



Automating Substation Design with Autodesk® Inventor®, Autodesk® AutoCAD® Electrical, and Substation Design Suite

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UT1708 There are approximately 3200 electric utilities in the United States. Each utility has their own standards, procedures, workflows, and more for designing substations. To solve the overwhelming task of automating substation design to fit each utility's specific situation, Autodesk and AutomationForce partnered to develop the Substation Design Suite, an add-in for Autodesk Inventor software and Autodesk AutoCAD Electrical software. This class describes Nashville Electric Service's (NES) experience in adapting these software packages for their unique work processes. The class includes discussion of the challenges NES faced in the beginning, the pros and cons of using provided content versus creating customized content and provides examples of customizing Substation Design Suite content and templates in Inventor and adapting AutoCAD Electrical to meet specific design requirements.

Learning Objectives

At the end of this class, you will be able to:

- Describe the challenges of implementing a model-based substation design system
- Develop a plan to adapt Inventor, AutoCAD Electrical, and Substation Design Suite for your utility's specific situation
- Automate the Inventor substation design process
- Adapt AutoCAD Electrical to specific substation design philosophies and procedures

About the Speaker

Terri Humel has an Associate's Degree in Mechanical Engineering from Nashville State Technical Institute. She is employed as the Principal Associate Engineer in Substation Design at Nashville Electric Service. She has 30 years of experience in the electric utility industry and 28 years of experience designing substations with AutoCAD®. Currently she is using Autodesk® Inventor® and the Substation Designer to produce intelligent 3D substation models. Part of her responsibilities include producing procedural and training manuals, devising and implementing new work processes and new software along with performing training. She's presented at AU for the past 3 years. Other accomplishments include authoring an article in the March 2013 issue of Electricity Today. thumel@nespower.com

Joe Weaver is the Principal Associate Engineer in the Control Design section at Nashville Electric Service. He has spent the past 28 years designing electrical substation protection, control and communications systems. Over the years, the tools used for drafting and design have evolved from vellum and pencils, through many versions of AutoCAD®, leading to the adoption of AutoCAD Electrical in 2010. During this time, he has also served as CAD manager for this section as well as many others in the Engineering Department. Currently, Joe is developing/adapting ACADE and the Substation Design Tool Kit for NES. jweaver@nespower.com

- **Challenges of Implementing a Model-Based Substation Design System**

A Little History

Around the end of 2007 the Control Design Section at Nashville Electric Service was introduced to AutoCAD Electrical®. During the same time period the Substation Design Section at Nashville Electric Service had completed a pilot study comparing AutoCAD 3D modeling techniques to Autodesk Inventor® model-based design. The decision was made to implement ACADE and Inventor® because they are design tools that could help us work faster, with greater consistency, accuracy and quality. Our designs could become living models rather than static documents.

One very important aspect for us is knowledge capture. With a large portion of our Engineering workforce nearing retirement age, there is a lot of experience and know-how poised to walk out the door in just a few years. Therefore one of the primary goals of changing to a model based design is to capture that knowledge in the intelligent symbols and automated routines possible with Inventor and AutoCAD Electrical.

The other major factors in this decision were the standard business needs. Faster, better cheaper. Through the use of BIM we could speed up the design process by entering information only once and having immediate access to all instances of a part as well as the information carried on these parts. Reduction of human input not only speeds up the process, but improves overall accuracy. BIM data is also faster to edit or correct by automating the changes throughout a project. All of this adds up to a better product for (eventually) lower costs.

Challenge 1

ACADE and Inventor were created for the manufacturing industry and at the time we didn't know of another utility using these software packages. Due to the unique requirements of our industry the first challenge we faced was adapting AutoCAD Electrical® and Inventor® for creating intelligent digital prototypes of substations, both physical and electrical.

This covers not only symbology and data but in both cases a certain level of "using the product in a manner inconsistent with its labeling". Adapting practices and methodologies intended for manufacturing to what is essentially plant design and maintenance wasn't simple or easy in most instances. There is not only a difference in physical scale and project scope, but the added needs of maintenance moving forward as well as adherence to industry and company standards.

A lack of others in the Power Utility industry using these products was also a challenge. Not being able to learn from the mistakes of others means we'd likely make them as well. The few people we did find are all private utilities and were understandably reluctant to share any information that could be considered intellectual property of their shareholders. Luckily, through a consortium sponsored by Autodesk, we were able to share some ideas with other utilities which put us on the right path a few times.

The decision to go with AutoCAD Electrical and Inventor came down to the fact that these two pieces of software (later combined with SDS) offered us solutions to most of our needs. The massive amount of information that could be maintained and manipulated was one large stone on the scales. Material accounting, generating wiring drawings, eventual integration with our Work management System and many other smaller items added up to potentially huge savings in time and resources.

Challenge 2

The second challenge we faced was training...

The Control Design and Substation Design sections received standard Autodesk AOTC training for AutoCAD Electrical® and Inventor. This training was a good introduction to the product, and at the end we knew how to design a couple of standard circuits, model simple parts and had a basic understanding of how the programs worked. However, that was a long way off from where we needed to be in a production environment.

Each section retained a consultant for a short time. For Substation Design, the consultant worked with IT to roll out Vault (Data Management software included with Inventor) and help devise naming conventions, folder structure and template formats, among other things. The consultant that worked with Control Design helped to get started on setting up a shared environment and creating their first templates and symbols. While helpful in learning some of the deeper details of how the program used the title blocks and symbol attributes, there were again limited resources for consulting. This did, however, again point us in the right direction on a couple of items.

Training on customization and the intricate details of how the many attributes are used by the program should be a major part of any training plan. Sadly, that level of training for AutoCAD Electrical is scarce. Much of the information I have been able to gather about the inner workings of the program has come from the Autodesk Forums and a handful of other websites. (See links section near the end of this document.)

Internal training is going to be the next big challenge. As symbology and procedures are being finalized, plans for documenting these procedures as well as the theory and principles behind them are just beginning. This is the other area where knowledge capture is critical. Keep good notes as you adapt these programs to your needs.

Challenge 3

The third challenge we faced was completing our current jobs while learning...

Having to keep up normal production makes it hard to stay focused on the task of learning new things, and in fact the two can completely disrupt each other as the new ideas and processes are trying to take root alongside the old knowledge. The Substation Design section jumped in to Inventor with both feet. We choose four budget projects to complete in the first six months of implementation, three of which were completed by the deadline. As Inventor and SDS continue to evolve we continue to issue projects while implementing new processes.

In Control Design we adopted an approach of blocking off a certain portion of the day for AutoCAD Electrical development and research. While not perfect, this did allow better progress in the early development stages. This period was mainly spent “playing around” with the program as blocks were created and tested. Small “what if” situations were addressed and tested. A lot of “what we didn’t know that we didn’t know” was uncovered in doing this and helped identify areas that we needed to put some effort into customizing or adapting processes.

However, there comes a point in time where to advance further, you have to start applying the knowledge gathered to an actual real-life project. We did this in a couple of small steps first. In fact the first couple of projects that used AutoCAD Electrical at all were at a substation scheduled for decommissioning. These were early learning opportunities that garnered a lot of valuable feedback from our construction department. Not all of it positive.

The real advances and solidification of our process have come as we designed our first full substation in AutoCAD Electrical®. There are often so many things you don’t know you need until you actually need them. Trying to follow a model based design process for this new substation pointed out a lot of things we had not been properly documenting because the field people has always just “handled” that and in the days of pen and ink you just didn’t document anything you didn’t have to. This falls under the umbrella of knowledge capture and is a big part of why we wanted to move to a model based design to start with.

Challenge 4

Some other challenges facing almost any company considering a change to model based design include; resistance to change from internal and/or external customers, adapting to new ways of thinking (i.e. - Model vs. Documentation), indecision/apathy among peers and the need to develop new philosophies/methodologies to make use of the software.

Resistance to change is just part of the human condition and will probably always be encountered in some form or fashion. To minimize this we have tried to always discuss the benefits gained before addressing the changes necessary to achieve those benefits. People are more receptive to change if they perceive some benefit is in store for them. In similar fashion, people who are indecisive or apathetic to the process can be swayed if shown sufficient benefits.

This can mean that some of the hardest changes to get people on board with are the ones that either offers no immediately recognizable benefits or that benefit someone else at our expense. These can usually be sold with the reason that in order to get all the other benefits, these changes have to be adopted for the program to function properly. A prime example of that is that our Electrical designers will have to do a good bit more research and enter considerably more information than in the past in order to provide the field crews with better information from which to wire equipment and panels from.

The upside of that is that once this research and data entry has been done once, if done properly, can be reused forever. One shining instance of this is the entering of pinlist information for a complex IED relay. After someone takes the time to enter this information into the parts catalog once, everyone from then on can access that information as they use that IED in their design. This applies to all kinds of information in and about a project.

The challenges of indecision and apathy can only be overcome by helping people clearly see the benefits of moving in certain directions and getting them excited over those benefits. Demonstrate as often as you are able little tidbits of usefulness. For example; ask someone how long they spend on Bill of Materials for a job and after they ponder it a bit hand them yours and tell them it took less time than they spent thinking about it.

Involving others and letting them know you want to deliver a product that benefits them as much as it does yourself is also a great tool for improving buy-in from your customers. Meetings with our field crews and Test Engineering sections have gone a long way towards acceptance of what is turning out to be a very different set of drawings than what they are used to.

- **Develop a plan to adapt Inventor, AutoCAD Electrical, and Substation Design Suite for your utility's specific situation**

In the Beginning

Inventor was such a radical change in the way we designed substations from AutoCAD for us in Substation Design. We had to convert blocks to library parts, devise new drawing standards, create a new folder structure and develop new project release workflow procedures for Vault, and make sure everybody was on the same page as we developed these new and changing processes. In mid-2011 we added Substation Designer Suite (SDS), an add-in for Inventor and ACADE. SDS is a specialized substation design tool that Autodesk, Automation Force and Duke Energy developed.

Similar to the Substation Design Group, Control Design faced a lot of choices to be made before even taking the first steps down the road to a BIM approach. In addition to those mentioned above, we were also implementing Autodesk® Vault® for file and version management. This was actually done ahead of Electrical as file management was a pressing issue.

Resources for the Autodesk® AutoCAD Electrical project were limited so an approach that limited committees and lots of meetings was adopted. This also helped offset some of the resistance to change and potential scope creep that so often occurs when there are too many cooks stirring the pot. Periodic reviews and calls for suggestions have served as the feedback and steering mechanisms. Over the course of a couple of years several new standards and methods have emerged.

Some benefits have been realized along the way in the form of better document management by using Autodesk Vault Professional® and the project file structure in AutoCAD Electrical®. Also, it has been seen how reports generated during the design can be useful as self-checking and tracking tools.

Our first full substation design with Electrical is nearing completion.

Step 1 of the Plan: Core Group

Coordinate input from all stakeholders and create a core group to develop an implementation strategy. The adaptation/implementation team should be made up of people who have a firm and broad grasp of both company procedures, standards and practices, but also be well versed in design philosophies and computer skills. The breadth of knowledge in such a group will give it a head start on identifying the needs of the company while balancing that against the level of effort required to meeting those needs.

A small team doesn't have to mean a closed knowledge pool though. Seek the input of others often. Not just immediate co-workers but your final customers as well. For us those are the Construction & Maintenance and Test Engineering departments. We have tried to keep them in the loop as much as is practical.

The adaptation of Electrical for Control Design's needs was relegated to just a couple of people. Keeping the team lean meant we were able to adapt quickly to new information and ideas. Starting essentially from scratch we focused first on Title Blocks and making the most out of the information contained in them. This tied in very closely with our adaptation of Autodesk Vault Professional.

Step 2 of the Plan: Customize

Having little out-of-the-box support for the Power Industry, we knew there would be a major effort needed in customizing symbols and part data. In addition to that effort, there would be new drawing and project templates, new title blocks, new standards, collaboration between Inventor and ACADE and more. A basic roadmap of these was sketched out by identifying our needs and the requirements of each.

Some other things to consider before starting your customization process are;

- Symbols – Out of the Box vs Custom Symbols
- Network installation vs Local
- New standards for new information
- New procedures for old processes
- Standardization of Options for drawing consist

Step 3 of the Plan: Set Goals

One thing to consider when starting this process is to establish early on as much of the “look and feel” of your designs as possible. Our first thought was to keep everything as much like we’ve always done it as possible to reduce culture shock. However, as we soon realized that culture shock was going to be inevitable, we did an about face and went with as much out of the box as possible. Part of this was driven by using this new software as an opportunity to force some changes we had wanted to make for some time. It was also felt that this made the new drawings stand out from the old and alerted the end users to treat them differently.

Inventor, out of the box, has no content for substation equipment. Our first goal was to assess the structural and electrical equipment needed to complete our project. Most of this equipment would be used in all of our substations. We decided to model and enter the iProperties to match the ordering descriptions for this equipment on an as needed basis. During this time we customized the Cable Library and Tube & Pipe Styles. (SDS now does most of this kind of work for us.)

One of the advantages from working on an as needed basis is we can decide to convert the files or part to Inventor or not for each project individually. This is important because our stations are drawn in a variety of media, requiring a different amount of time to complete. Another advantage is that we don’t create parts and equipment that are no longer on our system. This allows us to keep a cleaner library of parts.

For Control Design to keep moving forward, we set small achievable goals in the beginning. Rather than making a huge push to convert every known company symbol to a smart Electrical symbol, we chose a fairly common set of symbols that we knew we would need and set about creating them to meet the look and feel previously decided on. Closely tied to that is entering the parts data to the catalog to match the materials kept in our Storeroom. Other symbols and catalog data have been added as needed with a final push planned for some time after our first major project is complete.

This approach has a couple of benefits. Mainly, that since this is all very new, and we are changing a lot of things that we have “always done it that way”, not having a huge library in place has allowed us to make changes in our philosophy a couple of times without a major impact. The other is that by concentrating on just the symbols needed to complete a new substation we are identifying and creating the ones most often used for construction and can use the others as teaching exercises during internal training.

After some initial false starts and complete philosophy changes, we set our eyes on designing our next new substation in AutoCAD Electrical. The reasons for this include:

- Having a blank slate rather than meshing into old designs
- Allowed for easier deviation from existing standards
- Made the Electrical project a bit more high profile
- Long lead time on completion allowed time to deal with unforeseen problems

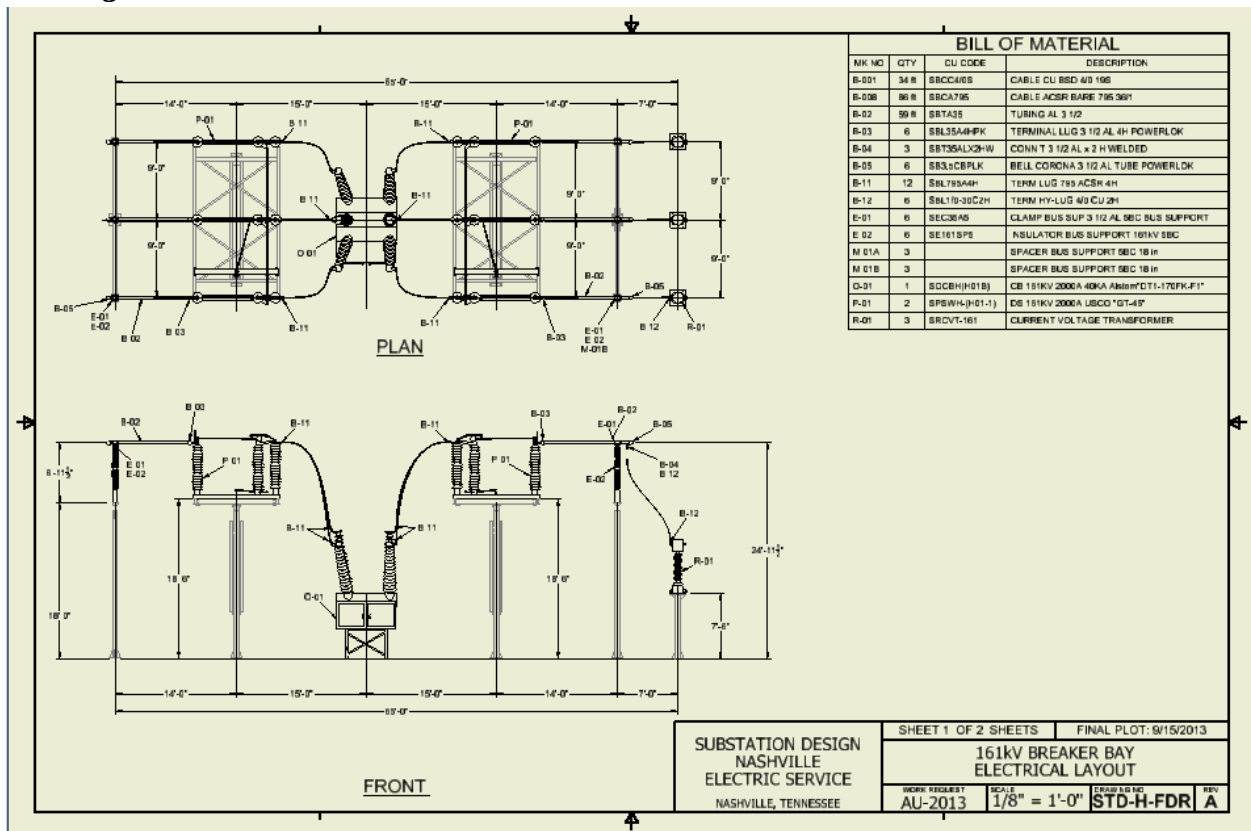
Once this project is complete we will do a post-mortem and determine which areas need more work or better documentation.

- **Automate the Inventor substation design process**

Over the Years

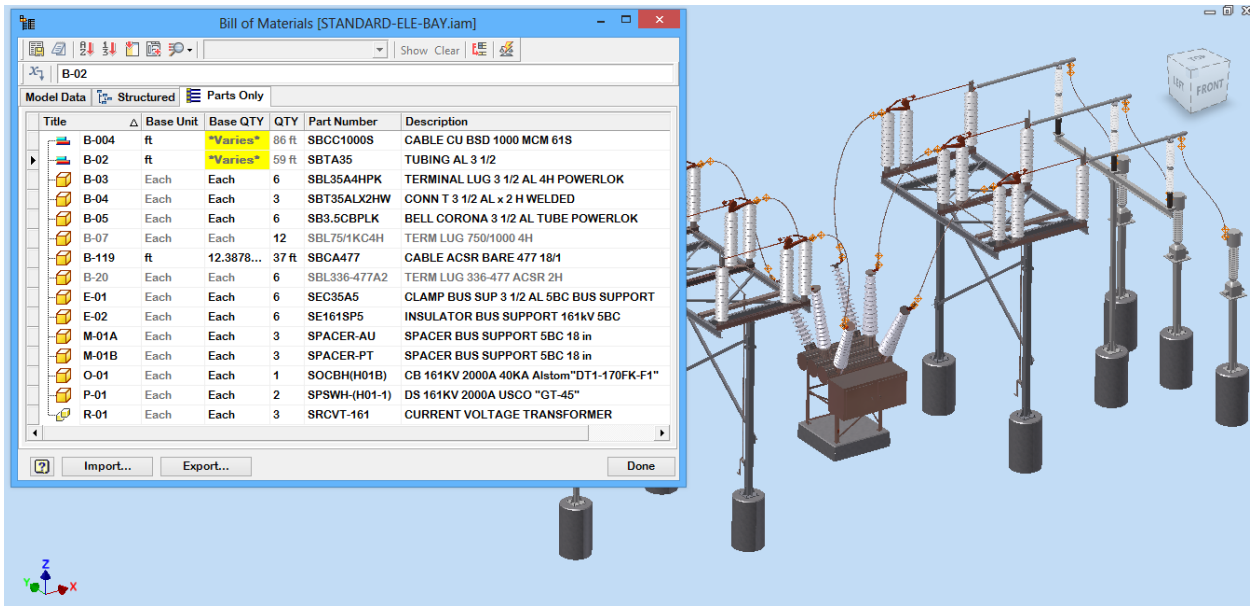
Thirty years ago, when I began working at NES the only automation we had was a mechanical T-square, adjustable drawing board and electric eraser. In 1985 we implemented AutoCAD Version 1.2 and a whole new world of automation open up for us. Today we are improving our design efficiency, material tracking and reducing human error by increasing our process automation using Inventor and SDS.

Drawing Process



Sectioning, dimensioning and Mark No. placement have always been the most tedious part of our work. Inventor's intelligence makes these tasks less time consuming to accomplish. Plus the engineering review process is streamlined because there is no chance that a placed Mark No. or dimension is wrong, it is what it is.

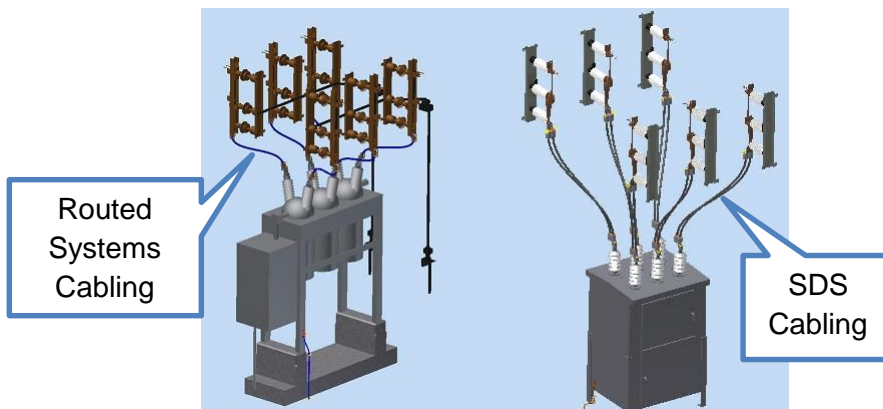
Bill of Material



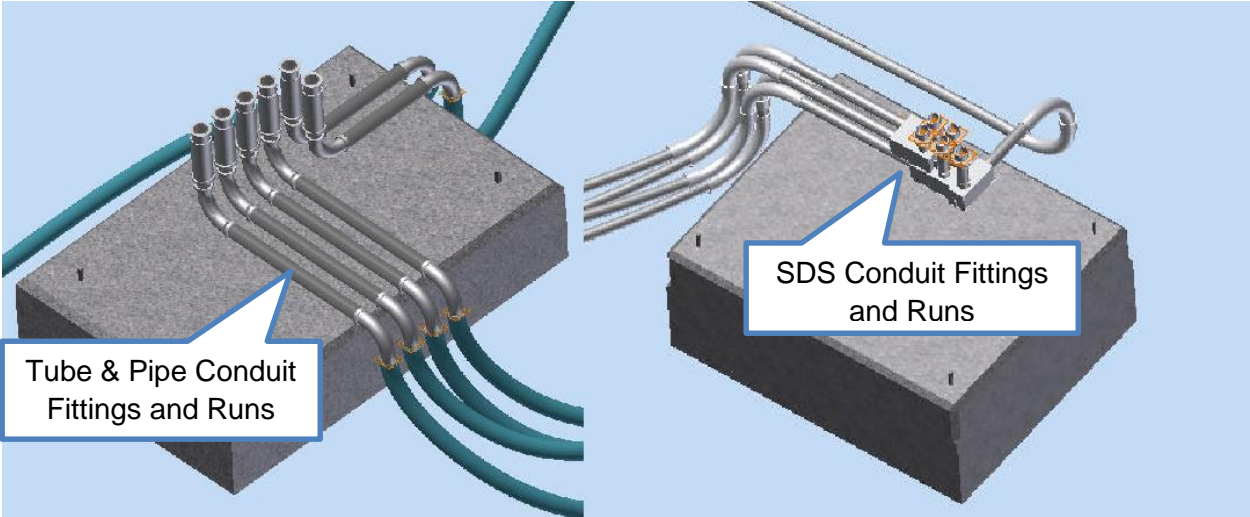
Creating the Bill of material (BOM) is time consuming and prone to human error. Inventor removes these factors. The BOM in Inventor is a table in an assembly that stores all the information about each part. Any time a part is replaced in the model the BOM instantaneously reflects the new information. The Parts List and Mark Nos. on the drawing also immediately updates with the new part information.

Cabling, Conduit and Grounding

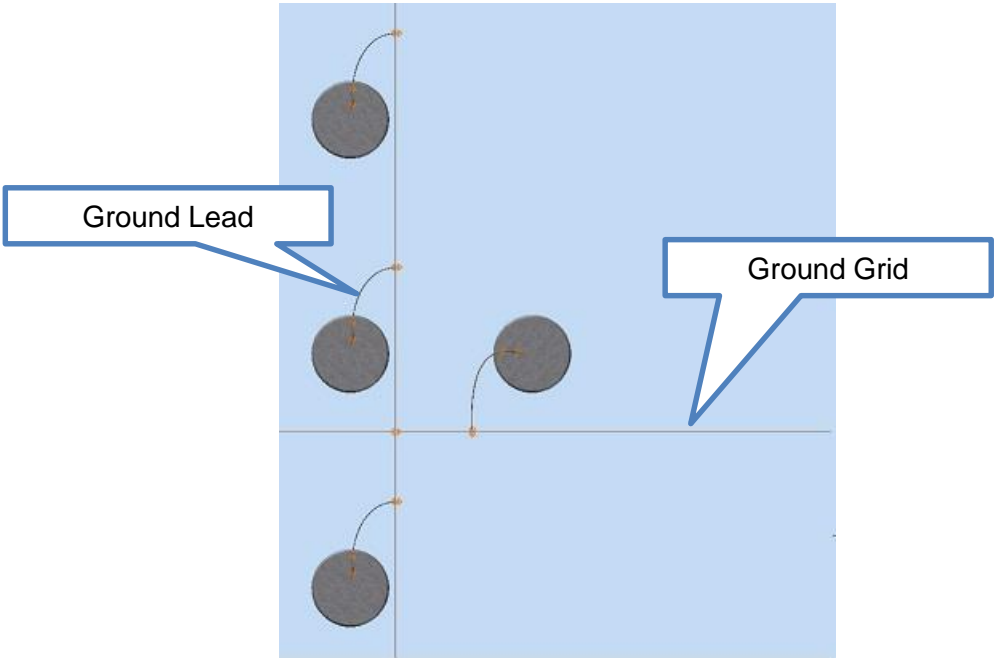
The Substation Design Suite brought true automation to the modeling of cable, conduit and grounding. Inventor Routed Systems allowed us to create cable leads, calculate the lengths and keeps track of the Bill of Material data. We had to constraint each terminal lug, then create the path, place the cable between two pins and finally route the cable through the path. With SDS we pick the terminal pad and the lug automatically constrains to the pad. Next we pick each lug and the cable is created. It sizes the cable according to the terminal lugs. The terminal lugs resize when the cable is edited.



Conduit was time consuming using Inventor tube and pipe environment. The fitting are placed and constrained. Then (2) files are needed for each run. Routing the run is done with the 3D move tool. The SDS conduit fittings constrain to a circular edge and sizes it's self by the diameter of the circle. The run is created by picking two circular edges.

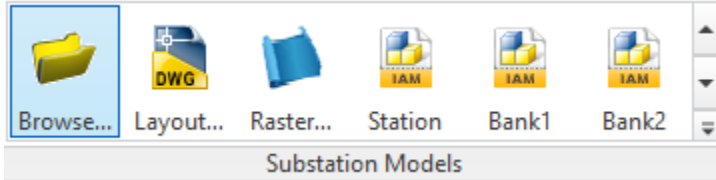


We hadn't set up a workable process for grounding before using SDS. Now with SDS we have tools for generating the ground grid and grounding leads.

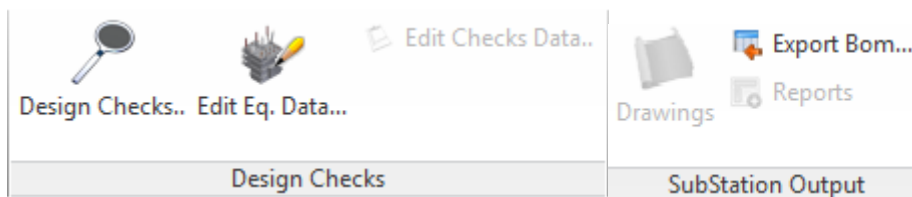


Content

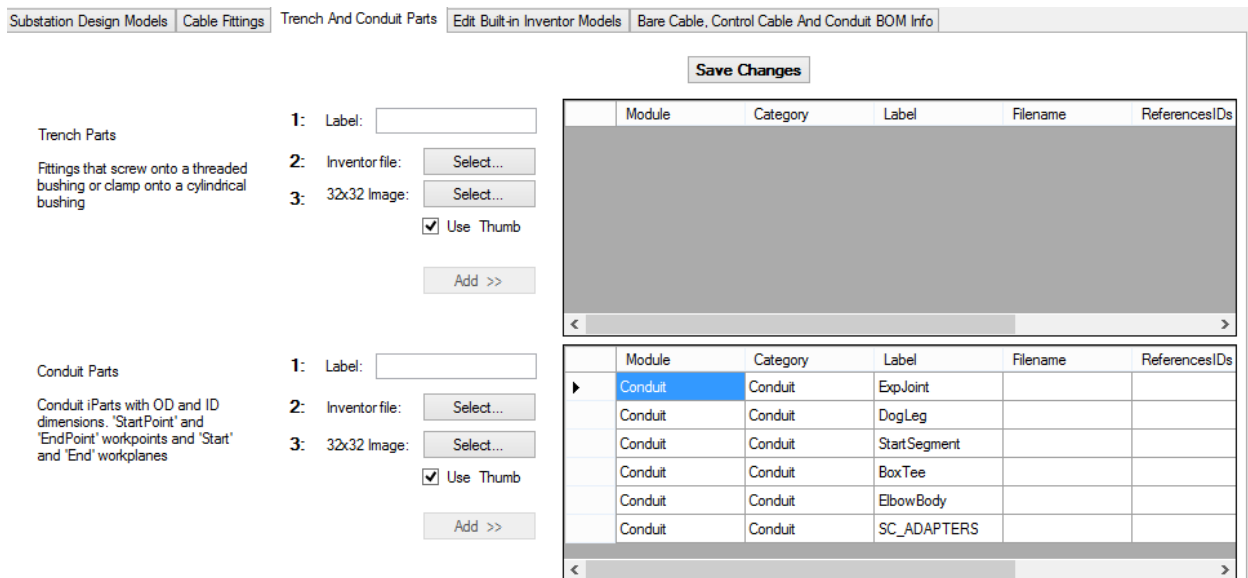
SDS has several existing Substation models to use as a starting point.



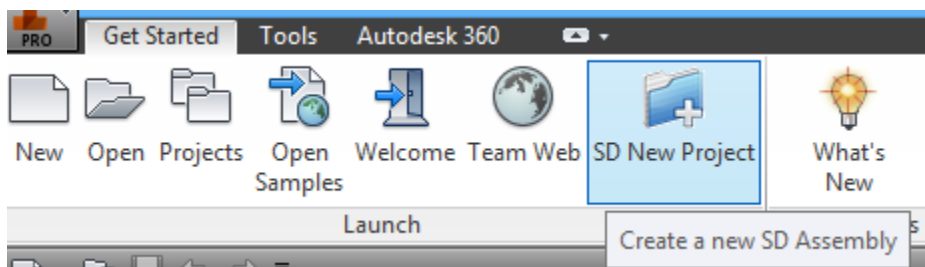
There are also tools for checking phasing and exporting the BOM to most ERPs



The Substation Designer Content Editor provides the ability to use existing models, fittings, BOM data, etc.



A customizable template is included to begin new projects.



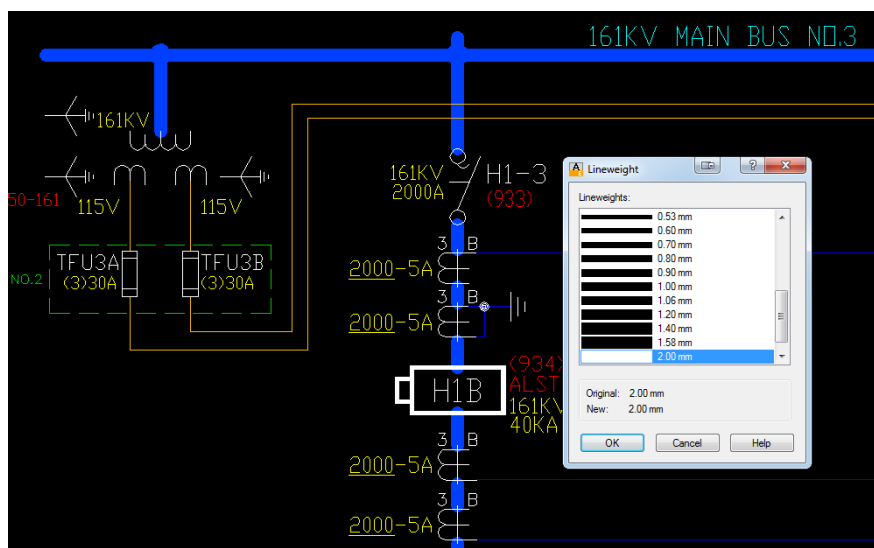
- **Adapt AutoCAD Electrical to specific substation design procedures**

In an attempt to keep this section within reason, I will break the areas we have customized into typical changes most people would expect to make, those specific to our industry, and those particular to our company.

For anyone about to use AutoCAD Electrical in a new environment/company there are some customizations that need to be made. These include pointing the search paths to shared folders if used in a networked environment, making any changes needed to the environment file (WD.ENV), creating or editing part data catalogs, title blocks and drawing templates and many others. Information on these types of changes is available on several websites including the Autodesk Forums.

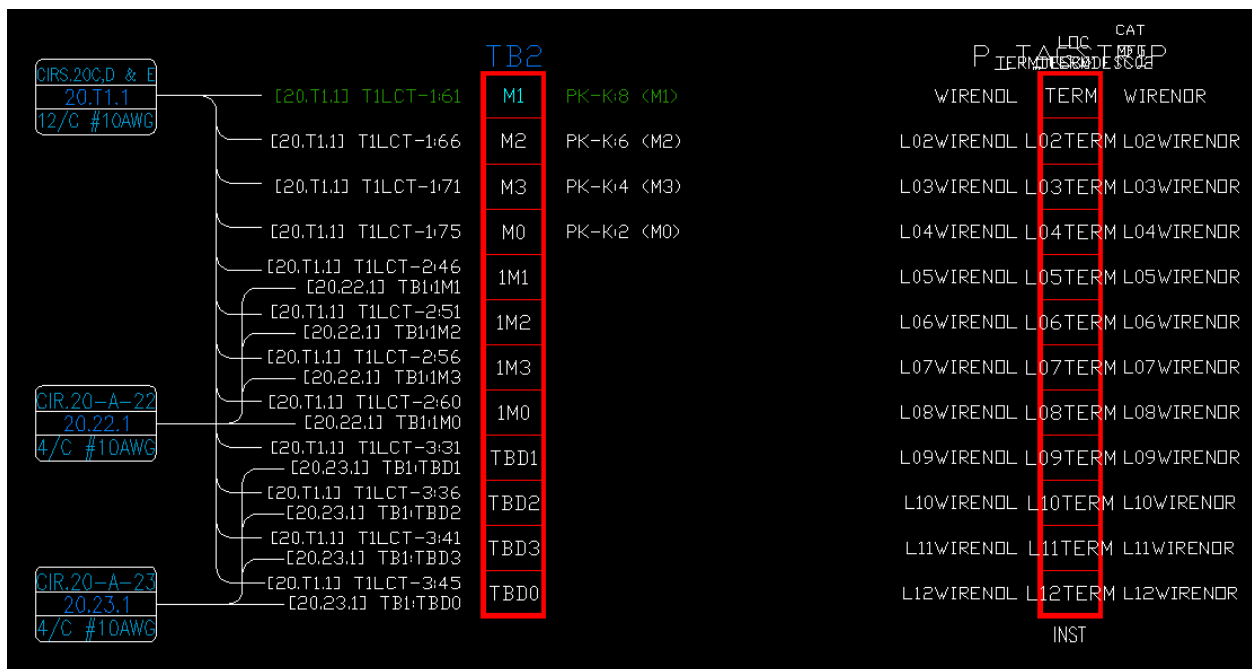
There will likely be a number of changes needed that are particular to the power industry. Aside from the many components that need schematic symbols and catalog data, these also need to be displayed as One Line symbols. Related to this is the need to show three single phase devices as one symbol on a one line. (VT's for example.) With a little help from Autodesk and Automation Force, we worked out a method using the WDTAGALT attribute to link three single phase devices to one symbol on the one line diagram

It isn't unusual to see high voltage busses in substations drawn as thicker lines to give a quick visual difference between busses and control wiring. Previously we used polylines for this. However, AutoCAD Electrical only recognizes lines as wires, so in order to model the substation busses, we had to get creative and give the lines a thickness. This isn't optimal, as plotting and display of lines with thickness values gets weird compared to polylines but it does work. Also, with the help of Automation Force once again, we were able to develop a routine that goes through a drawing (or set of drawings) and corrects any wire connection dots to match the thickness of the lines they are on.



Another area most utilities are going to encounter a problem lies with how AutoCAD Electrical handles terminals. Being written for the manufacturing community, the program tries to build termination strips from individual terminals, dividers and end caps. The tools for doing this work great. The problem is that we and most utilities are going to use terminal blocks of a pre-set number of terminals. (Typically 4, 8 & 12 point blocks.)

Working with Autodesk and Automation Force once again, we worked out how to use multi-level terminals to represent our terminal blocks. By setting these terminal's properties to the number of levels needed (12 in the example below) and using the terminal association functions, these can be modeled as single multi-point terminal blocks and will only show up once per terminal block in the BOM. The image on the right is an exploded view showing how the attributes were used to build a 12 point terminal block. Both the wire attributes and the terminal attributes have been made multiline attributes so that different wires can be split into two lines. Autodesk is currently exploring ways to make that work a little more seamlessly, but as you can see, we did get it to work. They fan-ins and cable markers are presently being drawn in by hand to make this a little more user friendly for the wiring crews. Automation Force is considering some possible solutions to that for inclusion in future releases of SDS.



Finally, there will certainly be many things that will need customizing based on company needs and standards. Some of these can be handled with new or edited symbols. For us, custom cable markers are an example of this. Our existing cable markers were simple triangles pointing in the direction of the equipment in the yard. Electrical cable markers give no indication of direction or demarcation. Custom symbols will fix that.

Sometimes, you may need to change existing standards and procedures to adapt to the software. For example, we had not traditionally given device ID's or TAG #'s to smaller more common items like terminal blocks, lamps and even cables. With Electrical everything needs a unique identifier, so we have had to develop and adopt some new standards for these items.

In a similar fashion, we have had to adopt some new symbols in order to use some of the features of the Substation Design Solution from Automation Force. A prime example of this is adopting new symbols for test switches in order to use the Test Switch Editor in SDS. In this case it was worth it to get the functionality of the editor.

Other company related changes include, but aren't limited to;

- Standards for Installation Codes – Use and creation
- New cross referencing method & symbols
- Custom report layouts and post processing scripts
- Logic & Test Switch planning spreadsheets
- Page Setup files for publishing/printing
- Wire annotation format standards

In Conclusion

Our experience with the deployment of AutoCAD Electrical, Inventor and SDS has led to the following observations and suggestions;

1. Training is essential. Not just introductory training, but in-depth nuts and bolts level training. A greater investment in time and resources in the beginning will shorten the overall process a great deal.
2. Choose a team that is both well versed in your company's standards and procedures as well as AutoCAD and/or Inventor. These people should also have an affinity for computers and programming as these traits will be useful.
3. Choose your battles. Everyone will encounter things that either just don't look the way you expect or (most likely) doesn't work the way you are used to. The choice is to either change how we do things or try and alter the program to suit our needs. It will usually take more resources (\$\$\$) to make changes to the program or alter functionality through custom programming. However, the results can be very much worth it.
4. Document everything you do. You will forget things you have done. Being able to look back and remember WHY something is the way it is very handy. It is also a big step towards your end user documentation and training.