

AUTOMATING SUBSTATION DESIGN IN TIMES OF EXTREME LOAD GROWTH

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1. Introduction

Headquartered in Las Vegas, Nevada Power Company is the electric utility for most of southern Nevada. Established in 1906, it serves 709,000 electric customers in a 4,500 square mile service territory. The system's 2004 summer peak load was 4969MW, (Megawatts). NPC faces the challenge of a phenomenal 5-6% average growth rate, one of the highest of any electric utility the country.

A typical substation design and construction timeline consists of: planning single-line development, budget process, route and site selection, preliminary design, major apparatus procurement, detailed design and finally construction. This project timeline, (engineering, permitting, procurement, construction, energization), usually takes 18-24 months, (24-30 months preferred). This does not include site acquisition.

Given the compressed design and construction timeline a method for automating the preparation of detailed preliminary designs to suit the intended site or several sites selected by NPC's Land Services Department was needed so that key decisions could be made early. The primary challenge lay in finalizing a substation physical layout that made the most efficient use of an allocated parcel of land. The focus of this paper will be on the challenges of automating a preliminary design process. Several factors affect the preparation of the preliminary substation design: load to be served, primary voltage, primary circuit breaker switching scheme, high or low profile design, transmission ROW, parcel size, physical terrain, environmental considerations, vehicular access, mobile transformer access, secondary feeder getaways, equipment maintenance and removal, and many others. In 1996 Nevada Power developed a reduced visual impact, (RVI), low profile substation design for distribution and transmission substations where little to no apparatus or bus was visible above the substation's 14' perimeter block wall. This design approach is still in use and the basis for most NPC urban 100MVA 138/12kV substation designs.

The substation design application's primary ruleset for equipment and apparatus spacing is based on the NESC-C2 Standard published by the IEEE. The application began as a spreadsheet that calculated rough area requirements based on several design factors and evolved into "SubSizer" which provided a more detailed AutoCAD resultant design. This AutoCAD application was customized using the VBA, (Visual Basic for Applications), programming environment. VBA provided a means of developing an application interface that ran in-process with AutoCAD. VBA also provided application integration with other VBA-enabled applications. This allowed AutoCAD, using other application object libraries to be an automation controller for spreadsheet and database applications.

2. Load Growth in Nevada

Established in 1906, Nevada Power serves one of the fastest growing regions in the United States. The company's service area is approximately 4,500 square miles in southern Nevada and includes over 700,000 customers and the urban centers of Las Vegas, North Las Vegas and Henderson. These cities all ranked in the top seven in the United States in terms of percentage population growth, (1990-2000) [1]. Figure 1 illustrates system load growth historical statistics since 1990 in terms of the system summer peaks.

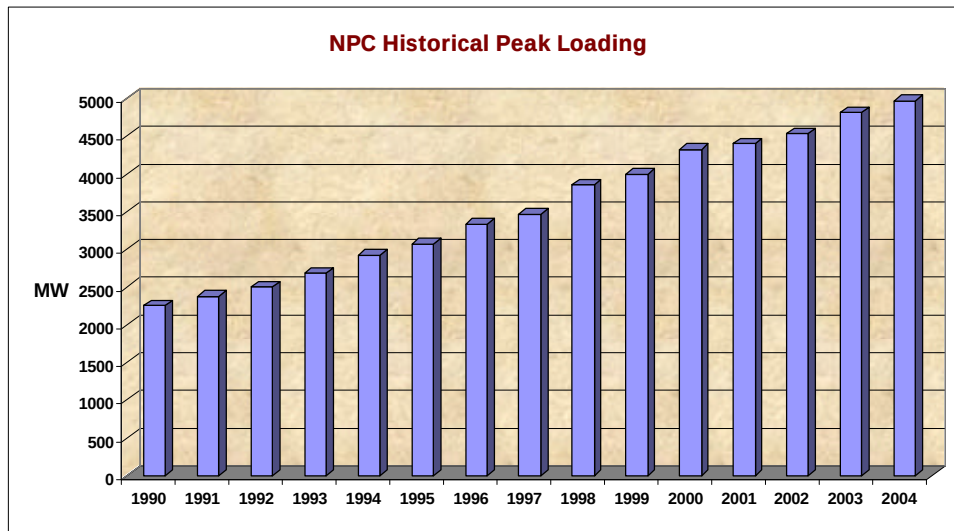


Figure 1. Nevada Power Company System Peak History

3. Land Acquisition and Site-Specific Parameters

For smaller 100 and 140 MVA 138/12kV distribution substations 330' x 660', (5 acre), parcels are preferred. In recent years substation designers have had to work with smaller 330' x 330', (2.5 acre), parcels. These parcels present more of a challenge as they are not always fully useable as street right-of-ways and landscaping allowances must be made.

Typical half-street right of way, (ROW), parcel setbacks in Las Vegas are 50' 40' and 30'. Landscaping buffer allowances are usually 20' or 10' depending on the adjoining street. Therefore in some cases a 330' x 330' parcel of land is only capable of sustaining a 260' x 280' perimeter block wall design. These smaller perimeter wall designs do not allow for much more than single-bus bus arrangement schemes that while cost effective do not provide much in terms of operational flexibility and reliability.

The land acquisition process for the larger 138kV and 230kV switching substations is generally more design-specific. A preliminary physical layout determines the required acreage and an appropriately sized parcel is then purchased by the Land Services Department.

4. Substation Design Philosophy

Substations or switching stations function as a connection and switching point for transmission lines, distribution feeders, and step-down transformers. The design objective is to provide maximum reliability, flexibility, and continuity of service and to meet these objectives with the lowest investment costs that satisfy system requirements [2].

Many factors influence the proper selection of the type of substation for a given application. The most appropriate type of station depends on such factors as voltage level, load capacity, environmental considerations, site space limitations, and transmission-line right-of-way requirements. [2]

The physical location of transmission-line routes and outgoing distribution feeders often dictates the substation's orientation and bus layouts and switching arrangements. The choice of different bus schemes is often dictated by factors like reliability, economy simplicity and visibility.

Several other important factors must be considered in substation physical design at Nevada Power and are listed below:

- Transmission line ingress
- Distribution feeder egress
- Initial and ultimate load capacities, (expansion)
- Adequate room for equipment maintenance and removal
- Mobile transformer access
- Provision for reactive power compensation equipment
- Substation yard terrain and grading, (prevailing water flow direction)

5. NPC Substation Design

For new substations, bus layout configurations and switching schemes are communicated to the Substation Design Department by the Transmission Planning Department in the form of a schematic single-line diagram.

For most Nevada Power 100MVA and 140MVA 138/12kV distribution substations where two lines terminate in the substation a “Single-Bus” bus arrangement scheme is used, (no tie breaker), see Figure 2. This scheme provides the greatest substation layout flexibility and the lowest cost. Single bus is simple and a low cost option since only one circuit breaker per HV circuit is utilized. No transfer breakers and few disconnect switches are required [5]. However, this bus scheme offers no operating flexibility. [3]

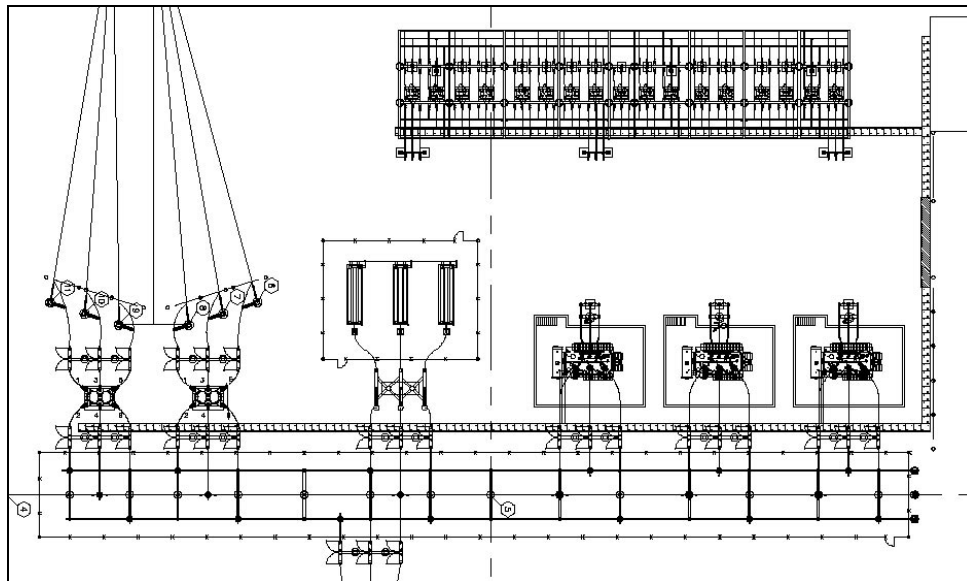
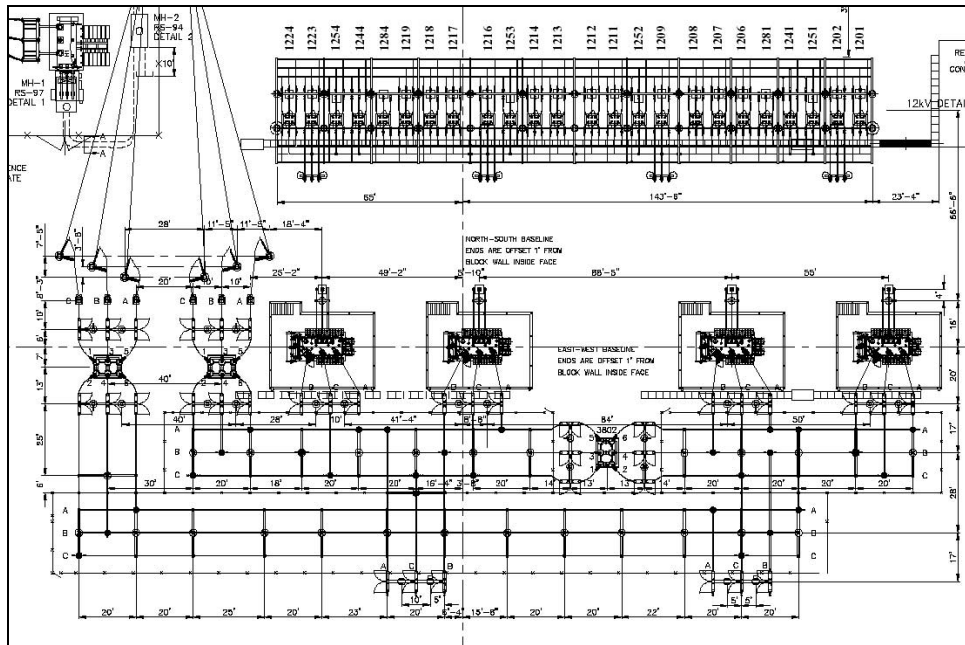
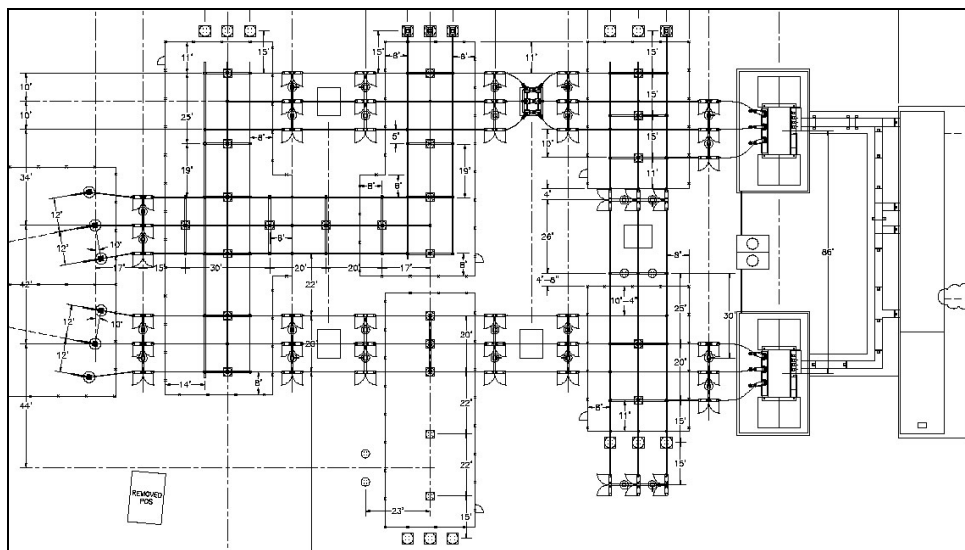


Figure 2. Single Bus Scheme, Robindale 100MVA 138/12kV Substation

Considerable improvement and flexibility can be obtained by adding bus tie breakers in the bus between transformers. This design scheme is commonly called “Sectionalized Single-Bus” and is shown in Figure 3. This modified single-bus arrangement permits faulted bus sections to be isolated rapidly from the remainder of the station. [5] This scheme is utilized in higher capacity 140MVA four transformer substations to provide greater operational flexibility.



When space permits an initial single-bus arrangement can be designed in such a way that it can be later converted to an ultimate “Ring Bus” arrangement to allow for future transmission line positions or capacitor banks. For this arrangement see Figure 4.



In the ring bus scheme the breakers are arranged in a ring configuration with circuits connected between breakers. The scheme has the advantage of greater flexibility with a minimum of breakers. [3]. Any breaker in the ring can be taken out of service for maintenance without disrupting the operation of the rest of the system. [4]. The

ring bus scheme is economical in cost, has good reliability, is safe for operation, is flexible, and is normally considered suitable for important substations up to a limit of five circuits [2].

In larger 138kV and 230kV switchyards the “Breaker-and-a-Half” arrangement is commonly used. This scheme provides the greatest flexibility and the highest reliability but requires more circuit breakers than a ring bus arrangement. For an example of this scheme see Figure 5.

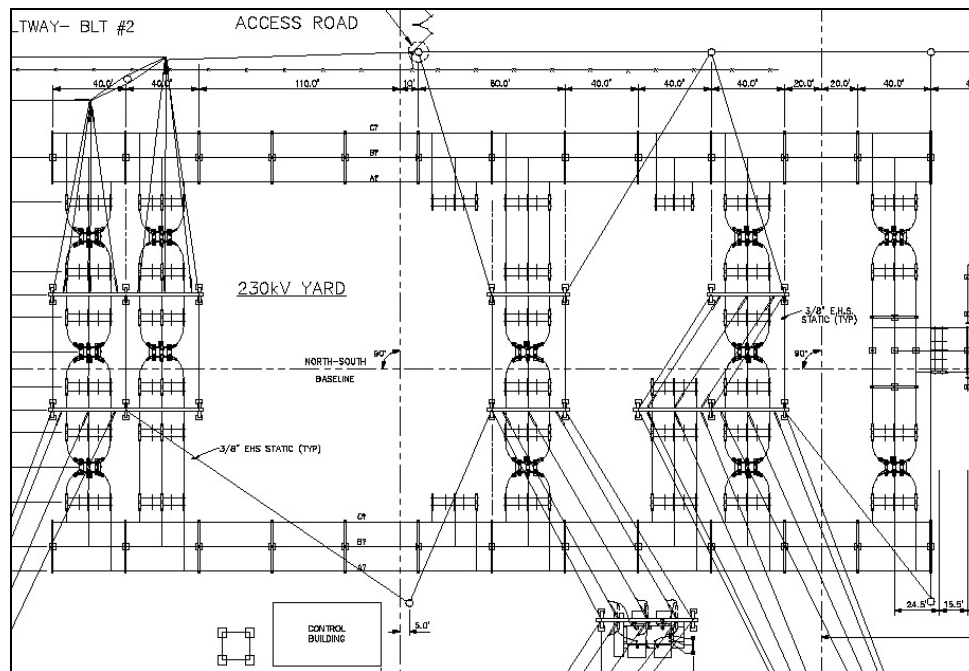


Figure 5. Breaker-and-a-Half Scheme, 230kV Yard, Northwest 500/230/138/12kV Substation

In this configuration two lines can be brought into the station with two main buses. One line comes into a center tap. At the tap it goes through a disconnect switch, breaker, and a disconnect switch to a main bus. From the tap on the other side it goes through a disconnect switch, breaker, and a disconnect switch to another point where it picks up another main bus. If this concept is fully developed the lines would be protected by two circuit breakers.

The breaker-and-a-half scheme has three breakers in series between the main buses. Two circuits are connected between the three breakers, hence the term breaker-and-a-half. This pattern is repeated along the main buses so that 1-1/2 breakers are used for each circuit. Under normal operating conditions all breakers are closed and both buses are energized. A circuit is tripped by opening the two associated circuit breakers. Tie breaker failure will trip one additional circuit, but no additional circuit is lost if a line trip involves failure of a bus breaker. Either bus may be taken out of service at any time with no loss of service. With sources connected opposite loads, it is possible to operate with both buses out of service. Breaker maintenance can be done with no loss of service, no relay changes, and simple operation of the breaker disconnects [2].

There are two design layout options commonly used at NPC for the breaker-and-a-half scheme. Where there are no visibility restrictions an “Open-Bus” arrangement is used with a combination of rigid and strain bus. The buses are arranged to run the length of the substation and are located toward the outside of the station. The transmission line exits cross over the main bus and are dead-ended on A-frame takeoff tower structures. The line drops into the bay in the station and connects to the disconnecting switches and circuit breakers. This arrangement requires three distinct levels of bus to make the necessary crossovers and connections to each substation bay and is thus considered a high-profile design.

The “Inverted-Bus or “Folded” breaker-and-a-half arrangement is a low profile option. With this arrangement all outgoing circuit takeoff towers are located in the outer perimeter of the substation, eliminating the crossover of line or existing facilities. Main buses are located in the middle of the substation with all disconnecting switches, circuit breakers and all bay equipment located outboard of the main buses. Since only two levels of bus are required to make the necessary crossovers the end result is a lowered profile, more spread out substation. This configuration is shown in Figure 6

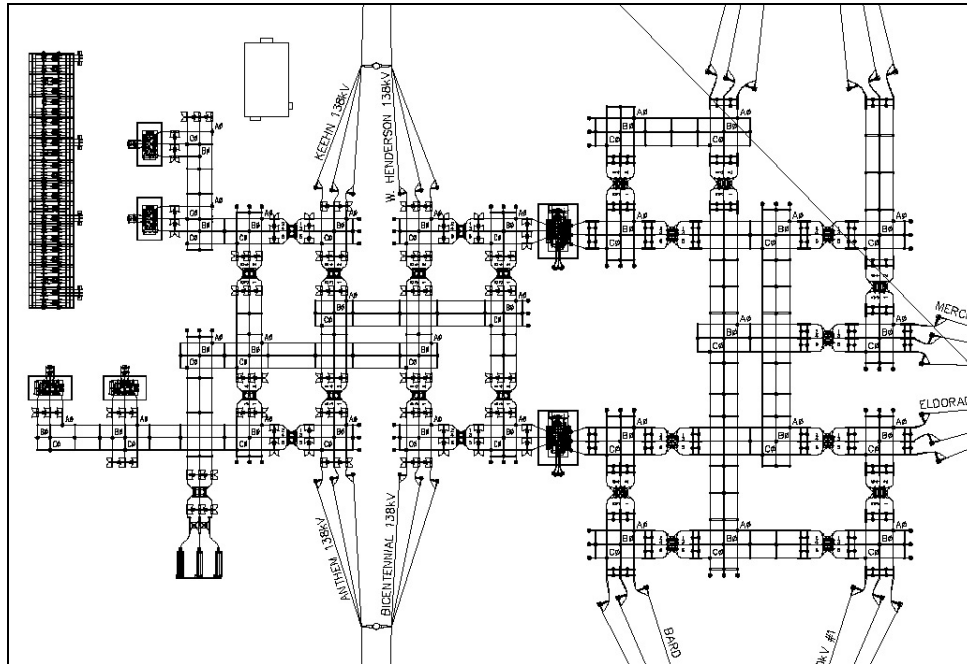


Figure 6. Inverted or Folded Breaker and a Half Scheme, Magnolia 230/138/12kV Substation

In 1996 a reduced visual impact, “RVI”, substation design approach was adopted at Nevada Power. This included high bus at 14’ and low bus at 7’ above grade, (with personnel safety guard fences), a 14’ block wall, metal-clad switchgear and low profile transformers. See Figure 7, El Capitan 100MVA 138/12kV substation for photos of this design. The low profile design approach is currently utilized at Nevada Power for 138/12kV 100MVA and 140MVA substations with the exception of the metal-clad switchgear, (an open air distribution breaker structure is now used).



Figure 7. Exterior and Interior Views of an RVI Substation

6. Applicable Design Standards

The majority HV electrical substation physical design is governed by three principal engineering standards: NESC-C2, IEEE Std. 979 and to some degree the NEC.

Substation electrical clearances and spacings are governed by the NESC-C2-2002, (National Electrical Safety Code), published by the IEEE. Particular attention is paid to minimum allowable electrical clearances, (vertical and horizontal), guards and the guarding of live parts, and protective grounding.

IEEE Standard 979-1994, “Guide for Substation Fire Protection” plays an important role in determining minimum allowable horizontal clearances between adjacent large oil-filled transformers and between large oil-filled apparatus and relay and control buildings.

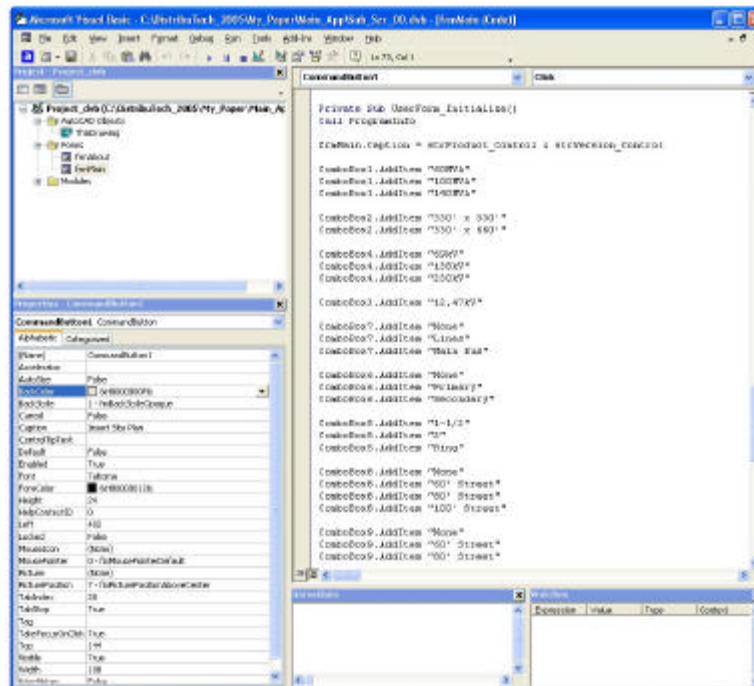
The NEC-2002, (National Electric Code), is mainly used for cable and conductor ampacity properties and sizing, grounding conductor sizing, permitted cables in conduit, etc...

7. Automating Substation Design

The objective of the application is to produce preliminary physical substation plot plans in a short amount of time given the desired substation size, configuration and land parcel details. During the land acquisition process at Nevada Power it is of great importance to explore several substation layout options within a short period of time typically answering questions like, “can we fit a 140MVA substation on this site?” A secondary objective is to provide preliminary plot plans of the substation equipment for the land use permitting package. The primary CAD design application used at Nevada Power for substation design is AutoDesk’s AutoCAD 2004. The main challenge one encounters in automating design applications is the learning curve associated with an application’s core development language.

Visual Basic for Applications, (VBA), was considered the logical choice for automating the AutoCAD application because it is a Microsoft Windows development environment. Microsoft licenses the VBA Integrated Development Environment to AutoDesk for inclusion in their products. In AutoCAD VBA can be used to programmatically control the creation and editing of individual drawing objects, manipulate linetypes and layers, control text and dimensional styles, and much more [6]. VBA programs are developed within AutoCAD using the VBA Integrated Development Environment, (IDE). See Figure 8 for an image of the VBA IDE interface. Using VBA the programmer can develop userforms or dialog boxes to create a user interface to prompt a designer for key substation design parameters. The application developed at Nevada Power was named “SubSizer”. It consists of a set of userforms or dialog boxes that prompt users for several key substation design parameters. The application’s main user interface is shown in Figure 9. Data captured from this userform’s text boxes and combo boxes is used to perform several tasks within AutoCAD. These tasks consisted mainly of AutoCAD entity edits and manipulations, attribute updates and block insertions.

In order to develop the SubSizer application’s user interface a number of key initial factors or design variables needed to be identified. These variables can be categorized as follows: administrative information for the AutoCAD title block, substation site parcel details and substation electrical design parameters. The substation electrical design factors are divided into distribution substations and switchyards depending on the physical arrangement desired. Table 1. describes these variables in detail.



	Variable	Description	Field Type	TextBox and ComboBox Options
Title Block Details	Sub Name	substation name	text	
	Sub Design	substation designer/engineer	text	
	Date	date	date	
	Work Order Num	NPC work order number	text	
Substation Site Parcel Details	Parcel Size	substation site parcel dimensions	text	330' x 660' 330' x 330'
	StreetROW_North_Dim	northern street ROW allowance	text	NONE 60' street 80' street 100' street
	StreetROW_South_Dim	southern street ROW allowance	text	NONE 60' street 80' street 100' street
	StreetROW_East_Dim	eastern street ROW allowance	text	NONE 60' street 80' street 100' street
	StreetROW_West_Dim	western street ROW allowance	text	NONE 60' street 80' street 100' street
	Landscape_North_Dim	northern landscape buffer inset	text	NONE 10' 20'
	Landscape_South_Dim	southern landscape buffer inset	text	NONE 10' 20'
	Landscape_East_Dim	eastern landscape buffer inset	text	NONE 10' 20'
	Landscape_West_Dim	western landscape buffer inset	text	NONE 10' 20'
	StreetName_North	northern street name	text	
	StreetName_South	southern street name	text	
	StreetName_East	eastern street name	text	
	StreetName_West	western street name	text	
Substation Electrical Design Parameters	Substation_Primary_Voltage	substation primary voltage in kV	number	69kV 138kV 230kV
	Substation_Sec_Voltage	substation secondary voltage in kV	number	12.47kV
	Substation_MVA	substation ultimate capacity in MVA	number	60MVA 100MVA 140MVA
	Substation_20gate_Num	number of 20' gates and drive aprons	number	1 2
	Sub_DistFeeder_Dir	distribution feeder egress direction	text	North South East West
	Sub_TransIn_Dir	transmission line ingress direction	text	North South East West
	Sub_Cap	substation capacitor bank	text	NONE Primary Secondary
	Sub_PCB_Config	circuit breaker configuration	text	Single Bus Single Bus Tie Ring Breaker-1/2
	Sub_CCVT	CCVT locations	text	NONE Lines Main Bus
	NESC_C2_Factor	NESC compliance factor	text	Minimum clearances Preferred Clearances
	Switchyard_230	number of 230kV line positions	number	
	Switchyard_138	number of 138kV line positions	number	
	Switchyard_12	12kV distribution feeders	text	NONE 100MVA 140MVA
	Switchyard_Cap	switchyard capacitor bank	text	NONE Primary Secondary

Table 1. Substation Design Application Variables

Figure 10 shows the NESC-C2 calculator that was integrated into the application as an additional design aid. This tool provides users with immediate access to preferred and minimum substation electrical clearances dictated by the National Electrical Safety Code published by the IEEE

Figure 10. Substation Design Application NESC-C2 Clearance Calculator

7.1 Modular Design Approach

To automate substation physical design it was necessary to unbundle standard NPC substation plot plan layouts into interconnecting modular units. These design modules contain various portions of substation design details, equipment and apparatus arranged in accordance to NESC-C2 clearance parameters. The units were also carefully designed to interface with adjacent units of like voltage class or BIL, (Basic Impulse Insulation Level). Figures 11 and 12 illustrate the modular units for the breaker-and-a-half bus arrangement scheme for the open-bus and inverted or folded bus design options. Units of like voltage class are further subdivided by substation design factors such as ultimate station capacity, NESC-C2 observance, (preferred or minimum), and major apparatus manufacturers.

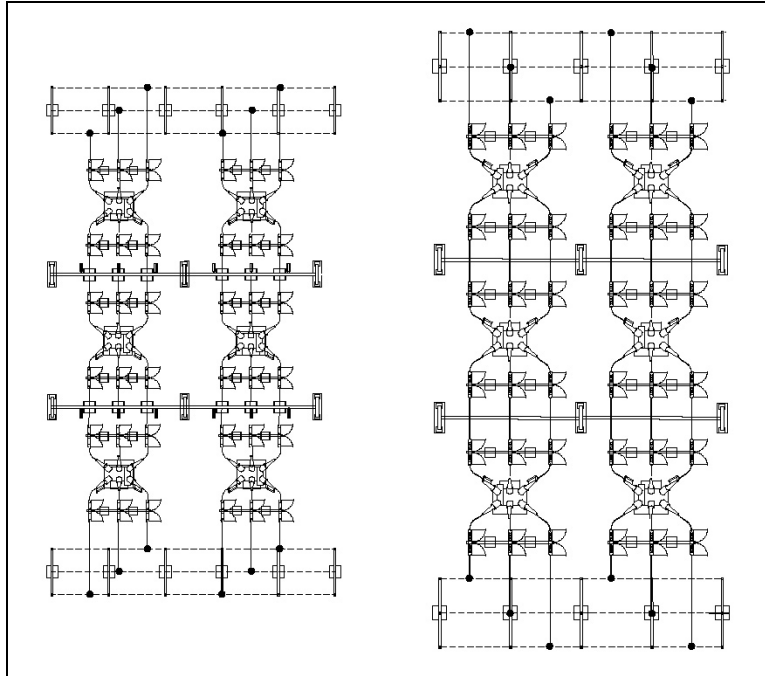


Figure 11. 138kV and 230kV Open-Bus Breaker-and-a-Half Modules

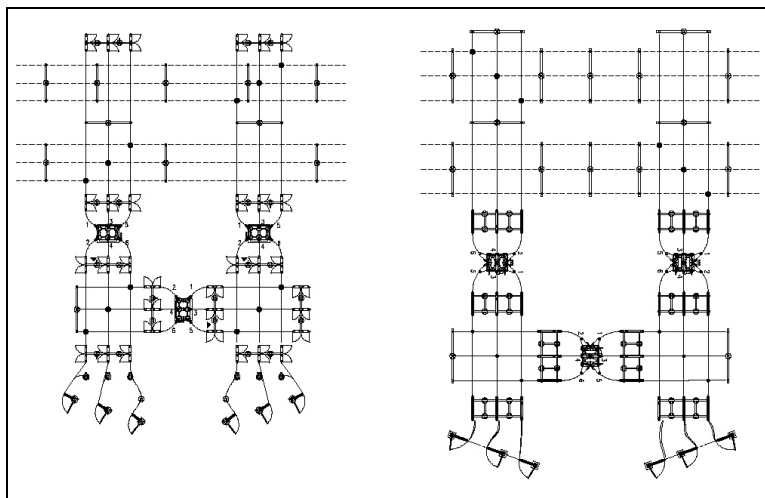


Figure 12. 138kV and 230kV Inverted or Folded Breaker-and-a-Half Modules

8. Summary

SubSizer has also greatly increased the production time of preliminary substation drawings for sizing studies and land use permitting packages. The application greatly speeds up the verification process of whether certain substation physical designs are compatible with intended land parcels. Throughout 2004 it was used to provide preliminary substation design information to Nevada Power's Valley Area Routing and Siting, (VARs), team. This team was formed to acquire land rights and to regain strategic and financial opportunities to accommodate system growth.

Automating AutoCAD with VBA to place and manipulate modular design units provides designers with an inexpensive and very powerful substation design tool. Both technical and non-technical users of the SubSizer application have the ability to create very detailed substation layouts in a very short amount of time.

9. References

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Biography

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