Breaking Paradigms in Control Building Design

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***Abstract*--Do your control buildings meet the needs of your company? Poor control building design will leave a lasting impact on your utility. This paper lists several common paradigms seen in control building designs and how the Tennessee Valley Authority (TVA) has remedied them creating a modern control building that has revolutionized the way TVA designs, constructs, maintains, and operates substations.**

The following five paradigms will be examined:

Paradigm #1: Live terminals in close proximity with our electricians and operators are acceptable.

Paradigm #2: Relays and other equipment must be mounted in a cabinet or other U-shaped structure.

Paradigm #3: Terminal blocks must be mounted in the cabinet or panel with their corresponding relays.

Paradigm #4: A standard, modular control building to suit the needs of every site, regardless of site specific demands, is simply not feasible.

Paradigm #5: A control building cannot enable the reinvention of the design, construction, maintenance, and operation of a substation.

***Index Terms*--Cabinet, Control Building, Fuse, Panel, Rack, Relay, Test Switch, Terminal Block**

I. Background

Prior to 1991, TVA utilized traditional control buildings constructed of brick and mortar. The relay mounting structure was composed of a pipe or strut frame with 24” x 90” steel panels arranged in a back-to-back row where the front panel contained meters, switches, and other operator interfaces while the rear panel contained the associated protective relays. This traditional electro-mechanical relay board design dates back to the early part of the 19th Century and can be seen in many historical catalogs and photographs from throughout the industry.

In 1991, TVA partnered with a local manufacturing company to design and provide the first factory built, metal control building. This design utilized 36” wide x 39” deep x 100” tall, rack-mounted, steel cabinets as shown in Figure 1. Although these cabinets employed rack mounted panels and could accept 19” rack-mounted relays, they were designed for heavy, electro-mechanical relays. The large size and 1,000 lb. weight of the cabinets required the control buildings to be fitted with oversize doors so the cabinets could be safely moved into and out of the building.

Figure 1 1990s vintage relay cabinets at TVA.

The first modular buildings were equipped with a cable tray system in the floor, under the relay cabinets as well as a cable tray on top of the cabinets, in the ceiling. The cable tray system in the floor increased the complexity of the structural members and necessitated taller I-beams in the base of the control building. This ultimately increased the height and cost of the building. These buildings were complete with toilet facilities, lighting, heating ventilating and air conditioning (HVAC), exit lights, and all other miscellaneous necessities. The buildings also included space for the required number of 19” racks for telecommunications.

Although several attempts were made to standardize building sizes, each building was eventually custom designed for each site to accommodate the needs of that site. It also became evident that the floor and cabinet space utilization was very poor due to the introduction of digital relays. As this design was used on larger and larger projects, limitations were quickly reached with the overall length of the modules and with shipping dimensions. With very long modules, the floor systems became quite robust due to the cable tray system in the floor and strength needed to support the long modules during shipping and handling. To overcome these limitations, custom, double-wide and four-module, double-wide / double-long buildings were created to meet the needs of sites.

For long modules, special permits and other provisions were required for transport. In at least one case, land had to be purchased and roads modified to accommodate the turning radius of the tractor trailer delivering the control building modules to the site.

Three departments were responsible for the design of the first modular control buildings: the Physical Department, the Protection & Control (P&C) Department, and the Telecommunications Department with the bulk of the responsibility falling on the Physical Department. These uneven levels of responsibility lead to many decisions being made for the P&C and Telecom departments on technical issues. Eventually, this discouraged involvement among the P&C and Telecom Departments.

In 2004, we realized that TVA had reached the end of the design life of the initial prefabricated metal buildings for the following reasons:

• Shipping of modules was difficult and expensive

• Relay cabinets were overdesigned for modern equipment

• The cable tray system unnecessarily increased the height, weight, and cost of the buildings

• Building designs were not standardized

• Unnecessary designs and safety risks associated with moving 1,000 lb. relay cabinets

• Cabinets promoted exposure to live terminals for personnel

• All departments not owning their spaces

Ultimately, TVA wanted a modern, future-proof, and safe control building that was easy to design, fast to install, and reasonably priced.

II. Live terminals

Live terminals can be found within every substation control building at every utility. They are the termination point where control wiring connects to relays & controls, and they are located on our panels, racks, and cabinets. For the purposes of this paper, live terminals are typically energized at less than 150 volts to ground. For a small substation, they number in the thousands and may reach several hundred thousand at a large substation. When we place employees in small spaces dotted with hundreds of live terminals and surrounded the employees with grounded surfaces, we have an electrocution risk. See Figure 2. As an industry, we are probably too comfortable with live terminals. The challenge to our industry becomes how to package live terminals to minimize their risk to personnel.

Figure 2 Electricians in close proximity to live terminals at an older station.

Relay cabinets are small booth, shaped enclosures with equipment and live terminals typically mounted on three sides. Please refer to Figures 3 and 4. Many have interior swinging panels and thresholds impeding personnel ingress and egress from the cabinets. Some cabinets have dual swinging doors where the exterior door swings to the left and the equipment panel swings to the right. Swinging doors on cabinets can have relays, switches, or other jagged components capable of snagging an employee on entry or exit. Also, open doors on relay cabinets are perpetually in the way. The author has seen many stations while under construction or modification where multiple doors were open, effectively blocking the access aisles in the station. In another case, the building wall prevented doors of adjacent cabinets from fully opening and formed a man trap.

Circuits within relay and control cabinets originate from many sources: DC distribution boards, AC distribution boards, instrument transformers, SCADA equipment, and at other relay and control cabinets. For this reason, it is generally not possible to de-energize every circuit in a cabinet to allow work to safely proceed. This forces workers to maneuver in tight spaces, in close proximity with live terminals.

The National Electric Safety Code, NESC, requires a three foot minimum working clearance “about” electrical equipment for circuits less than 150V to ground. However, it does not specify working space “within” electrical equipment such as “in” a cabinet. During operation and testing, employees are routinely working within relay cabinets to manipulate fuses, perform testing, or perform other operational duties. This represents a problem.

On the other hand, relay panels are similar to relay cabinets because they are typically U-shaped and form an enclosure to contain a man, but they do not have a door. Why do we need the U-shape? Typically, relays, meters, switches, indicating lights and test blocks are mounted on the front of the panel. Other items such as terminal blocks, fuses, transducers, auxiliary relays, auxiliary transformers, and other miscellaneous items are mounted on the left and right side panels of the relay panel. This forms the “U”. The U-shaped design forces the relay panel to have a significant depth dimension, and like cabinets, forces employees to maneuver in close proximity with live terminals.

<u>Note: Due to the U-shaped design, relay panels and cabinets will be considered as identical in this paper and will be referred to as cabinets</u>.

Figure 3 Shows two views of an employee simulating work in a 24" cabinet. Note: If equipment was installed in this cabinet, then working spaces would be further reduced. Also note cabinet threshold by employee's shoe.

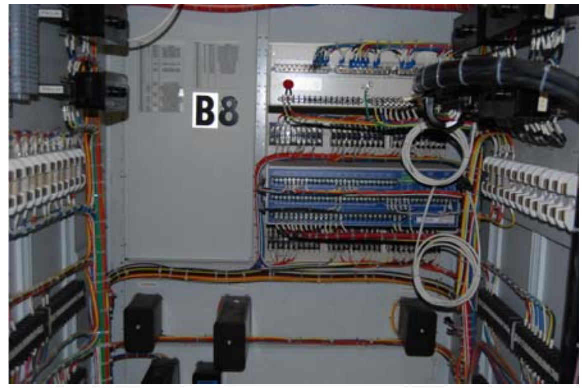

Figure 4 36" wide relay cabinet showing live terminals on three sides of the employees having to work in this cabinet.

We felt TVA could abandon the cabinet concept, retire the right and left side panels, move all user interfaces to the front, and create a relay and control board with a minimal depth dimension. This concept would immediately improve personnel safety with additional significant benefits to be discussed later.

Abandoning the side panels of a cabinet would not be easy. All of the equipment mounted on the side panel areas would have to be moved to another location, be incorporated into another device, or be retired.

III. Racks

TVA considered most of the currently available protection equipment being purchased or could be purchased, was rack mounted. We then focused our attention on the 19" wide x 96" high telecom rack as a possible mounting structure.

Racks first appeared in the early 1930s and, generally, have changed little since that time. The rack consists of two parallel vertical channels, two floor angles, and two top angles. The vertical channels are drilled and tapped on both sides according to Electronic Industries Alliance (EIA) standards.

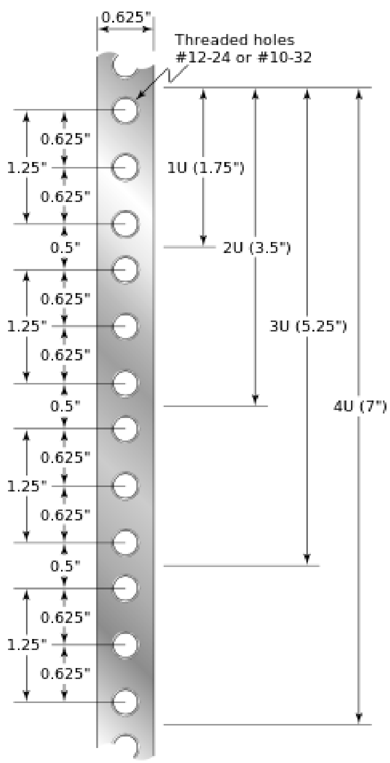

Figure 5 Mounting hole spacing on a universal rack. *Diagram by Sakurambo*

The Rack Unit (RU) or (U) is the standard vertical unit of measure associated racks and rack mounted equipment. In all cases, a rack unit is 1-3/4". This value is determined by how often the rack drilling pattern repeats itself: 5/8" + 5/8" + ½" = 1-3/4". This is shown in Figure 5. The height of all equipment designed to mount on a rack is given in RU or U. For example, a commonly available digital relay is 4RU in height. The exact height is slightly less than 4 x 1-3/4" to allow room for manufacturing tolerances between the mounted equipment and the rack. This tolerance is approximately 1/32".

At least two hole patterns are available on racks:

- 1-1/4" – ½" alternating pattern
- 5/8" – 5/8" – ½" alternating pattern

TVA selected the 5/8" – 5/8" – ½" pattern since it allows for more alignment options with the equipment to be mounted on the rack. Because of the drilling pattern, this is commonly called "The Universal Rack." The tapped holes accommodate 12-24 screws. TVA uses "Pilot Point" screws to ease starting and facilitate assembly. The first 1/8" of Pilot Point screws have no thread and only align the screw straight in the hole as shown in Figure 6. These screws also clean the paint from the threads in the hole to make a good electrical bonding connection.

Figure 6 Pilot point screw for mounting equipment to a rack.

TVA's P&C Department has partnered with its Telecommunications Department to select a single rack and accessories vendor to meet the needs of both departments. During this process, we found many racks and rack accessories were commonly needed by both departments. This gave TVA significant purchasing power with the selected vendor. TVA has standardized on an aluminum rack that will accept 1000 lbs. of evenly distributed load, and weighs only 41 lbs. Please refer to Figure 7.

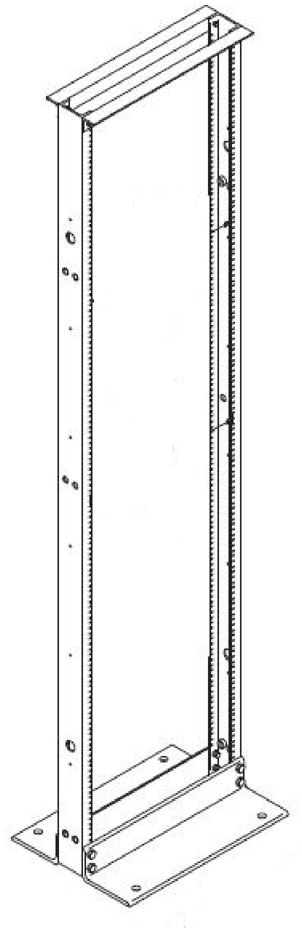

Figure 7 Universal rack. *Courtesy Chatsworth Mfg*

Numerous vendors supply universal racks and also supply accessories for racks such as filler plates, wire & cable rings, keyboard trays, ground bar kits, wireway sections, seismic kits, and many other components. This is important because these items can be easily sourced if a vendor retires a component or goes out of business.

Once a rack mounting structure was selected, TVA began the process of dispositioning the equipment on the side panels. We determined control switches and meters could be mounted on standard ¼" thick, aluminum filler plates provided by the rack manufacturer. We selected 3RU plates for 4" indicating meters, and selected 5RU plates for control switches and lockout relays. Slight reductions were made to the TVA standard center-to-center spacing of switches and meters allowing a better fit on the new filler plates.

IV. Fuses

To relocate the fuses from the side panels to the front of the rack, TVA needed to obtain a dead front, rack mounted fuse holder that would accept commonly available control circuit fuses with the ratings shown in Table 1.

TVA Control Fuse Requirements	
Current Ratings	1 to 60A
AC Voltage Rating (over all current ratings)	600V
DC Voltage Rating (over all current ratings)	300V
AC Interrupting Rating	100 KA
DC Interrupting	20 KA

Table 1 TVA control fuse requirements.

TVA evaluated virtually every dead front fuse holder on the market. Fuse holders were dismissed for various reasons:

• Off-shore fuses were not commonly available

• Current or voltage requirements could not be met

• Flimsy manufacturing

• Would not accept dual wires in their lugs

• Could not be replaced without disassembly of adjacent fuses

TVA ultimately selected a dead front, finger safe fuse and holder. Although no factory made, rack mounted fuse holder was available, TVA created a 3RU fuse assembly providing space for 15 fuse holders and has a cover plate concealing the connections and has room for circuit identification labels. See Figure 8.

Figure 8 Dead-front fuse assemblies mounted on a rack for easy access to the fuses.

This design gave TVA a standard, dead-front fuse holder and fuse that could be used in any rack or cabinet application throughout the system. It could also be used for plant applications where 250V battery systems with high fault currents were encountered.

V. Test switches

Test switches were another problem. When TVA embraced multi-function, digital relays for protection applications, TVA also embraced the widespread use of knife-blade type test switches. Typically, a microprocessor relay would be allowed one test switch assembly with 30 test points that occupied 3RU. Even with 30 test points, the test switch only had the ability to isolate <u>some</u> of the circuits connected to the relay. TVA prefers to provide isolation in <u>all</u> circuits connected to digital relays except the power supply connections. Limited test points forced designers to auction test points to the most critical circuits. Test personnel then had to lift wires on the back of the relays to commission or perform routine testing of the relays. Several human performance events occurred due to wires being improperly re-terminated once testing was complete. Additional rows of 3RU test switches were provided to help combat this problem. In fact, 3RU & 4RU relays were being purchased at the time, and TVA was faced with installing 6RU or even 9RU of test switches below each relay to allow full isolation. So, the test switches were requiring more space on the cabinet than the relay did!

TVA began a look at the world market of test switches to find one that required a minimum of space and delivered a high density of test points. This new test switch needed to have the following attributes:

• Must be rack mounted

• Must be dead front

• Must automatically short current circuits without pre-jumpering of the test plug to avoid open CT circuits

• Must be front accessible

• Must ideally occupy only 2RU of space

• Must be rated for 20A continuous

TVA chose a small, modular, enclosed test switch. This test switch delivers eight test points in a space of 2RU high x 1-1/2” wide. When ten of the test switches are placed on a 2RU frame, this gave us a total of 80 test points in a 2RU space as shown in Figure 9.

Each test switch is fitted with a nameplate attached to the door of the test switch. The nameplate gives the device number, the description of the test switch, and the wire tags of the wires connected to the switch.

TVA also utilizes modular auxiliary relays from the same vendor. When space permits in the 2RU test switch frame, auxiliary relays may be placed in the frame to further remove equipment from the side panels and place them on the front of the rack as shown in Figure 10.

Figure 9 Test switch assembly containing ten test switch modules giving a total of 80 test points in a 2RU frame mounted below a relay. Note: TVA nameplates are affixed to test switch doors for identification of test switches.

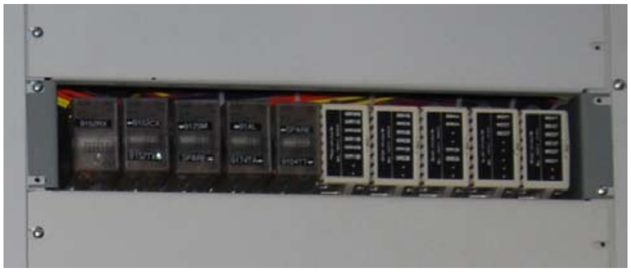

Figure 10 Photograph of five test switch modules and five auxiliary relays mounted in the same bracket.

VI. Miscellaneous Components

Many miscellaneous components on side panels became unnecessary with the use of microprocessor relays. When auxiliary transformers are required, they are mounted on filler plates and attached to the rear of the rack. Other small items such as tripping and blocking diodes, DC-DC converters, ice cube relays, and bells etc. are mounted in a similar manner on the rear of the rack. Please refer to Figure 11.

Through the use of the telecommunications rack, clever equipment placement, and selection of modern components, TVA has almost negated the need for cabinets.

Figure 11 Equipment mounted on a blank panel attached to the rear of a rack.

VII. Terminal Blocks

They sound so simple, but they're not! Terminal blocks in relay cabinets serve several functions:

• They are a place to land cables from the field

• They are a place to land conductors from the rack

• They must be able to accommodate oversized field conductors when used to compensate for voltage drop

• They must be able to accept ring lug style wire terminals

• They must be able to accommodate at least four conductors (two per side)

• They must be rated a minimum of 30A, 600V

• They represent a labor rate to mount and wire

• They require space, but we can't allow too much space

TVA looked at many of the DIN rail mounted terminal blocks on the market and discovered some offered an ultra-high density of terminations per linear inch. This seemed like a good idea, but when applied out at the substation with lots of #10 and #14 wires, the terminal block area became a congested, inaccessible mess. Also, small terminal blocks are difficult to label. So, we learned terminal blocks can actually be too small. We learned terminal blocks that were approximately ½" wide offered the best density without sacrificing access and wire training area.

TVA selected a modern terminal block shown in Figure 12 that is similar to traditional terminal blocks found in mid-century substation designs. The differences are these terminal blocks are made up of DIN rail mounted, individual terminal points employing captive screws and UL94-V0 material having an excellent heat, flame, and shock resistance. Unlike many DIN rail mounted terminal blocks, this material will not melt and allow metal components of adjacent terminals to move over and short to each other if the terminal becomes hot. The captive, Philips head screws in the blocks significantly reduce the labor associated with wiring the terminals because electric screw drivers can be easily used. The captive screws are self-aligning, negate the need for "holding" screwdrivers, and do not have the problem of screws that can be dropped or disappear during the life of the control building.

Figure 12 Modular 30A, 600V terminal block with captive screws. *Courtesy IDEC*

Historically, field cables arrive at relay cabinets and land on terminal blocks on the right and left sides of the cabinet. The area occupied by terminal blocks requires the dedication of a large amount of side panel and floor space and can be the driver that determines the depth of the relay cabinet. Space for several hundred terminal points and wire training is usually provided in each cabinet. Since TVA was moving toward a more 2-dimensional design, room was not available for terminal blocks on the racks. One or two test cases were tried where a “terminal block rack” was created, but this was quickly discontinued because of poor floor space utilization and an overly complicated ceiling cable tray system.

The surfaces of the exterior walls inside a control building are largely unused. To better utilize this space, TVA elected to place two vertical rows of 150 terminal blocks per rack on the walls of the control building immediately behind the rack that they serve. This provided the following benefits:

A. Cables in the ceiling cable trays were minimized and thereby reduced the size and complexity of the ceiling cable tray system to minimal proportions

B. Floor openings aligned with the terminal blocks allowed field cables to be easily inserted through the openings and landed at the appropriate terminals to speed installation. This negated the need for major cable handling efforts within the building.

C. Floor space utilization in the control building was improved

E. Side panels were eliminated

F. The concerns regarding working space “within” electrical equipment disappeared because personnel could no longer get “in” relay cabinets

G. The overall working space “about” the racks and terminal blocks increased from 36” to 48”, and TVA exceeded the NESC limits as seen in Figure 13.

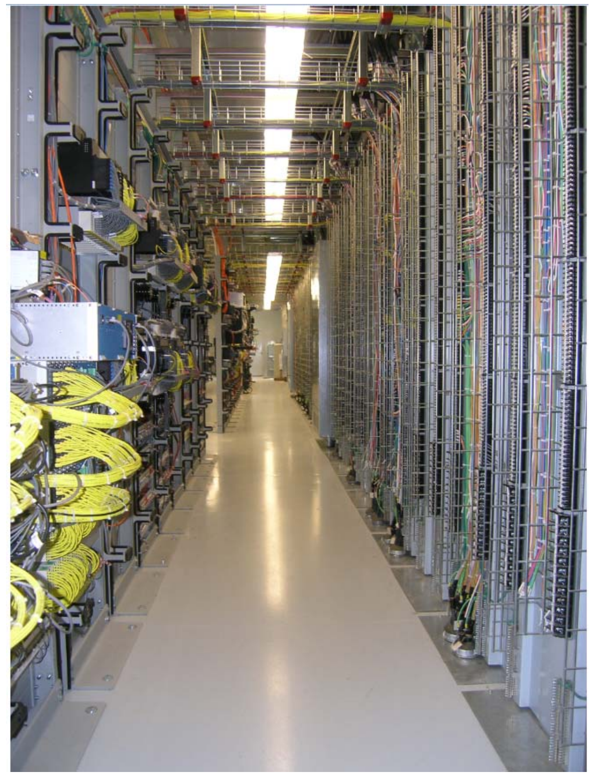

Figure 13 Looking through four control building modules showing terminal blocks on the walls and the large, 48” working clearances behind the racks.

Some might question how placing the terminal blocks on the wall of the control building has minimized exposure to live terminals. With terminal blocks on the wall, the distance between the live terminals on the wall and the live terminals on the rack is now 48.” Moving the fuses to the front of the rack and providing enough test switches to totally isolate all relays has removed the need for personnel to go behind the racks in normal circumstances. If a complex maintenance problem occurs or additional construction is needed, then personnel will need to be behind the racks to perform work just as personnel would need to go into cabinets and perform work. This design succeeds because employees are not forced to work in small, closed spaces in the proximity of live terminals.

VIII. Wire Baskets

To further reduce construction time, TVA made use of wire baskets for training wires and cables on the walls and over to the racks. The incoming cables enter a 5” x 8” wire basket having numerous locations on which to tie and support the cables and individual conductors. The conductors of adjacent racks leaving the terminal blocks share a 3” x 4” wire basket. This basket runs up the wall where it transitions to a horizontal run passing over the corridor and terminating at a three inch wireway between the associated racks. All the wire baskets are of “open top” design that allow cables and conductors to be easily added or removed. Please refer to Figure 14 showing the wire baskets to the racks, and refer to Figure 15 showing a photographic section through the building. Note, TVA used wire basket covers at a station or two, and they were quickly retired because they were always in the way when they were removed, they were conductive and could easily cause a short or other damage if they fell, and they were cut from steel sheets and left with knife-like edges that contributed to hand injuries.

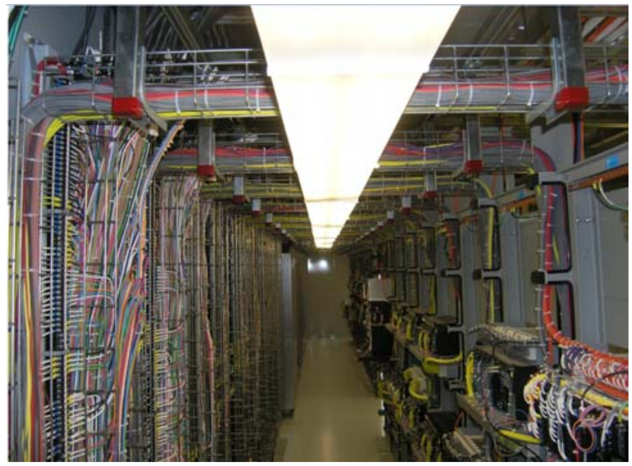

Figure 14 Wire baskets on the wall and over to the relay racks

Figure 15 Photograph through the control building showing the live front and dead front hallways in two consecutive P&C modules. Note: The photo also shows the cross streets between modules.

IX. Modular Control Building

As with most utilities, TVA's control buildings consist of four main components:

• Protection and control equipment

• Telecommunications equipment

• DC system such as batteries, distribution panels, and chargers

• Rest room facilities

At TVA, the complexity of all four items above can significantly change from site-to-site due to the requirements at each site. For example, Station A may require a large protection and control footprint, minimal telecommunications footprint, a dual DC system, and a rest room. Station B may require a minimum protection and control footprint, a large telecommunications footprint, a regular DC system, and a rest room. Finally, Station C may only require a minimal protection and control footprint, a minimal telecommunications footprint, a small DC system, and no rest room. Of course, there are many other combinations.

Traditionally, the individual site requirements forced TVA to work with our building vendor to create custom buildings for each site. This was very inefficient and expensive for all parties.

About this time, TVA design personnel were fortunate to be given a tour of a modular American Telephone & Telegraph (AT&T) facility in Chattanooga. This facility was a hub for fiber optic trunk-lines in and out of the area. The building was a linear, modular building consisting of five concrete sections assembled to form a single interior space. Each section had a dedicated purpose and was complete with its own HVAC units. As the facility expanded over time, they simply removed the end wall and added sections as needed.

This was a fantastic idea that would solve the changing needs of TVA's control buildings! It also solved the ongoing problem of shipping extremely long control building modules. With this motivation and vision, TVA went to work creating individual modules to meet the needs of the three interfacing TVA departments.

We first examined the shipping limitations of the Departments of Transportation (DOT) in the seven states where TVA operates. We didn't want to build something that couldn't be shipped. TVA selected 16' as the nominal width and 12'-9" as the maximum height for all modules of the building. The DOT maximum length varied from 80' to 120', but our objective was to design modules to be as short as reasonably possible with a maximum of around 35'.

With the state DOT limitations and TVA's organization arrangement in mind, TVA created eight standard modules that when combined in the necessary quantity and order could solve the protection and control, telecommunication, DC system, and restroom needs at any site. These modules also allowed each organization to "have their own space."

There was a desire to place as many racks as possible in the Telecom and P&C modules. This thought was abandoned due to the desire to provide "cross streets" at the ends of the modules so personnel could quickly move from the rear of the racks to the front of the racks or vice versa. To accomplish this, roughly, the last two of feet of each module is left blank with no racks. This space adjoins a similar area in the adjacent module to form an access corridor or "cross street." This blank area at both ends of each module is accompanied by blank wall space that became useful for DC distribution panels and HVAC units while still allowing clear area for access. Refer to Figure 15 for a photograph showing the cross streets.

The standard modules are as follows:

A. Command Module #1 contains the battery room, provisions for 2-battery chargers, operator's desk, rest room, two access doors, eye wash, DC distribution panels, AC distribution panel, and HVAC. This module is 16' wide and 35' long and shown in Figure 16.

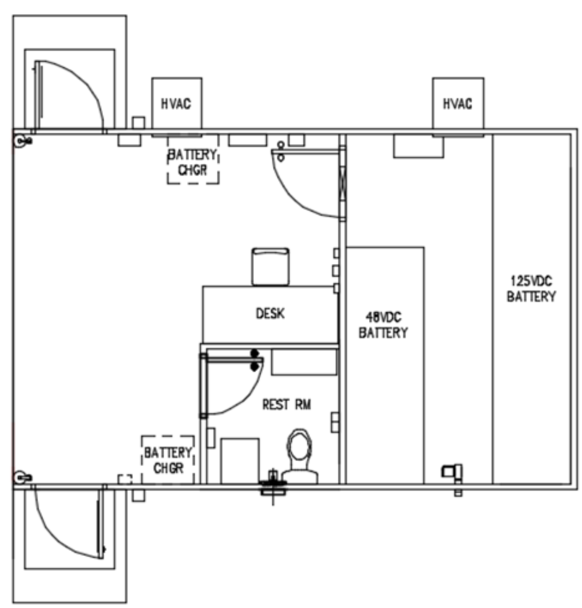

Figure 16 Command Module #1.

B. Command Module #2, contains the battery room, provisions for 1-battery charger, operator's desk, one access door, eye wash, DC distribution panels, AC distribution panel, and HVAC. This module is 16' and 20' long and shown in Figure 17.

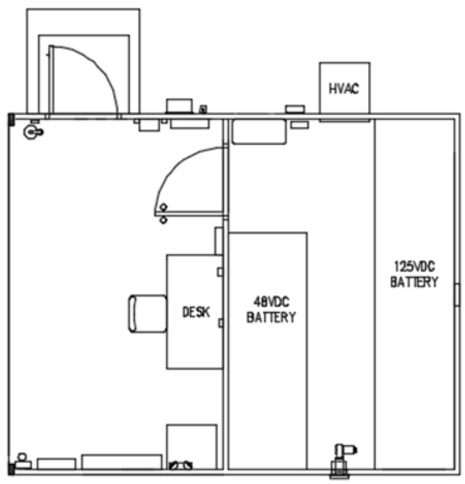

Figure 17 Command Module #2.

C. P&C Module #1 contains 20 protection & control racks with wall mounted terminal blocks, DC boards, and HVAC. This module is 16' wide and 26' long and shown in Figure 18.

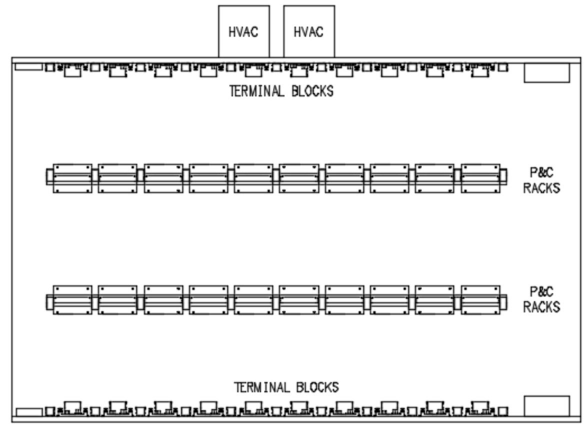

Figure 18 P&C Module #1.

D. P&C Module #2 contains 10 protection & control racks with wall mounted terminal blocks, DC boards, and HVAC. This module is 16' wide and 16' long and shown in Figure 19.

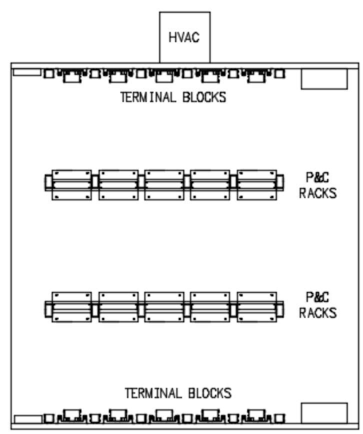

Figure 19 P&C Module #2.

E. Telecom Module #1 contains 21 telecommunication racks, cable trays, microwave entrances, HVAC, and AC distribution panel. This module is 16' wide and 25’ long and shown in Figure 20.

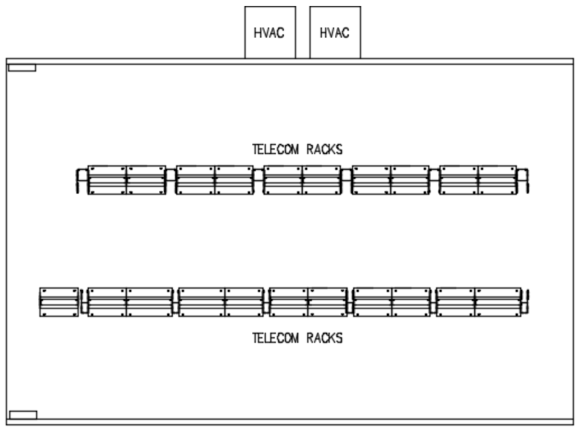

Figure 20 Telecom Module #1.

F. Telecom Module #2 contains 11 telecommunication racks, cable trays, microwave entrances, HVAC, and AC distribution panel. This module is 16’ wide and 15’ long and shown in Figure 21.

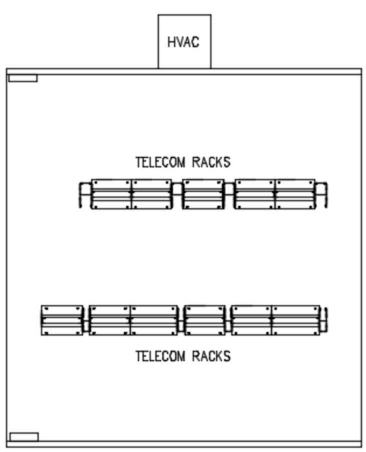

Figure 21 Telecom Module #2.

G. Combined P&C and Telecom Module contains six protection & control racks, eight telecom racks, DC distribution panel, cable trays, microwave entrances, and HVAC. This module is 16’ wide and 22’ long and shown in Figure 22.

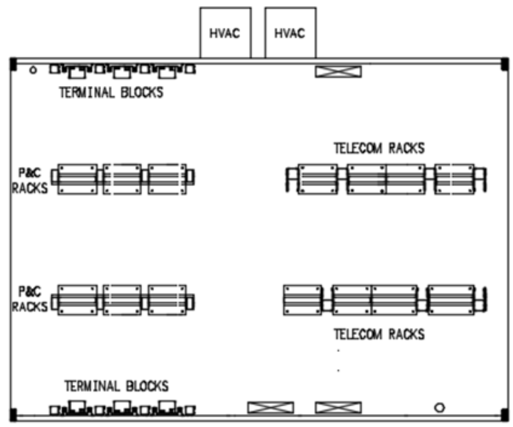

Figure 22 Combined P&C and Telecom Module.

H. End Cap Module contains one access door. This module is 16’ wide and 2’ long and shown in Figure 23.

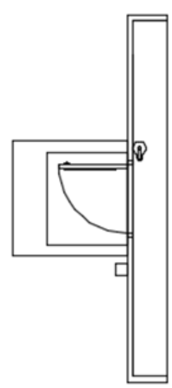

Figure 23 End Cap Module.

At the initial installation, TVA arranges the modules for each building in a standard order of:

• Command Module

• Telecom Module(s)

• P&C Module(S)

• End Cap Module

Modules are provided in the quantity as needed. Since the future growth of the modular control building is always away from the Command Module, space for future growth beyond the End Cap Module is always provided for additional modules if they are needed.

With this concept, TVA can assemble small control buildings such as shown in Figure 24.

Figure 24 Small control building at a substation consisting of a Command Module #2, a Combined P&C and Telecom Module, and an End Cap Module.

TVA can assemble medium sized control buildings such as shown in Figure 25.

Figure 25 Medium sized control building at a substation consisting of Command Module #1, one Telecom Module #1, one P&C Module #1, and an End Cap Module.

TVA can assemble large control buildings such as shown in Figure 26.

Figure 26 Large control building at a 161kV generating site consisting of Command Module #1, two Telecom Modules #1, four P&C Modules #1, and an End Cap Module.

X. The Rogue Module

TVA provides dual batteries and dual circuitry at many locations. With the modular control building design, no room is available for a second battery. To alleviate this problem, TVA designed a ninth module entitled the Rogue Module for the second battery. The term Rogue comes from the fact that this module is freestanding and does not architecturally connect to the main control building. This concept also provides the safety feature of physical separation of the second battery from the rest of the control building.

XI. Foundations for Control Building Modules

TVA places the control building modules on 24" diameter cylindrical concrete foundations that extend above grade by a few inches. In the top of each foundation, is an embedded plate to which the bottom of each module is welded. The cylindrical foundations are placed in drilled holes using round forms to extend the concrete above grade. This method of construction is simple, effective, and inexpensive. Refer to figure 27.

Figure 27 Control building during assembly showing foundations and cable trenches along the sides of the building. The Command Module with its temporary plywood wall is shown in the distance resting on its foundation.

XII. Cable Trenches at Control Buildings

To allow the control cables to enter the control building, a cable trench is placed along each side, and slightly under, the control building. A removable, galvanized metal frame is placed on the top of the trench to support trench covers that are approximately 4" narrower than the trench. The reduced cover width allows the cables to exit the top of the trench and be stubbed up inside the building as shown in Figure 28.

Figure 28 Cable trench showing removable metal frame to support covers. Note: Gutter downspouts will be provided with an extension over the cable trench when construction is complete.

XIII. Restroom Facilities

Restrooms at a substation can be quite expensive:

• Domestic, potable water may not be available at the site.

• Municipal sewer systems may not be available or accessible.

• The soil may not percolate.

• The local authority may not grant a septic permit.

Therefore, it may be advantageous to not provide a permanent restroom at every substation. It is expected that larger substations will require more people to maintain and will have more people at the site whereas smaller facilities will see much less traffic. TVA has developed two Command Modules to cover these options: one module with a restroom and one module without a restroom. To determine which stations receive a restroom, TVA adopted the following policy:

> Three transmission lines = a restroom

This generally means that if a substation is large enough to have three or more transmission lines terminated at the station, then a Command Module with a rest room will be provided.

When restroom facilities are provided, TVA equips them with elongated bowl toilets and deep-well utility sinks for the comfort and needs of the employees. A floor drain is also provided in case of leaks or a blocked toilet.

XIV. TVA's Wiring Shop

Like many utilities, TVA has assembled and wired protection & control cabinets in the field. Some of the more complicated cabinets required hundreds of hours to complete. Wiring cabinets was not easy work. Electricians were required to stand for many hours at a time while making higher terminations or be on their hands and knees while making terminations near the floor. When wiring cabinets in the field, the electricians were typically on travel status thereby adding to the overall labor rate. Consistency of quality was also problematic given the geographical size of TVA; different groups of electricians were wiring cabinets from one site to the next. To help alleviate these problems, TVA experimented by using a third party to assemble and wire the cabinets off-site. This method was piloted on several large stations, but was ultimately not successful at TVA.

Still looking to improve quality and reduce costs, TVA created a wiring shop where all racks and cabinets would be assembled and wired for the entire transmission system.

"Factory environment" are the words that describe TVA's wiring shop. TVA developed an automated design process that knows the origination and destination, wire size, length, wire color, type of lug needed, and the wire tag of every wire in the rack or cabinet. This information is fed into wire handling machines that automatically cut the wires to the correct length, strip the wires for the proper lugs, and print the wire tag information with the lug information along the length of the wire. TVA's electricians then lug the wires and wire the racks. To avoid the inconvenience of wiring racks vertically, TVA developed rotating support stands to allow all racks to be wired horizontally. This allows the electricians to work from a comfortable, seated position where all tools and supplies are handy and the rack can be rotated to any convenient angle.

To improve consistency, all apprentice electricians for the transmission system are routed through the wiring shop for four to six months where they gain experience in TVA wiring methods by wiring projects of increasing complexity.

The small, convenient sizes of the P&C and Telecom modules allows these modules to be shipped from the building vendor to TVA's wiring shop where TVA installs all the prewired racks and all rack-to-rack and module-to-module wiring and cabling.

Once the protection & control racks are placed in the P&C modules and terminated, TVA's Test Engineers install the relay settings on the relays and commission the equipment using stand-in breakers. This has the benefit that a small, consistent, dedicated staff commissions all new racks of equipment and can quickly identify and resolve problems.

When all equipment has been installed and tested in the P&C and Telecom modules at the wiring shop, the modules are shipped to the substation site for final assembly into the control building.

The modular design, the use of racks, and the wiring shop concept allowed TVA to greatly reduce the man-hours associated with wiring racks. Please refer to Figure 29.

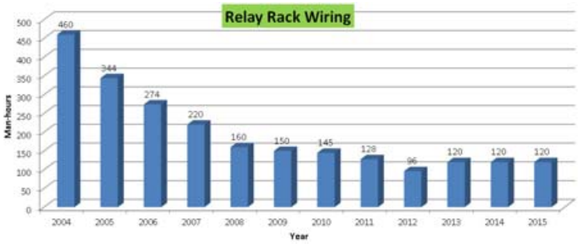

Figure 29 Graph of TVA's man-hours per rack from 2004 through 2015. TVA began using racks late in 2004.

XV. Conclusion

The modular control building design with the rack mounting system has greatly improved TVA. We moved the terminal blocks to the walls of the control building allowing us to retire the relay cabinet and U-shaped relay panels. We replaced these with commonly available telecommunications racks. Use of racks allowed us to minimize live terminals in close proximity with our personnel. Racks allowed TVA to increase working clearances "about" electrical equipment to 48" thereby exceeding the NESC requirements. With racks and a better utilization of floor space, TVA was able to create nine future-proof modules capable of meeting the control building needs at any site. Finally, with a standard, modular control building, TVA was able to reinvent our substation construction and testing processes to improve quality, reduce man-hours, and reduce costs.

Biography

Robert Frye is a Principle Electrical Engineer in the Substation Engineering, Protection & Control department at the Tennessee Valley Authority in Chattanooga, TN. He is responsible for standards and standard designs for protective relays and controls in the TVA transmission system and at hydro, fossil, and nuclear plants. Prior to his position in Protection & Control, he was a Specialist Engineer in the System Protection & Analysis department, he was a Project Manager over the Conservation Voltage Reduction program in the Demand Response Department, and he was a System Engineer at Watts Bar Nuclear Plant. Robert is a registered professional engineer in Tennessee, and he earned his B.S.E. degree from the University of Tennessee at Chattanooga. He was recently selected as TVA's Engineer of the Year for 2016 and a top ten finalist for the Federal Engineer of the Year for 2016. Robert is a member of the IEEE Power System Relaying and Control Committee. Robert is can be contacted at rmfrye@tva.gov