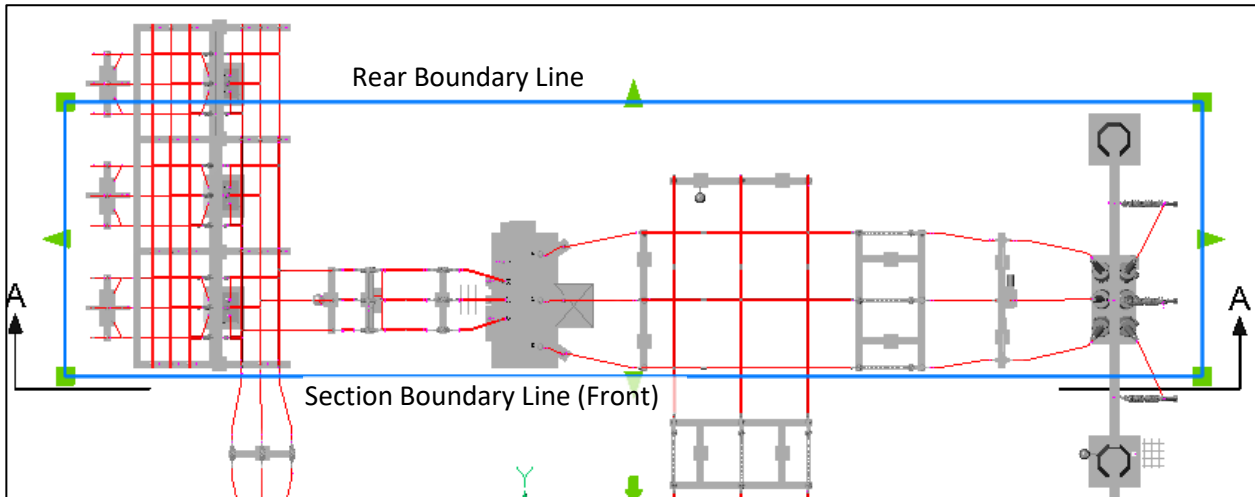
- Intersection Fill Lines – sets Show to No
- Hidden Lines – sets Show to No.
- Cut-away Geometry – set Show to No
- Cut-away Geometry Hidden Lines – set Show to No
- Curve Tangency Lines – set Show to No

These settings will eliminate unnecessary lines while retaining a standard elevation appearance.

8.2.3. Multi Pt Section

The **Multi Pt Section** is similar to the 2 Pt Section except that it provides for "jogs" in the line. For instance a single horizontal line might include a wanted item or exclude an unwanted item. The user can jog, or offset, around the item to include or exclude it.
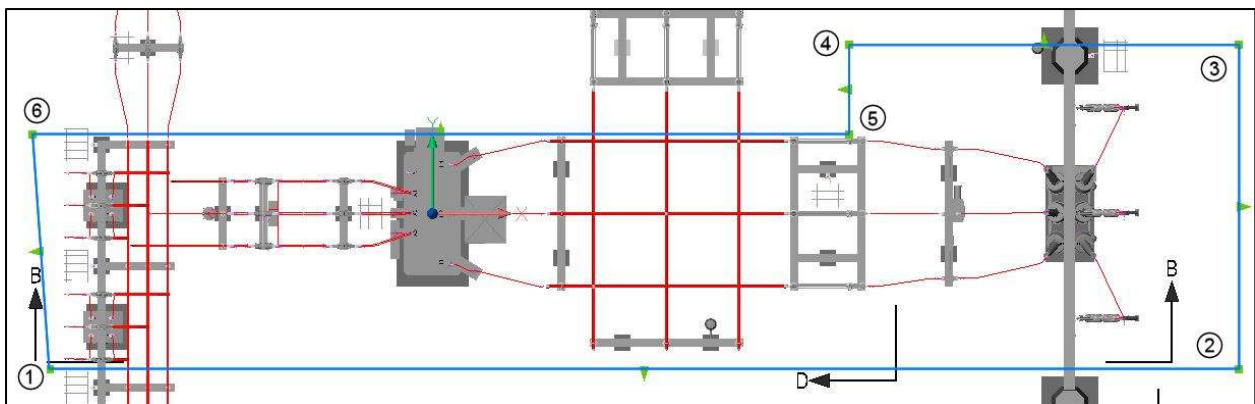
Figure 19 - A Closed Section

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8.2.4. Closed Section (BricsCAD only)

The **Closed Section** is used when the user needs to define the back boundary of the Section. This is similar to drawing a closed multi-sided polyline except rather than a "c" to close, the user just presses Enter. Figure 19 shows a Closed Section.

In this example, the Section starts at 1, then 2. Points 3 and 4 are selected so that the structure top column is included. However, to exclude the switch, point 5 is then selected and then point 6. The user then hits Return to complete the Closed Section. Points 3, 4, 5 and 6 define the back Boundary of the Section.

8.2.5. The AutoCAD SectionPlaneToBlock Command

The next step after creating the Section entities is to create the actual **Elevations** from the Sections. This is accomplished with the **SectionPlanetoBlock** command. The command, as defined by AutoCAD, "Saves selected section planes as 2D or 3D blocks".

This command will invoke the Generate Section/Elevation dialog box. To create the initial block, the settings should be as shown in the Figure 20. Click the **Select section plane** button and pick the appropriate Section object

Figure 20 - Generate Section/ Elevation dialog box

Next click the **Section Settings...** button at the bottom the box. This will invoke the Section Settings dialog box shown in Figure 21. These settings are quite detailed. However, make the following changes.

- Intersection Fill Lines – set Show to No
- Background Lines – set Hidden Lines to No.
- Cut-away Geometry – set Show to No
- Cut-away Geometry Hidden Lines – set Show to No
- Curve Tangency Lines – set Show to No

After modifying the Settings, click OK. On the Generate Section/ Elevation form click **Create**. The user will be asked for an output file to save the Elevation. It will then take several minutes to create the Elevation, so be patient. When all of the Elevations defined in Figure 19 are generated, you should have a drawing for each in the designated folder.

Changes should never be made to these drawings. If changes are required, they should be made to the 3D drawing and new Elevations generated. To do this, enter the

Figure 21 - Section Setting dialog box

SectionPlanetoBlock command and in the Generate Section/Elevation dialog box (see Figure 20 above), select the Section Plane then click the Create button. You will be asked to overwrite the existing file.

8.2.6. Section Plane to File

Selecting one of the **Sections** from the list and clicking the **Section Plane to File** button, the above process is greatly streamlined. The Generate Section/Elevation form will be displayed. The selected Section will be selected on the drawing, the settings will automatically be set, the Export to a file button selected and the file name populated. The user will only need to click the **Create** button. If the output file already exists, a form will popup asking to Overwrite the file or Cancel.

If more than one Section is selected in the list, they will be processed individually. Unfortunately, due to AutoCAD's implementation of the SectionPlanetoBlock command, the user will have to interact with each Section.

8.2.7. Insert XRef

Clicking this button will insert Elevation drawing for the selected Section. A window will pop up requesting an appropriate scale. Refer to Section 10.2.1 below for additional information on inserting the XRef.

8.3. Bubbles

Bubbles, or Callout Bubbles, also referred to as Item Nos., are used to detail the drawing and help the Material Supplier and Contractor understand and interpret the drawing. While drawings can be produced without Bubbles, this can lead to confusion and possibly Change Orders in the construction phase. Figure 22 shows the Bubble Tools form. Figure 23 shows a sample of Bubbles.

Figure 22 - The Bubbles Tool

8.3.1. Get File

Clicking this button will prompt the user for the Excel file containing the **Bill of Material** (**BOM**). This file will be used to populate the list of Items and Descriptions.

8.3.2. X

Deletes the **Filter Field** text and repopulates the Item list.

8.3.3. Filter

Typing a partial description in this field will filter the items in the Items list. The search assumes leading and trailing wild cards ("*") and the user can include as many additional wild card characters as necessary.

Figure 23 - Partial Elevation with Bubbles and Bus Labels

8.3.4. Items List

Double clicking an item in the **Items** list will add items to the Bubbles list at the bottom. As the cursor is moved up and down, any description that does not fit on the line will be shown in the box below. This form can be resized to show more of the description by clicking and dragging near the lower right corner. As VBA does not support resizable forms, this may be a little awkward.

8.3.5. Bubble List

This list contains the items to be inserted into the drawing. This list can be modified by double clicking items in the list to remove them and double clicking Items in the Items list to add them to the Bubble list.

8.3.6. Make

Clicking the **Make** button will prompt the user for a starting point for a **Leader** line and the location of the Bubbles. If there is a single item, it will be inserted with no further interaction. If there is more than one item in the Bubbles list it will prompt for a stacking direction and the Bubbles are stacked in that direction. However, if you right click the mouse it will stack on a 45° angle. If you inadvertently click the Make button more than once in succession, an error will popup. Cancel this by hitting Esc 3 or more times.

As a shortcut, if you click the Make button with no items in Bubble list, it will insert the first five items in the Items list. This is particularly useful if you have a single Item.

8.3.7. Get

Clicking the **Get** button has two modes. If no Bubbles on the drawing are selected, it will bring up the last list of Items. By clicking Get and then Make, the user can insert the same Item(s) repeatedly. If one or more Bubbles are selected (these should be in the same group), those items will be listed in the Bubbles list. This list can then be modified as described above. The user can then click either the Make button (described above) or the Update button.
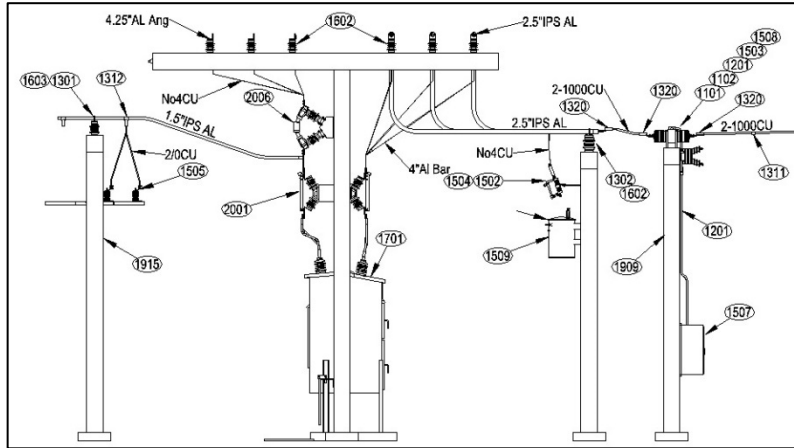
8.3.8. Update

Clicking the **Update** button will replace any selected Bubbles with the items in the Bubbles list. The number of Items in the list does not have to equal the number of Bubbles selected.

8.3.9. Undo

Clicking Undo will Undo any of the button actions above.

8.4. Bus Labelling Tool (LB)
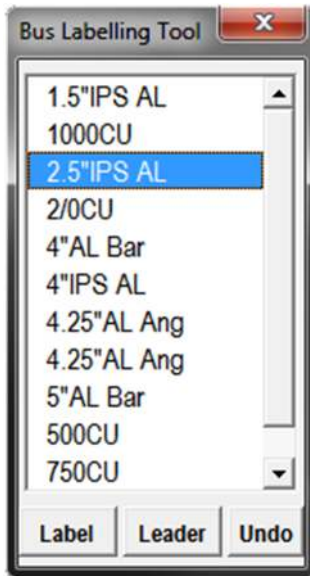
Figure 24 - Bus Labelling Tool

The **Bus Labelling Tool** simplifies the labelling of bus with its conductor size (see Figure 24). When the tool is loaded, the listbox is populated with all of the conductors identified on the XBusXXX layers. If the list contains conductors not used, then the layers should be **Purged**. The user first selects a conductor description and then clicks either Label or Leader. Figure 25 demonstrates these options.

8.4.1. Label

The **Label** button will prompt the user for three points – the Label location, an alignment point(generally along the conductor line) and then indicate which side of the bus. It will place the conductor description at the first point and parallel to the second point and either above or below as indicated by the third point.

8.4.2. Leader

The **Leader** button will prompt the user to select a Conductor point and then a Label point. Moving the cursor for the Label point will turn on the Leader arrow. The user should allow additional length to the line for the Label offset.

8.4.3. Undo

Clicking Undo will undo the last operation.
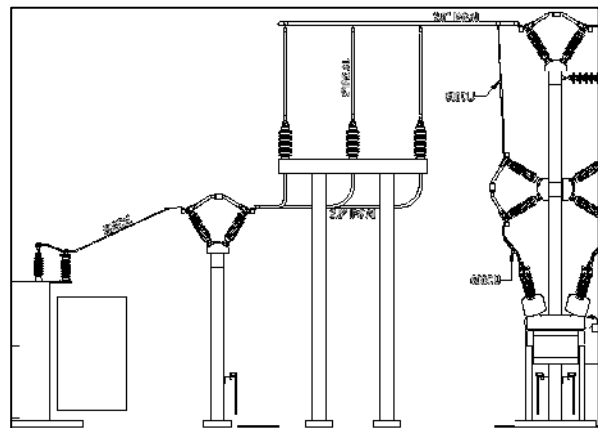
Figure 25 - Bus Label Examples

8.5. Bill of Materials

The **Bill of Material** (**BOM**) tool (Figure 26) takes advantage of the power of 3D design in that ALL materials are included in the Plan drawing. BOM creates a Bill of Material of the Units, Footings and total length of Bus by type. It then outputs the results to an **Excel** worksheet or **CSV** file. A sample Bill of Material printout is included in the Appendices.

8.5.1. Output to:

Select the file output to an Excel or CSV file.

8.5.2. Progress:

This list will display the progress of the BOM process.

8.5.3. File name:

The File name box will be populated with the File name based on the Drawing name and the Path based on the location of the Drawing folder.
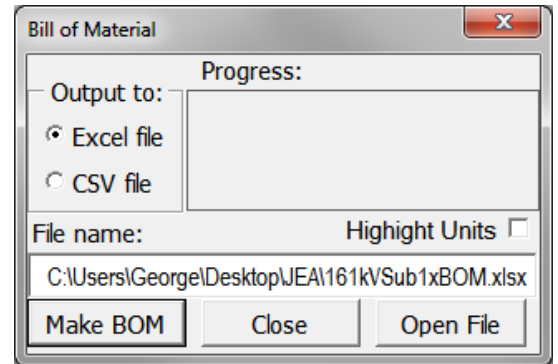
Figure 26 - Bill of Material Tool

8.5.4. Highlight Units

If the box is checked, the Units/Assemblies/Bus will be highlighted as it is processed. On completion of the BOM, the user must execute a Regen to cancel the highlighting.

8.5.5. Make BOM

Clicking this button will initiate the BOM creation process.

8.5.6. Close

Clicking this button will close the BOM tool.

8.5.7. Open File

Clicking this button will open the file displayed in the File name box.

8.6. The Convert Line to Bus Icon

The **Convert Line to Bus** icon invokes the Bus app. Utilizing the AutoCAD **Sweep** command, this app will create a 3D Solid the diameter of the specified bus along the selected line, arc, polyline or spline entity(s). The entities must be drawn on a layer with a specific name beginning with one of the following: XBus, XCnd, XPip or XGnd. See Appendix 10.3 for acceptable layer names.

The entities to be converted can be selected either before clicking the icon or after clicking the icon. Making gross selections with a crossing window will result in only line entities on the XBusXXX layers being converted to bus. Any other lines, Units or other entities will be ignored.
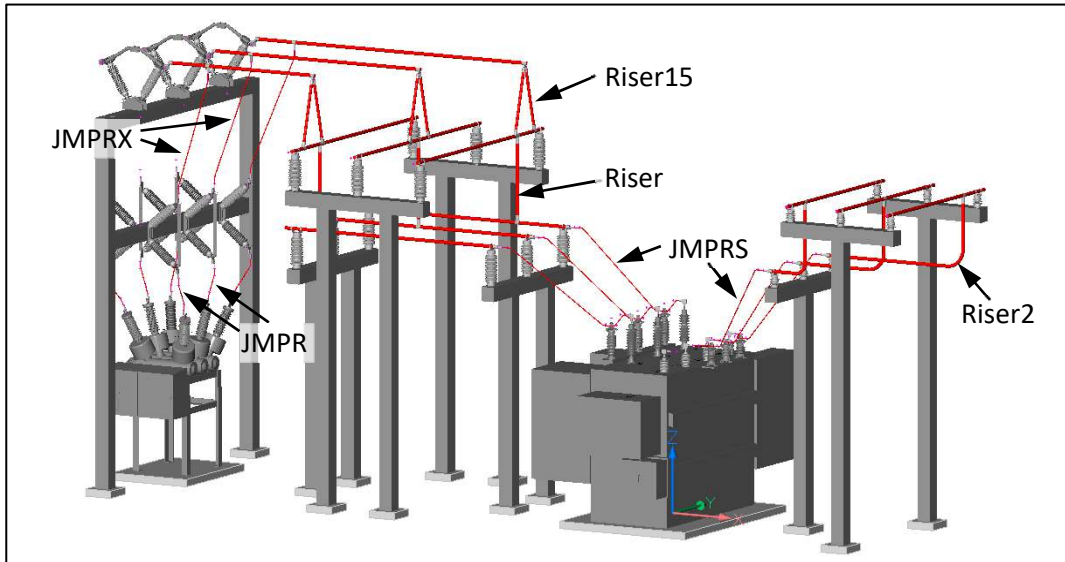
The linear entities should not be deleted after creating the bus entities. The line entities are required by the Bill of Material app to determine the total length of the bus materials.

8.7.   The Jumper Icons

Jumpers make connections between two connectors. Figure 27 illustrates the various Jumper configurations. The Jumpers Icon is a fly-out icon that allows the selection of one of the following Jumper applications.

8.7.1.   JMPR

The **JMPR** app is the basic app for creating jumpers between breakers and switches, breakers and bus, bus and transformers, etc. It will connect a jumper between the Node points of two connectors. The conductor direction will lie in the X-Axis of the connector (see Figure 28). Also note the Node at the left end of the connection.
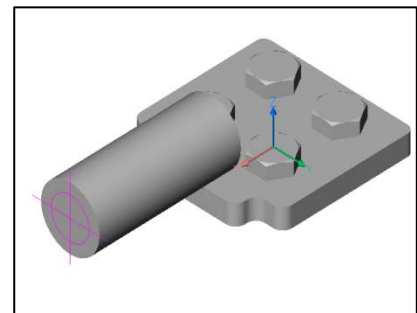
8.7.1.1.   JMPRS

Figure 28 - The Conductor runs in the X-Axis (Red) for this connector

The app, **JUMPRS**, connects multiple consecutive connectors. It is equivalent to executing the JMPR app multiple times with each jumper connected to the previous.

8.7.1.2.   JMPRX

The **JMPRX** app will make connections when no other Jumper will accommodate the connectors. It generally connects from Node to Node to Node etc. Alternately the connection point can be overridden with a different Osnap. It is required in cases where the connector X-Axis is not in line with the connection (generally Tee connectors).

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8.7.1.3. Riser

The **Riser** will construct a vertical connecting bus between two busses at different elevations. This is a vertical riser, hence the name.

8.7.1.4. Riser2

The Riser2 app creates a jumper with a right angle bend. A typical application would connect a switch to a pipe bus at a different elevation with an elbow connector or bend in the bus.

8.7.1.5. Riser15

The Riser15 app creates a riser between two crossing busses at different elevations using an A-frame connector. This is used when a single horizontal bus supported on one end connects to lower bus running orthogonally. A single Riser would not be stable hence the use of the A-frame connector on the upper bus (see Figure 29). The A-frame connections project at 15° from the vertical, thus the name Riser15.
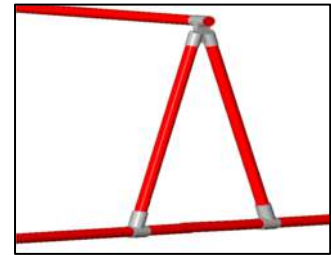
Figure 29 - A-Frame Connection

8.8. Mini Apps

The following Mini Apps are included to assist in the production of the Design Drawings. These apps make certain assumptions and include data that the user should thoroughly understand before using.

8.8.1. CheckBusLength and Couplers

Pipe bus comes in standard lengths of 10 to 40 feet in 10 foot increments. The **CheckBusLength** app will display all pipe busses exceeding a specified length. The **Couplers** app will add a coupler to at the specified distance from the Startpoint of a bus for any bus that exceeds the specified length.

8.8.2. Endcaps

It is standard practice to put Endcaps on all open ended pipe bus. The **Endcaps** app will find all pipe bus ends that are not enclosed by a connector and add an Endcap to the bus.

8.8.3. DisplayBus

For the BOM app to correctly accumulate the total length of bus, the original linear geometry must not be deleted. The **DisplayBus** app will highlight all linear geometry on the XBusXXX layers. It is important to understand that this app must explode all Assemblies in order to display the geometry in the Assembly. A Msgbox will display after highlighting

the geometry prompting to "Click OK to UNDO". You must click OK or the Assemblies could remain exploded.

8.8.4. DesignData

The **DesignData** app will display the **Substation Design Guidelines** sheet (shown in the Appendixes). The values shown in the supplied guidelines are based on manufacturer's data and should be used only after thorough understanding of the data. As an option, you can substitute your own guidelines.

8.8.5. UserManual

Open the User Manual.

9. AutoCAD Commands

To use the 3D Toolbox, a basic understanding of AutoCAD 2D elements and drawing commands is required. A detailed knowledge of 3D elements and commands, while beneficial, is not necessary due of the inherent ease of the Toolbox design. However, the following commands and concepts will be required in the development of Design drawings and, in time, should be mastered.
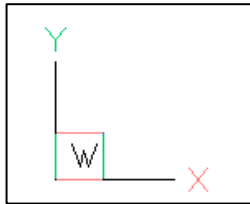
Figure 30 - The Default 2D UCSIcon set to WCS

9.1. The UCS

The **Universal Coordinate System** (**UCS**) is a moveable Cartesian coordinate system that establishes the XY, YZ and XZ work planes. When a new drawing is created, the UCS is, by default, set to the **World** UCS (referred to as the **WCS**). The default visual style is set to 2DWireframe and the **UCSIcon** appears as in **Error! Reference source not found.**. When working in 3D the visual style should be changed to one that better displays 3D objects. The simplest usable style is 3D Hidden and can range up to Realistic and Shaded. Choose a style that best suits you and your workstation CPU power and memory. Any style other than 2DWireframe will display the UCS as shown in Figure 31.

When working in 3D it is important to know the **Current** UCS. If it is in question, issue the command **UCSIcon** and respond with **ORigin** to display the icon at the Origin of the Current UCS. However, be warned that if the origin is not on the screen or it is too near the screen border for the icon to display, it will display in the default location, normally the lower left corner. If it is still questionable, *Zoom Extents* and then Zoom out just a little more. To place the Icon back in the corner, issue the *UCSIcon* command and respond "Corner".
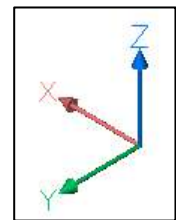
Figure 31 - A 3D Icon

The UCS origin and orientation can be changed using the *UCS* command. The simplest response to the UCS command is "World". This will set the UCS back to the default World

setting. Issuing the command **Plan** and accepting the default response, Current UCS, you will be returned to the default Plan view with the Y-axis to the top and X-axis to the right.

The following are the acceptable responses to the UCS command:
- **Specify origin of UCS** (default if you click a point) – Defines a new UCS using one, two, or three points:
    - If you specify a single point, the origin of the current UCS shifts to that point without changing the orientation of the X, Y, and Z axes.
    - If you specify a second point, the UCS rotates to pass the positive X axis through this point.
    - If you specify a third point, the UCS rotates around the new X axis to define the positive Y axis.
- **Face** – Aligns the UCS to the selected face of a solid object. It will **not** find the face of a solid that is part of a Block, Unit or Assembly.
- **NAmed** – Saves or restores a named UCS.
- **Object** – Aligns the UCS to the selected object. If this is Block, Unit or Assembly, it is aligned to the insertion point and the Entities UCS.
- **Previous** – Restores the previous UCS.
- **View** – Aligns the XY plane of the UCS to a plane perpendicular to your viewing direction. The origin point remains unchanged, but the X and Y axes become horizontal and vertical on the screen.
- **World** (default if you press Return) – Restores the World UCS.
- **X/Y/Z** – Rotates the UCS around the specified axis by a specified angle.
- **Z Axis** – Aligns the UCS to a specified positive Z axis. The UCS origin is moved to the first point designated and its positive Z axis passes through the second point designated.

Normal use of the Toolbox will not require the user to change the UCS. However, each Unit inserted in the drawing will have its own unique UCS. This UCS can be displayed by issuing the UCS command, selecting the "Object" response and then clicking the Unit. The Jumper apps make extensive use of the Units UCS to correctly orient the jumper. If the JMPR or JMPRS apps refuse to correctly orient the jumper, then you should check the Unit UCS. Some Units orient the UCS in the direction of the bus and not the jumper. The solution is to use the JMPRX app.

Extensive knowledge and use of the UCS commands is a necessity in the development of new Units.

9.2.   Model Space vs Paper Space

Prior to Release 11, AutoCAD provided a single drawing environment referred to as **Model Space**. While final drawing plots can be produced in Model Space, it is quite tedious to setup plotting areas, title blocks, notes, etc. In R11 the concept of a second working environment, **Paper Space**, was introduced for this purpose.

By default, new drawings open in Model Space and to this point all of our work has been accomplished in Model Space. In a new drawing, at the lower left corner of the drawing area just above the command line are, by default, three tabs – Model, Layout1 and Layout2. Clicking either of the Layout tabs will open a default Paper Space layout as shown in Figure 32.

Paper Space is meant to represent just what it says – one or more paper layouts of the drawing. In Paper Space, everything is drawn on a "sheet" at a 1:1 scale and, utilizing **Viewports,** one or more views into Model Space, can be placed on the sheet. The Viewport can then be scaled so that the desired portion of Model Space fits within the Viewport. Dimensions, notes, borders, title blocks and other print related items which do not really belong in Model Space can then be added in Paper Space. This approach will be used for creating drawings such as the Foundation Plan. However, for elevations the following approach will be used.

9.2.1. Elevation BB

To create a **Paper Space** drawing of Elevation BB, click on Layout1. This will open the Paper Space layout in the default format as shown in Figure 32. By default, an 8½ x 11 page is displayed in white with a single Viewport (the solid rectangle). The Viewport shows the drawing Model Space zoomed to the extents of the Viewport. A dashed line, if present, just inside the sheet shows the printer limits of the page based on the selected printer.
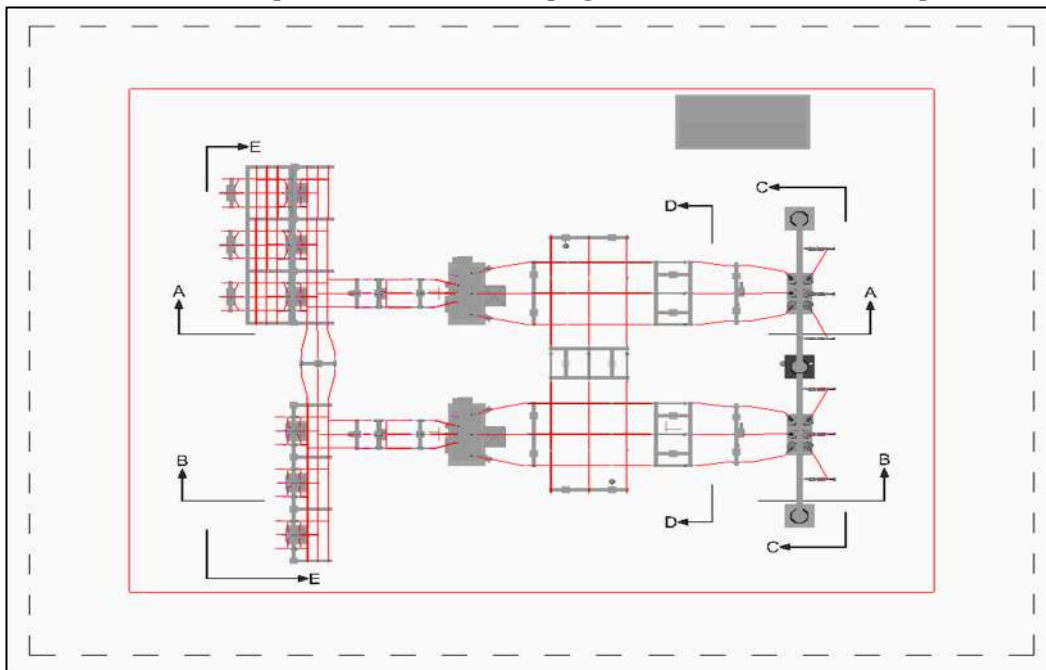
Figure 32 - New Paper Space Layout

First, delete the Viewport since we will be creating an **XRef** of the Elevation drawing which was created earlier with the SectionPlaneToBlock command. Click on the Viewport boundary and press Delete. This will delete the view of the Model Space but will have no effect on the drawing.

To modify the layout, right click on the Layout tab and click **Page Setup**. This will bring up the Page Setup dialog box shown in Figure 33. Select the printer **Name** from the dropdown list and then select a **Page Size** and **What to plot**. For this example, choose the **PDF printer**, the **Ledger (17 x 11) paper size** and **Extents** to plot. Leave the **Plot Scale** at 1:1. Set the **Drawing Orientation** to **Landscape**. Click Preview if you wish, then click **OK**.

Figure 33 - Layout Page Setup Dialog Box

At this point you should see the Paper Space layout with the larger page and probably no dashed line since PDF writers do not have a non-printable area.

Next Insert the drawing for Elevation BB as an **XRef** near the left border just below the vertical center. The exact position can be determined later. Finally enter a scale for the XRef.

While the scale will depend on the size of the Elevation drawing, for an 11 x 17 drawing sheet, the suggested scale is 3/32" = 1'-0". The appropriate scale factor is 0.0078125 (which is 3 ÷ 32 ÷ 12).

And finally we should dimension the elevation view in Paper Space. This is easily done using an associative dimension that will take its measurements from the XRef scale. Because we are working in Paper Space, the text height value should be relative to the paper size. In this case, a height of 1/8" (0.125) is appropriate. All other dimension parameters should be sized accordingly. A MIDdle Osnap will aid in the dimensioning.

After dimensioning, an appropriate title block should be added. Figure 34 shows the completed Paper Space sheet with dimensions and title block.

The insertion of the Elevation drawing can be simplified by opening the **Sections** tool, selecting the desired Section and clicking **Insert XRef**.

9.2.2. Foundation Plan

Finally we will demonstrate the process for developing a drawing sheet based on the Substation Plan View. In this instance we will create a rudimentary **Foundation** Plan. The following is a step by step procedure. Where the procedure calls for flipping to/from Paper
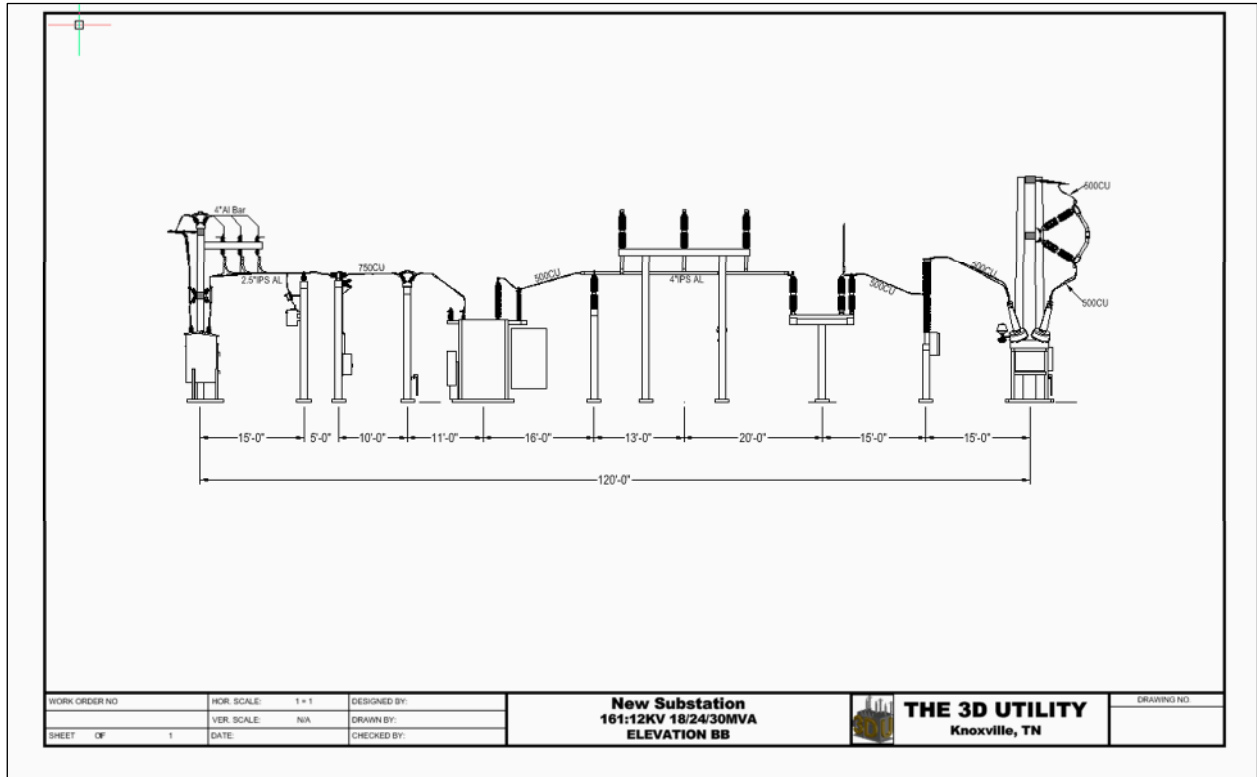
Figure 34 - Elevation BB in Paper Space

and Model Space, you can do so by one of two ways. Either by clicking the Model/Paper Space toggle on the Status Bar or by double clicking in the appropriate space on the drawing.

1. Select the **Layout2** tab. It should appear something like Figure 32. This time do not erase the Viewport.
2. Right click the Layer tab and bring up the **Setup** dialog (Figure 33).
3. Select the **PDF** printer, **11 x 17** drawing sheet, **Landscape** and **Extents** under what to plot. (Modify these settings to fit your need.) Clicking OK will take you back to the Layout.
4. Click on the Viewport and, utilizing the grips, stretch it to cover most of the sheet inside the title block border.
5. Flip to Model Space. Be careful, this will effectively put you in Model Space and any changes you make will affect the drawing.
6. While in Model Space, bring up the Layer Control form and select all rows.
7. Under the **VP Freeze** column select, click one of the rows. This will freeze all layers in that Viewport.
8. De-select the **Footings** layer so that it is displayed. (See below for an explanation of the Footings layer.) At this point the only items showing in your window should be footings.
9. Zoom Extents
10. Flip back to Paper Space and click on the Viewport border. If you are not concerned that the drawing is not displayed at a standard scale, skip the next step.

11. Bring up the **Properties** window and scan down for the value of **Custom Scale**. You must pick a value, less than the value shown, that would represent a standard scale. For instance, if the value is 0.005653, you will need to round down to the nearest standard scale. In this case 1:200 is 0.005. Set the Custom Scale to 0.005.
12. Finally, in the Properties, set the **Display Locked**: to **Yes**. This will keep you from inadvertently clicking inside the Viewport and panning or zooming the Model Space.

You can now proceed with dimensioning and notating the drawing. The final drawing should look something like Figure 35.

Regarding the Footing layer. The footings included on the Structure and structural Assembly Units are nested blocks. For some reason AutoCad will not display these nested blocks in Viewports. However, with the aid of a small app (**Ftg**), the nested footings can be overlaid with a 3D box and placed on the layer Footing. These boxes can then be displayed in the Viewport by enabling the layer Footing.
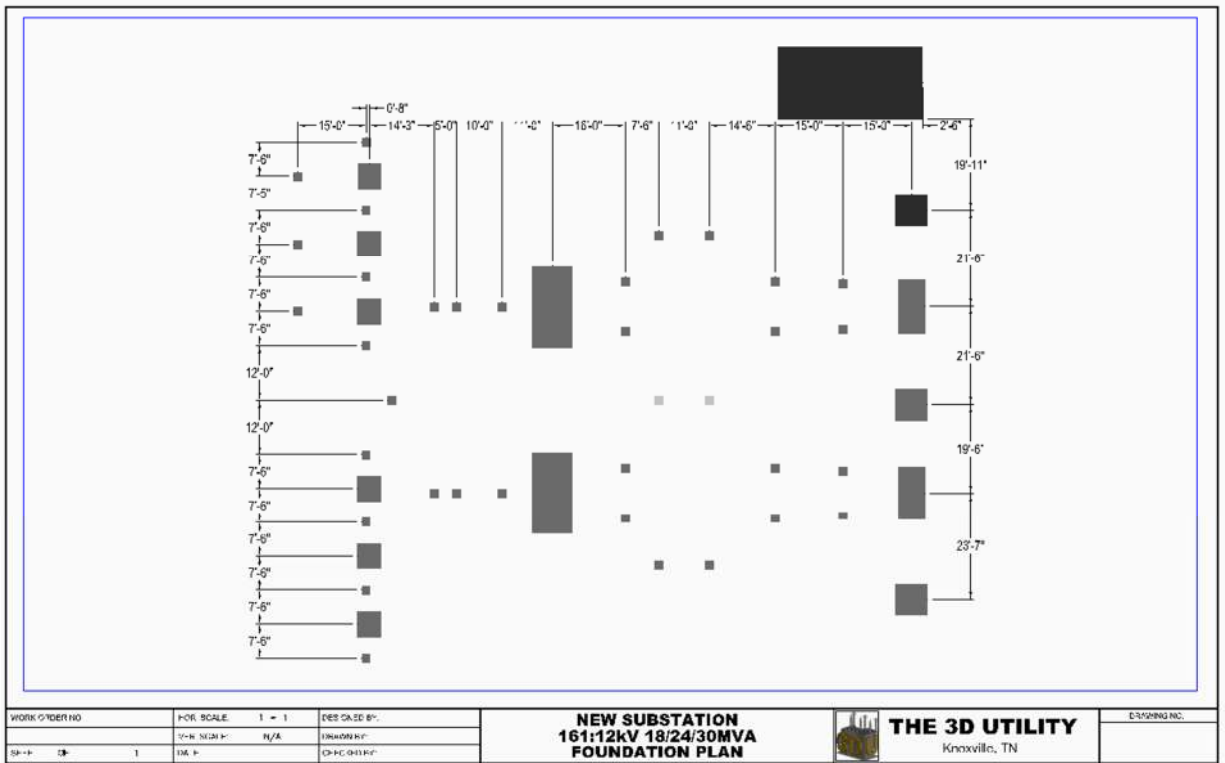
Figure 35 - Foundation Plan

10. Appendices

10.1. Installation

10.1.1. VBA for AutoCAD

The 3DToolBox requires the installation of the AutoCAD module of Microsoft Visual Basic for Applications. Go to following link and follow the instructions for your version of AutoCAD:

https://knowledge.autodesk.com/support/autocad/downloads/caas/downloads/content/download-the-microsoft-vba-module-for-autocad.html

10.1.2. The 3DToolBox

Installation of the **3DToolBox** is simple and requires no installation program. To install the files and applications execute the following steps:

1. In your My Documents folder, create a new folder and name it **3DUtility**.
2. Extract the files/folders from the Zip file to the 3DUtility folder.
3. In AutoCAD, type Appload to bring up the Load/Unload Application.
4. Under Startup Suite click the Contents... button to bring up the loader.
5. Click Add and navigate to the My Documents\3DUtility\Programs folder.
6. Select the3DUtility.dvb and click Open. The selector dropdown to the right of the File Name box should show VBA Files (*.dvb).
7. Again click Add. Navigate to the My Documents\3DUtility\Programs folder if necessary.
8. In the dropdown selector, select AutoLISP Files (*.lsp).
9. Select the files 3DToolBox.lsp, 3DToolBoxAux.lsp and JUD.lsp and click Open.
10. Click Close on the Load/Unload Applications form.
11. Close and reopen your dwg file to load the apps.

The Apps should now be available for this drawing and all future drawings that you open.

To implement the **Menu** system, execute the following steps:

1. At the command prompt, type **CUI** to open the Customize User Interface.
2. Under the Customize tab, right click on Partial Customization Files and click Load Partial Customization File.
3. Navigate to the My Documents\3DUtility folder and select 3DUtility.cui.
4. From the Menubar click Tools then Toolbars then 3DUtility and click on 3DToolBox. This should open the 3DToolBox toolbar which you can dock in your menu. The toolbar has three items. The first and second are dropdown menus with various items. You can find these in the manual. (If the Menubar does not show just above your Ribbon, type Menubar at the Command Prompt and set the value to 1.)

10.2. Units

10.2.1. Condulet

The Condulet (**Cdl**) Unit name breaks down as follows:
- F8 or Bu– Describes this as a form 8 or Bushing
- C, E, LB, LL, LR, T or X – Describes the style
- -1, -1.5, -2, -2.5, -3 – Identifies the conduit diameter

10.2.2. Connector

The Connector (Cnn) Unit name breaks down as follows:
- Type
    - BS – Bus Support
    - Cm – Compression
    - Cp – Coupler
    - Gd – Ground
    - PG – Parallel Groove
    - Sr – Spacer
    - Te – Tee
    - Tl – Terminal
- Connection
    - Bl – Bolted
    - Ca – Cable
    - Cp – Coupler
    - Ex – Expansion
    - Sl – Slip
    - Vl – Vertical
    - CF – Cable to Flat
    - CC – Cable to Cable
    - TC – Tube to Cable
    - TF – Tube to Flat
    - TT – Tube to Tube
    - AF – A-Frame
    - EC – End Cap
- Metal
    - Al – Aluminum
    - Bz - Bronze
    - Cu – Copper
- Size
    - 2", 2.5", 3", 4", 5", 6"
    - 336AC, 636AC, 954AC
    - Various Cu sizes from 250 to 1250
- Bolt Circle
    - -3BC – 3" Bolt Circle
- Angle

o   Number following @ symbol is angle

Examples:
- CnnTTAl4 – Connector,Tee, Tube to Tube, Aluminum 4"
- CnnCpTTAl4@90 – Connector, Coupler, Tube to Tube 4" @90°
- CnnBSCACu2-550-750 – Connector, Bus Support, Cu, 2 550MCM-750MCM

10.2.3. Equipment

The Equipment (**Equ**) Unit name breaks down as follows:
- Bu – Bushing
  - BIL
  - – 2000A (ampacity)
  - (Manufacturer)
- CT – Current Transformer
  - BIL
  - (Manufacturer – Model)
- FC – Fuse Cutout
  - KV
- LA - Lightning Arrestor
  - KV
  - (Manufacturer)
- Lu – Luminaire
  - (Manufacturer)
- MC – Meter Cabinet
- MS – Metal-Clad Switchgear
- TB – Test Box
- Tn – Terminator
- VT – Voltage Transformer
  - KV
  - (Manufacturer – Model)
- Xf – Transformer
  - KV

Examples:
- EquBu350-2000(ABB) – Equipment, Bushing, 350kVBIL, 2000A, ABB
- EquCT110(GE-JCW) – Equipment, Current Transformer, 110kVBIL, GE model JCW
- EquLu(Holophane) – Equipment, Luminaire, Holophane

10.2.4. Insulators

The Insulator (**Ins**) Unit name breaks down as follows:
- SP – Station Post
  - Pm – Polymer
  - Pr – Porcelan

- ▪ SS – Standard Strength
- ▪ EH – Extra High Strength
- ▪ TR – ANSI TR rated.

Examples:
- • InsSPPmSS550 – Insulator, Station Post, Polymer, Standard Strength, 55kVBIL
- • InsSPPrTR210 – Insulator, Station Post, Porcelain, ANSI TR210

10.2.5. Major Equipment

The Major Equipment (**Mjr**) Unit name breaks down as follows:
- • Br – Breaker
  - o SF – SF$_6$
  - o BIL
  - o -2000A (ampacity)
  - o (Manufacturer – Model)
- • CS – Circuit Switcher
  - o SF – SF$_6$
  - o BIL
  - o -1200A (ampacity)
  - o (Manufacturer – Model)
- • MS – Metal-Clad Switchgear
  - o –Number of Bays
- • RH – Relay House
  - o –LxW
- • Xf – Transformer
  - o Ol – Oil
  - o BIL
  - o –MVA

Examples:
- • MjrBrSF750-2000(ABB-PMI) – Major Equipment, Breaker, SF$_6$, 750kVBIL, 2000A, ABB model PMI
- • MjrXfOl250-18mVA – Major Equipment, Transformer, Oil, 250kVBIL, 18mVA

10.2.6. Structures

The Structure (**Str**) Unit name breaks down as follows:
- • Br – Breaker Structure
  - o T## - Unique identifier
  - o Voltage designator (common to all types)
    - ▪ 01 – 15kV
    - ▪ 02 – 25kV
    - ▪ 04 – 46k V
    - ▪ 06 – 69kV
    - ▪ 11 – 115kV
    - ▪ 13 – 138kV

- ▪ 16 – 161kV
  - o – Height in feet (common to all types)
- De – Deadend Structure
- Hh – H-Structure
- LM – Lightning Mast
- MG – Metering Structure
- Pi – Pi Structure
- Sw – Switch Structure
  - o Ve – Vee switch
  - o VB – Vertical Break switch
  - o 3P – Three pole (three phase group operated switch)
  - o 4P – Four pole (only used at 15 &25kV where the neutral is switched)
- TS – Tee Structure

The Structure group also includes Fence (**FNC**) blocks:
- Bl – Concrete Block
  - o – WxH
- CP – Corner Post
  - o -Height
- CK – Chain Link
  - o -WxH
- Gt – Gate
  - o -Width
- LP – Line Post

Examples:
- StrBrT1101 – Structure, Breaker ,T11 identifier, 15kV
- StrDeHh06-25 – Structure, Deadend, H-Structure, 69kV, 25'
- StrLM-65 – Structure, Lightning Mast, 65'
- StrSw3PVB16-20 – Structure, Switch, 3 Pole, Vertical Break, 161kV, 20'
- FncCk-5x9 – Fence, Chain Link, 5' wide x 9' high

10.2.7. Switches

The Switch (**Swt**) Unit name breaks down as follows:
- CB – Center Break
- HS – Hook Stick
- HV – Hook Stick Vee
- RB – Regulator By-Pass
- SB – Side Break
- VB – Vertical Break
- Ve – Vee Switch
- The following are common to all switches
  - o 1P – Single Pole
  - o 3P – 3 Pole group operated
  - o 4P - Four pole (only used at 15 &25kV where the neutral is switched)

- o BIL
- o –Amperage
- o (Manufacturer)
- Op – Switch Operator
  - o SA – Swing Arm
  - o WG – Worm Gear
  - o GP – Ground Plate

Examples:
- SwtVB3P350-1200(USCO) – Switch, Vertical Break, Three Pole, 350kVBIL, 1200A, USCO
- SwtHV1P110-1200(USCO) – Switch, Hook Stick Vee, Single Pole, 110kVBIL, 1200A, USCO
- SwtRB1P150-1200(SS) – Switch, Regulator By-Pass, Single Pole, 150kVBIL, 1200A, Southern States
- SwtOpWG – Switch, Operator, Worm Gear

10.3. Layer Names

The Software Toolbox recognizes several special layers that are associated with bus, conduit or pipe. To correctly integrate the Hardware Toolbox with the Software Toolbox, the layer names must conform to the following:

10.3.1. XBus – Pipe or wire bus
- 1, 1.5, 2, 2.5, 3, 4, 5, 6 Diameter in inches
- No4, 20, 30, 500, 750, 1000 MCM
- AL or CU

10.3.2. XBus#Bar – Flat bar bus
- # - Width in inches

10.3.3. XBus#Ang – Angle bus
- # - Leg width in inches

10.3.4. XGnd – Ground conductor
- 20, 30, 500, 750, 1000 MCM
- 38, 516
- CU, EHS, HSS

10.3.5. XCnd – Conductor
- 336, 477, 636, 954
- AC

10.3.6. XCdt – Conduit
- 0.5, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5, 3.0, 3.5. 4.0 Diameter in inches
- Emt, PVC

10.3.7. XPip – Pipe
- Outside Diameter in Inches

10.4. Sample Bill of Material

The following BoM is for the substation shown on the title page.

No	Item	Description	Qty
Bill of Materials			
Drawing Name: 161kVSub.dwg			
1001	Bus1.5Al	Bus, 1.5" Al	135
1002	Bus1000Cu	Bus, 1000 Cu	298
1003	Bus2.5Al	Bus, 2.5" Al	219
1004	Bus20Cu	Bus, 2/0 Cu	57
1005	Bus3.25AlAng	Bus, 3.25" AlAng	274
1006	Bus4.25AlAng	Bus, 4.25" AlAng	138
1007	Bus4Al	Bus, 4" Al	423
1008	Bus4AlBar	Bus, 4" AlBar	138
1009	Bus500CU	Bus, 500 CU	344
1010	Bus5AlBar	Bus, 5" AlBar	156
1011	Bus750Cu	Bus, 750 Cu	216
1012	BusNo4CU	Bus, No4CU	56
1101	CdlF8T-1	Condulet, Form 8T, 1"	2
1102	CdlF8X-1	Condulet, Form 8X, 1"	2
1201	Cdt1EMT	Conduit, 1" EMT	60
1301	CnnBSSlAl1.5-3BC	Connector, Bus Support, Slip, Aluminum, 1.5", 3BC	9
1302	CnnBSSlAl2.5	Connector, Bus Support, Slip, Aluminum, 2.5"	6
1303	CnnBSSlAl2.5-3BC	Connector, Bus Support, Slip, Aluminum, 2.5", 3BC	12
1304	CnnBSSlAl4	Connector, Bus Support, Slip, Aluminum, 4"	12
1305	CnnCpTCAl2.5-900-1250	Connector, Coupler, Tube to Cable, Aluminum, 2.5", 900-1250	3
1306	CnnCpTCAl4-350-600	Connector, Coupler, Tube to Cable, Aluminum, 4", 350-600	6
1307	CnnCpTFAl2.5	Connector, Coupler, Tube to Flat, Aluminum, 2.5"	3
1308	CnnGdCFBz	Connector, Ground, Cable to Flat, Bronze	8
1309	CnnPGCCAl-395-800	Connector, Parallel Groove, Cable to Cable, Aluminum, 395-800	18
1310	CnnPGCCCU-4-20	Connector, Parallel Groove, Cable to Cable, Copper, 4-20	2
1311	CnnSrCCCu-750-1000	Connector, Spacer, Cable to Cable, Copper, 750-1000	18
1312	CnnTeTCAl1.5-4-250	Connector, Tee, Tube to Cable, Aluminum, 1.5", 4-250	12
1313	CnnTeTCAl2.5-4-250	Connector, Tee, Tube to Cable, Aluminum, 2.5", 4-250	2
1314	CnnTeTFAl2.5	Connector, Tee, Tube to Flat, Aluminum, 2.5"	9
1315	CnnTeTTAl2.5	Connector, Tee, Tube to Tube, Aluminum, 2.5"	4
1316	CnnTeTTAl4	Connector, Tee, Tube to Tube, Aluminum, 4"	12
1317	CnnTlCFAl900-1250	Connector, Terminal, Cable to Flat, Aluminum, 900", 1250	9
1318	CnnTlCFAl900-1250@45	Connector, Terminal, Cable to Flat, Aluminum, 900", 1250@45°	6
1319	CnnTlCFCu-2!0-800	Connector, Terminal, Cable to Flat, Copper, 2/0-800	18
1320	CnnTlCFCu-2X500-2000	Connector, Terminal, Cable to Flat, Copper, 2X500-2000	36
1321	CnnTlCFCu-4!0-1000	Connector, Terminal, Cable to Flat, Copper, 4/0-1000	72
1322	CnnTlCFCu20-800	Connector, Terminal, Cable to Flat, Copper, 20", 800	14
1323	CnnTlCFCu4!0-1000@90	Connector, Terminal, Cable to Flat, Copper, 4!0", 1000@90°	6
1324	CnnTlECAl2.5	Connector, Terminal, End Cap, Aluminum, 2.5"	6
1325	CnnTlECAl4	Connector, Terminal, End Cap, Aluminum, 4"	18
1326	CnnTlSCCu1.25-4!0-1000	Connector, Terminal, Stud to Cable, Copper, 1.25", 4/0-1000	36
1327	CnnTlSFAl1.25	Connector, Terminal, Stud to Flat, Aluminum, 1.25"	14
1328	CnnTlTFAl1.5@90	Connector, Terminal, Tube to Flat, Aluminum, 1.5"@90°	9
1329	CnnTlTFAl2.5	Connector, Terminal, Tube to Flat, Aluminum, 2.5"	3
1330	CnnTlTFAl4	Connector, Terminal, Tube to Flat, Aluminum, 4"	12
1401	DedWg33AA	Deadend, Wedge, 336AA	12
1501	EquBrMs-5X2.5	Equipment, Breaker, Metal-Clad Switchgear, 5X2.5	6
1502	EquCL110	Equipment, Current Limiting Fuse, 110kVBIL	2
1503	EquCT110(GE-JCW)	Equipment, Current Trf, 110kVBIL(GE-JCW)	6

1504	EquFC110	Equipment, Fuse Cutout, 110kVBIL	2
1505	EquLAIC-3-12kV(OB)	Equipment, Lightning Arrestor, Intermediate Class, 3-12kV(OB)	9
1506	EquLu(Holophane)	Equipment, Luminaire(Holophane)	3
1507	EquMC(TVA)	Equipment, Meter Cabinet(TVA)	2
1508	EquVT110(GE-JVW)	Equipment, Voltage Trf, 110kVBIL(GE-JVW)	6
1509	EquXf110	Equipment, Transformer, 110kVBIL	2
1601	InsDiPmSt52-4	Insulator, Distribution, Polymer, Strain, ANSI TR52	12
1602	InsSPPrTR205	Insulator, Station Post, Porcelain, ANSI TR205	57
1603	InsSPPrTR225	Insulator, Station Post, Porcelain, ANSI TR225	6
1604	InsSPPrTR295	Insulator, Station Post, Porcelain, ANSI TR295	12
1605	InsTmStPm161kV	Insulator, Transmission, Strain, Polymer, 161kV	3
1701	MjrBrSF110-1200(Siemens-	Major Equipment, Breaker, SF6, 110kVBIL, 1200(Siemens-SDV6)	6
1702	MjrBrSF750-1200(Siemens-	Major Equipment, Breaker, SF6, 750kVBIL, 1200(Siemens-SPS2)	2
1703	MjrCSSF750-1200(SS-CSV)	Major Equipment, Circuit Switcher, SF6, 750kVBIL, 1200(SS-CSV)	2
1704	MjrRH-14x30	Major Equipment, Relay House, 14x30	1
1705	MjrXfOl750-30mVA	Major Equipment, Transformer, Oil, 750kVBIL, 30mVA	2
1801	SSB1	Stainless Steel Bolts, 1/2"	484
1901	StrBrT1101	Structure, Breaker, T11, 15kV	1
1902	StrBrT1116	Structure, Breaker, T11, 161kV	1
1903	StrBrT1201	Structure, Breaker, T12, 15kV	2
1904	StrBrT1216	Structure, Breaker, T12, 161kV	1
1905	StrBrT2101	Structure, Breaker, T21, 15kV	1
1906	StrBrT2201	Structure, Breaker, T22, 15kV	2
1907	StrMg3P01-17	Structure, Metering, Three Pole, 15kV, 17'	2
1908	StrPi16-13	Structure, Pi-Structure, 161kV, 13'	2
1909	StrPi16-22	Structure, Pi-Structure, 161kV, 22'	2
1910	StrSw16-19	Structure, Switch, 161kV, 19'	1
1911	StrSw3P01-18	Structure, Switch, Three Pole, 15kV, 18'	2
1912	StrSw3PVB16-10	Structure, Switch, Three Pole, Vertical Break, 161kV, 10'	2
1913	StrSw3PVB16-20	Structure, Switch, Three Pole, Vertical Break, 161kV, 20'	1
1914	StrTe01-17	Structure, Tee, 15kV, 17'	2
1915	StrTe01-18	Structure, Tee, 15kV, 18'	3
2001	SwtHV1P110-1200(USCO)	Switch, Hook Stick Vee, Single Pole, 110kVBIL, 1200(USCO)	36
2002	SwtOpGP	Switch, Operator, Ground Plate	13
2003	SwtOpSA	Switch, Operator, Swing Arm	9
2004	SwtOpWG	Switch, Operator, Worm Gear	4
2005	SwtVB3P750-1200(USCO)	Switch, Vertical Break, Three Pole, 750kVBIL, 1200(USCO)	3
2006	SwtVe3P110-1200(USCO)	Switch, Vee Switch, Three Pole, 110kVBIL, 1200(USCO)	9
2007	SwtVe3P750-1200(USCO)	Switch, Vee Switch, Three Pole, 750kVBIL, 1200(USCO)	1
2101	_Ftg-16X32	Footing, 16X32	1
2102	_Ftg-2X2	Footing, 2X2	38
2103	_Ftg-5.25X5.75	Footing, 5.25X5.75	6
2104	_Ftg-6X12	Footing, 6X12	2
2105	_Ftg-7X7	Footing, 7X7	3
2106	_Ftg-9X18	Footing, 9X18	2

10.5. Substation Design Guidelines

Substation Design Guidelines

BUS DESIGN									
Bus Size (IPS)	1	1-1/2	2	2-1/2	3	3-1/2	4	5	6
Outside Diameter	1.315	1.9	2.375	2.875	3.5	4	4.5	5.563	6.625
Copper, Sch 40, 48" Spacing, 24kA									
1 Span, 1 Fixed	9	15	19	25	32	39	43	52	52
2 Spans, Middle Fixed	7	12	15	20	26	32	35	43	42
3+ Spans, 1 Fixed	8	13	17	22	28	34	38	46	46
Aluminum, 6063-T6 Alloy, Sch 40, 48" Spacing, 24kA									
1 Span, 1 Fixed	9	14	19	26	33	38	44	57	70
2 Spans, Middle Fixed	8	12	16	21	27	32	36	47	57
3+ Spans, 1 Fixed	8	13	17	23	29	34	39	50	61
Ampacity @ 40°C rise over 30°C, 2fps wind									
Cu	850	1270	1570	1990	2540	3020	3365		
Al, 6063-T6 Alloy	681	984	1234	1663	2040	2347	2664	3348	4064

Note: Spans should be applied only to specified conditions.

Ampacities	1	2	3
1/4"x4" Al Bar	980	1760	2462
1/4"x5" Al Bar	1184	2092	2905
3-1/4"x3-1/4"x1/4" Al Angle	1902		
4"x4"x1/4" Al Angle	2236		
4"x4" IWCB	3360		
4"x6" IWCB	4470		
8"x8" IWCB	7550		
1 - 500 MCM CU	810	1296	
1 - 750 MCM CU	1040	1664	
1 -1000 MCM CU	1240	1984	

Note:
Current ratings based on 30°C temperature rise over 40°C ambient horizontally mounted conductors with a 2ft/sec crosswind.

NEMA Clearances for Outdoor Substations								
Nom. Voltage (kV)	15	25	34.5	46	69	115	138	161
BIL (kV)	110	150	200	250	350	550	650	750
Cond Spacing								
Ph-Ph (Cl to Cl)	2'0"	2'6"	3'0"	4'0"	5'0"	7'0"	8'0"	9'0"
Ph-Ground	10"	12"	15"	1'6"	2'5"	3'7.5"	4'2"	4'10"
Clearance above Grade	9'	10'	10'	10'	11'	12'	13'	14'
Clearance above Roadway	21'	22'	22'	22'	23'	25'	25'	26'
Switch Spacing (Cl to Cl)								
Horngap	3'0"	4'0"	5'0"	6'0"	7'0"	10'0"	12'0"	14'0"
Vert. Break Disc.	2'0"	2'6"	3'0"	4'0"	5'0"	7'0"	8'0"	9'0"
Hor. Break Disc.	2'6"	3'0"	4'0"	5'0"	6'0"	9'0"	11'0"	13'0"
Min. Phase Spacing								
Metal to Metal	12"	15"	18"	21"	31"	53"	63	72"
Strain Insulators 10" Dia.								
Number per String	2	3	4	4	5	8	10	12

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BIL KV	TR No	Upright Cantilever (lbs)	Underhung Cantilever (Lbs)	Top BC (in)	Bottom BC (in)	Height (in)	Leakage (in)
			Station Post Insulators				
95	202	2000	2000	3	3	7.5	10.5
95	222	4000	4000	5	5	7.5	10.5
110	205	2000	2000	3	3	10	15.5
110	225	4000	4000	5	5	12	15.5
150	208	2000	2000	3	3	14	24
150	227	4000	4000	5	5	15	24
200	210	2000	2000	3	3	18	37
200	231	4000	4000	5	5	20	37
250	214	2000	2000	3	3	22	43
250	267	4000	4000	5	5	24	43
350	216	1500	1500	3	3	30	72
350	278	3000	3000	5	5	30	72
550	286	1700	1700	5	5	45	99
550	287	2600	2600	5	5	45	99
650	288	1400	1400	5	5	54	116
650	289	2200	2200	5	5	54	116
750	291	1200	1200	5	5	62	132
750	295	1850	1850	5	5	62	132
900	304	950	950	5	5	80	165
900	308	1450	1450	5	5	80	165

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