TRANSMISSION LINE HARDWARE DESIGN FOR LIVE-LINE MAINTENANCE

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ABSTRACT

The need for considering live-line maintenance techniques during the specification and design of transmission line conductor hardware is reviewed. Typical hardware designs and specific recommendations are presented that allow for efficient use of live-line maintenance techniques.

1.0 INTRODUCTION

The importance of transmission lines and interconnection systems continues to increase as a result of the industry wide trend to locate more efficient generation plants far from the load centers. The result of this remote generation is to place a greater demand on the reliability of these transmission lines. In addition, the higher voltages employed for these lines means that an outage for line maintenance could result in a large incremental energy replacement cost. In a recent survey (Ref. 1) of sixteen utilities throughout the United States, the average cost of a transmission line outage was calculated at over sixteen thousand dollars per hour. Fortunately, several techniques exist for maintaining transmission lines while they are energized.

Many utilities have the ability to perform bare hand maintenance on energized lines. In this method, a lineman is positioned at the hot end of an insulator string in order to facilitate placement of tools and removal of hardware. This method is fast and cost effective. However, this technique cannot always be used, if for example, a bucket truck were required but was unable to get onto the right-of-way. Worse yet, political pressure may prevent its use. For these reasons, utilities should not rely on this method alone, but should incorporate hot-stick maintenance methods into the design of their towers and line hardware.

In the past, some transmission lines have been designed and constructed before any thought was given to tools that would be required to maintain the energized line. When this happens, there are increased costs to the utility due to the design of special live-line tools, and also an increase in labor whenever the live-line methods are used. In addition, it increases the probability of an expensive line outage in order to repair the line.

With the emphasis in recent years on new insulation systems and new conductor bundle geometries, the need to design live-line maintenance methods into the hardware as well as the towers becomes even more critical. The purpose of this paper is to briefly describe how utilities can reduce their maintenance costs and improve the reliability of their transmission line systems by initially planning and designing for live-line maintenance considerations in the early stages of the transmission line hardware design (Ref. 2).

2.0 CONSIDERATIONS FOR LIVE-LINE MAINTENANCE

Several factors must be considered when planning the use of live-line maintenance procedures (Ref. 3). They include: structure type, climbing and working clearances, conductor and insulator hardware, and conductor loads. A brief review of each of these factors before proceeding to specific design examples is useful.

2.1 STRUCTURE TYPE

The structure type, whether it is a wood pole, lattice, tubular steel, concrete or other type, will dictate many things for maintenance crews. The first among these is accessability to climbing. Structure design also dictates how attachments will fit the structure. These attachments will be used to support ladders, booms and conductor support tools. Support for these tools becomes of paramount importance. By integrating maintenance aspects into the structure design there is an increase in safety and efficiency since maintenance becomes one of the basic considerations rather than an afterthought (Ref.4).

2.2 CLIMBING AND WORKING CLEARANCE

As the voltage is increased, so also is the electrical working clearance due to federal, state and utility regulations. With an increased working clearance, it is increasingly difficult for a lineman to perform very simple tasks with hot-stick tools, such as installing and removing cotter keys, clevis pins and tools that attach directly to the conductor hardware.

2.3 CONDUCTOR AND INSULATOR HARDWARE

Conductor hardware is probably the most important item when considering live-line maintenance. Special attention must be given to the hardware design and the interfaces between the hardware and the hot-stick tools used to support the conductor load while maintenance of insulator strings is accomplished.

The insulators must also be considered. For example, pin and clevis insulators are more difficult to disconnect and reconnect than ball and socket type insulators, the reason being that there are several more parts to handle and align. Fog type insulators can also prove to be difficult to handle due to inaccessibility of their parts. In addition, insulators of higher load ratings are generally much larger and heavier than lower rated units. This tends to increase the amount of difficulty in handling the insulators while connecting and disconnecting.

2.4 CONDUCTOR LOADS

The conductor size, weight per foot, span length, line angle and tension will quite often dictate the tools used for live-line maintenance. If the loads are light, single pole strain carriers may be utilized. Heavier loads may require the use of a two pole strain carrier. In each case, the conductor hardware must be designed to accept the appropriate tool.

3.0 DESIGN EXAMPLES

Special attention must be given to the conductor hardware specification and design in order to productively incorporate live-line maintenance techniques. This paper presents a number of typical design examples that have occurred. These examples will demonstrate the problems that can occur and the solutions to these problems that can be designed into the structure and hardware at the start of the job. These examples are not all inclusive; they are meant to stimulate thought and to show how initial planning can eliminate potential problems.

3.1 YOKE PLATE DESIGN

Maintenance holes, notches and rigging holes should be designed into the hardware yoke plates. A typical deadend hardware assembly without maintenance holes is shown in Figure 1. The single pole strain carrier yokes for this assembly must be designed to use the hardware clevis fittings as bearing points. This arrangement has the drawback of making it difficult to remove and reinstall the insulators since the clevis fittings have a tendency to rotate when they are loaded in this manner.

Figure 2 shows how the addition of maintenance holes provides precision of tool location for the single pole strain carrier without bearing on, or interfering with,

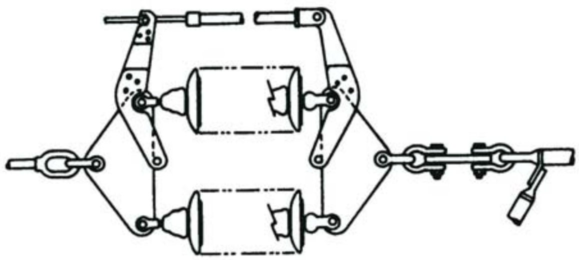

FIGURE 1

A typical deadend hardware assembly without provisions for live-line maintenance.

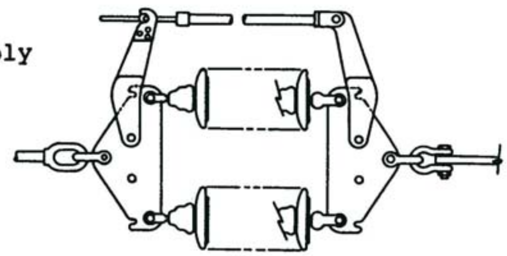

FIGURE 2

Improved hardware design with working holes and notches.

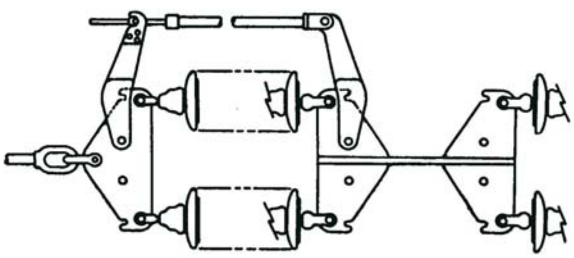

FIGURE 3

Plan view of a twin insulator tangent or angle assembly.

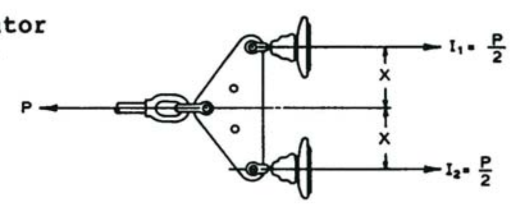

FIGURE 4

Typical division of conductor load "P" into a twin insulator string "I_1" and "I_2".

the hardware clevises of the assembly. By locating two working holes on either side of the hardware yoke, the same tool can be used on twin insulator string suspension assemblies requiring a welded suspension yoke as shown in Figure 3. In addition, the second working hole can be used to attach a second single pole strain carrier if both insulator strings are damaged. A minimum of a 7/8 inch diameter working hole is typically required.

The single pole strain carrier shown in Figures 2 and 3 uses the lever and fulcrum principle in order to relieve tension on the insulator string to be changed. By extending the strain carrier yoke arm, the load on the single pole is reduced. This transfers additional conductor load to the remaining insulator string. This is demonstrated in Figures 4 and 5. The addition of notches on the assemblies of Figures 2 and 3 also allows the use of a two pole strain carrier on these assemblies. Figure 6 shows that by using a two pole strain carrier, the load in the remaining insulator string is not increased.

The addition of notches on suspension yoke plates (shown in Figure 7) also facilitates the placement of a two pole strain carrier and prevents the hardware yokes from moving or slipping on the strain carrier yoke. Typical two pole strain carrier yokes are 5 inches wide and require a 1 inch wide and 1/2 inch deep, or a 3 inch wide and 1/2 inch deep, notch in the hardware for proper seating. Figure 8 shows minimum notch and working hole dimensions of a typical three conductor tangent yoke.

The addition of these holes and notches during the fabrication of these yoke plates adds very little to the initial cost of the hardware since all the holes are normally drilled simultaneously and notches can easily be added to flame cut templates. However, substantial savings can be realized due to more efficient hot-stick maintenance procedures. In addition, these notches and working holes also aid in the positive location of strain

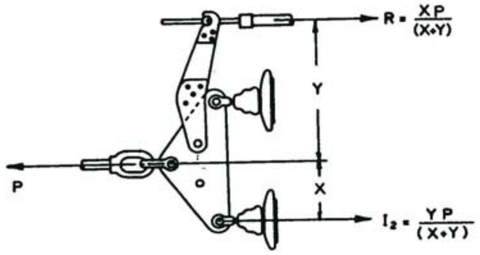

FIGURE 5

Division of conductor load "P" into a single pole strain carrier "R" and the remaining insulator string "I_2".

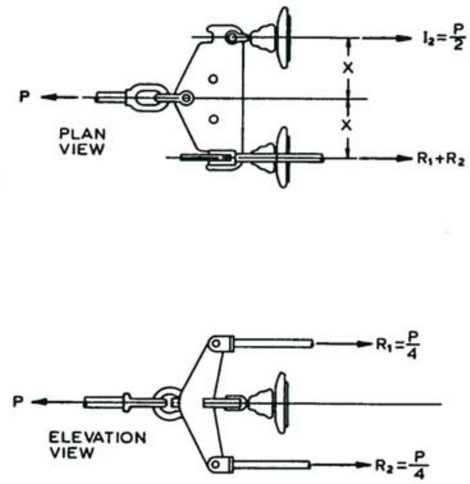

FIGURE 6

The use of a two pole strain carrier will not increase the load "I_2" in the remaining insulator string.

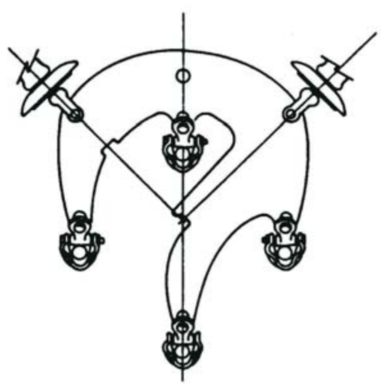

FIGURE 7

Notches and working holes can be added to almost any suspension or angle yoke plate.

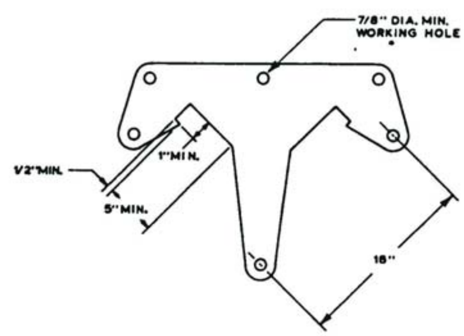

FIGURE 8

Minimum dimensions for working holes and minimum notch dimensions and clearances for a two pole strain carrier yoke.

carrier yokes when bare hand maintenance techniques are utilized, as shown in Figure 9.

3.2 STRUCTURE AND HOT-LINE LINK ATTACHMENTS

The typical arrangement shown in Figure 10 utilizing a steel strap to connect the ball-clevis to the tower shackles can lead to difficulty in positioning the hot-line tools. In this example, a two pole strain tower yoke must be attached to the steel angles of the tower since no additional tower working holes were provided. This does not result in positive tool location and can result in improper loading of the tower members.

A typical solution to the problem is shown in Figure 11. Working holes can and should be added to the tower; this would allow positive placement of a two pole strain carrier. In addition, a forged hot-line oval eye-ball fitting was added to the hardware. This would allow placement of the two pole strain yoke at the shoulder of the hot-line link. However, this arrangement can create problems on vee string assemblies. When the insulators are lowered by an insulator cradle, the first insulator may bind on the shank of the rigid ball fitting. This could result in damage to the insulator as well as the hardware.

An improvement over the arrangement shown in Figure 11 is shown in Figure 12. In this example, an additional hardware fitting is added in order to give good articulation below the hot-line shoulder on the oval eye-oval eye link as the insulator string is lowered in the cradle.

At the present time, there are no standards on the dimensions and location of these hot-line shoulders. Care must be taken not to specify a hot-line link that is too short to be fabricated or accommodate a two pole strain carrier yoke. A minimum length of 10 to 15 inches, depending on strength rating, must be allowed for hot-line

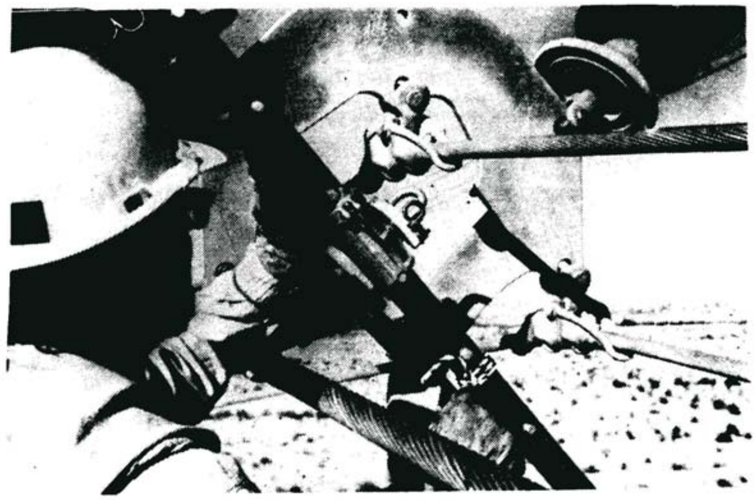

FIGURE 9

Notches and working holes are just as important in locating tools when bare hand maintenance techniques are used.

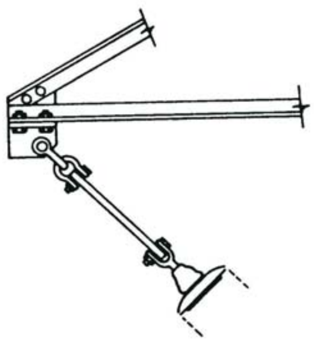

FIGURE 1Ø

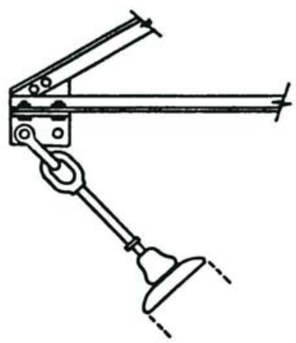

FIGURE 11

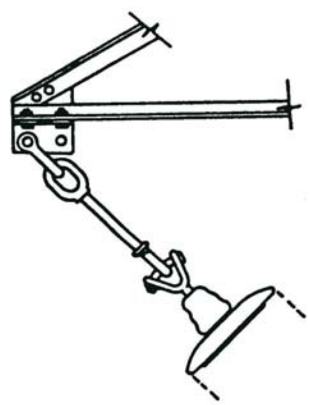

FIGURE 12

links that require independent forging operations on each end, such as the oval eye-oval eye link in Figure 12. If these hot-line links are used on the energized conductor hardware, corona rings may be required on the tangent conductor hardware of transmission lines operating at EHV voltages. These corona rings may adversely affect the live-line maintenance procedures, as will be discussed in section 3.4.

In addition to the tower working holes shown in Figures 11 and 12, tabs placed on the steel davit arms of steel or wood poles can be useful in locating live-line maintenance tools (Ref. 4). When the minimum vertical clearance of the conductors does not allow for the addition of hot-line links on each phase of a structure utilizing steel davit arms, a vertical tab with a working hole can be used to locate a standard steel arm yoke, as shown in Figure 13.

3.3 CLEVIS FITTINGS

Although most hot-line maintenance today involves disconnecting an insulator string at a ball-socket joint, there are several reasons why properly designed clevis and clevis pin hardware is important:

- In certain fog type insulators, reaching underneath the insulator skirts to remove or reinstall the cotter may be extremely difficult.

- In pin and clevis insulators used at EHV levels, the clevis pin attaching the insulator to the clevis fitting will be difficult to remove because of corona shielding; therefore, removal of the pin at the yoke plate is the only practical approach.

- The advent of polymer suspension insulators will result in more clevis type connections between the insulator and yoke plates.

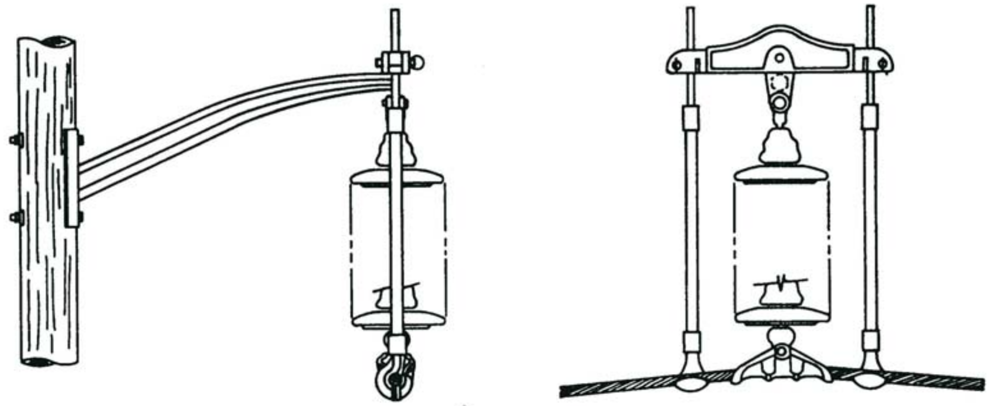

FIGURE 13

Special tabs on the end plates of steel davit arms can facilitate maintenance without sacrificing vertical clearance of the conductor.

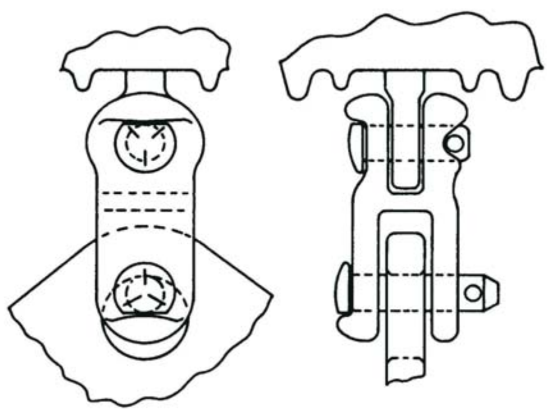

FIGURE 14

Figure 14 shows a properly designed EHV clevis-clevis attaching the last insulator in a suspension string to the yoke plate. Note that the bottom clevis pin has a generous chamfer to facilitate inserting the pin into the clevis body with a hot-stick. Note also that the hole in the yoke plate is oversized to enable simultaneous placement of the clevis pin through this fitting and the yoke.

In addition, the clevis pin has a trimmed head with the cut in the same direction as the cotter key hole in order to facilitate insertion of the humped cotter key. This trimmed head also helps prevent rotation of the clevis pin if the hardware is subjected to vibration.

3.4 CORONA RINGS

Corona rings become significant on higher voltage systems. Removal of a corona ring is difficult and time consuming. If the ring and associated hardware are designed to allow clearance for placement of the hot-line tools, then considerable time and effort can be saved.

Consideration should be given in the hardware specifications to define the size and shape of the maintenance tools to be used around the corona rings. With this information the corona ring can be designed to allow working an assembly hot without removing the ring. In addition to the dimensions around the corona ring, clearance should be allowed for fitting of the insulator cradle tool. Figure 15 shows a properly designed deadend assembly and corona ring that allow placement of the two pole strain carrier without removal of the corona ring. The dashed lines in Figure 15 show the potential interference problem between the corona ring and maintenance tools. Care must also be taken to design corona rings that do not hide working holes and notches.

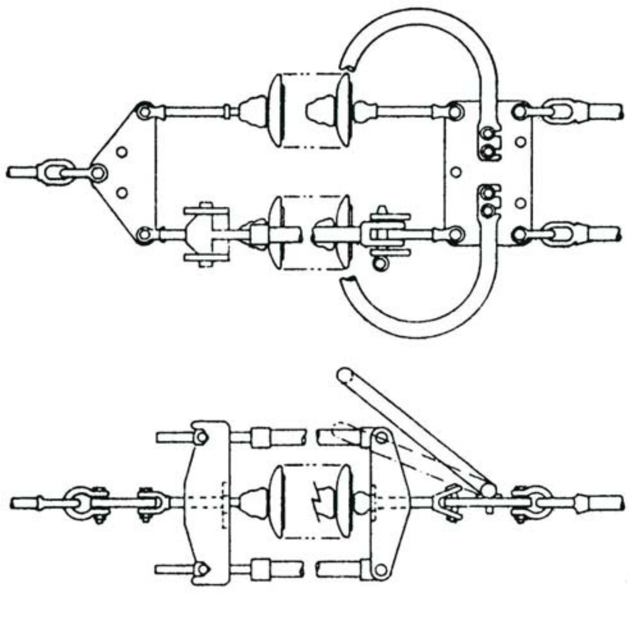

FIGURE 15

FIGURE 16

FIGURE 17

The design of this type of hardware and corona ring may result in a higher initial hardware cost; however, the additional labor to remove and replace corona rings may justify this cost.

3.5 HARDWARE ORIENTATION

With the advent of larger and more sophisticated conductor bundle geometries and shapes, care must be given to the orientation of the hardware with respect to the tower.

During the specification and design of conductor hardware, the pulling direction of cotter keys, clevis pins and socket cotter keys should be given. Two different socket-Y-clevises are shown in Figures 16 and 17. As can be seen from these photographs, the direction of cotter key pull is different with respect to the hardware. This may not be critical on a tangent structure, however, on a deadend structure this direction can be significant. Figure 18 shows the typical rigging required to position a lineman in order to pull a socket cotter key with a hot-stick. Rigging such as this is very time consuming and should be minimized for an efficient maintenance operation.

Another example is demonstrated in Figure 19, which shows a plan view of a bundle conductor deadend structure and the deadend hardware. The design and orientation of the hardware and conductor bundle resulted in the pulling direction of the socket cotters always to the left of the bundle. Unfortunately all hot-line maintenance had to be performed from the tower. As a result, the socket cotters on hardware assemblies 3 and 6 could only be reached with considerable difficulty.

Therefore, consideration must be given to the orientation of the hardware, otherwise maintenance can be very

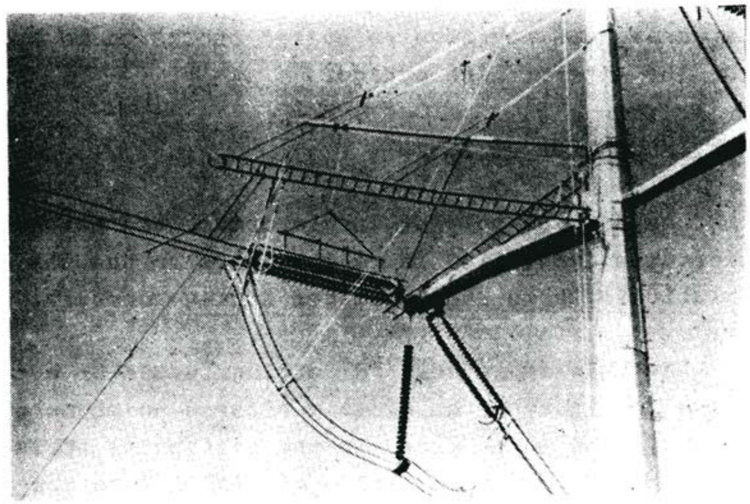

FIGURE 18

Typical rigging required to position a lineman in order to pull a socket cotter key with a hot-stick.

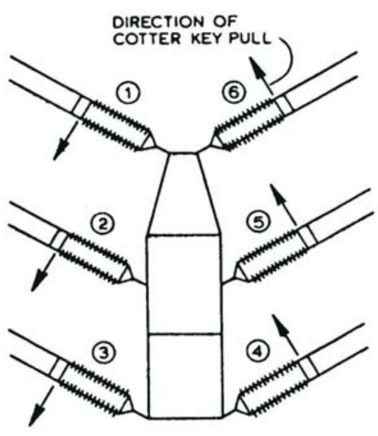

FIGURE 19

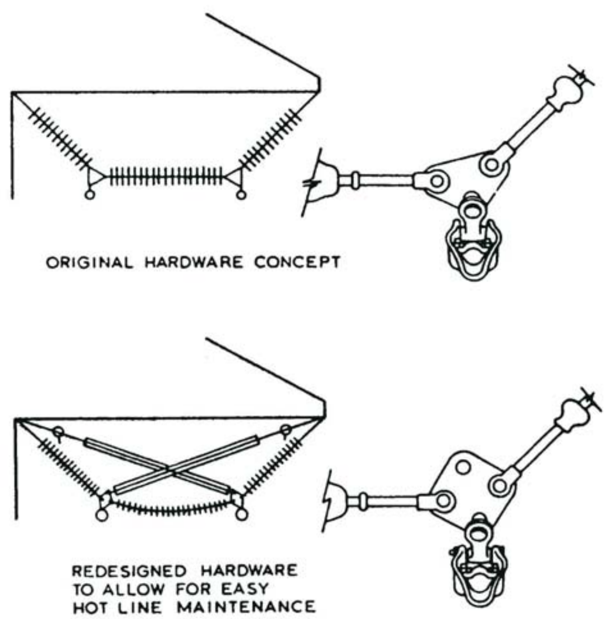

FIGURE 20

expensive and may require bucket trucks to be brought to the job site or line outages.

3.6 NEW INSULATION DESIGNS

Aside from polymer insulators, there has been considerable innovation in recent years in the design of insulation systems and insulator string geometry.

As an example, the "U"-string insulator arrangement shown in Figure 20 originally offered no means of performing hot-line maintenance on the horizontal string of insulators. By the addition of material to the yoke plate and a maintenance working hole on each yoke, the hot-line rigging arrangement shown in Figure 20 was made possible.

With new and high strength insulator systems being proposed along with compact transmission lines including multiphase transmission, careful pre-planning must be done to assure that these systems can be changed out while the line is still energized.

4.0 CONCLUSION

This brief coverage of a few specific examples is not meant to be complete. Rather, these examples are intended to show typical situations that could easily be overlooked in an EHV hardware specification or design that could later lead to increased costs for a utility.

It is important for both the operating and design engineers to plan live-line maintenance procedures prior to the specification of transmission line hardware. By incorporating adequate and cost effective maintenance procedures into the original design of the conductor hardware, the reliability of transmission systems will be increased. The potential for a costly line outage in order to changeout a damaged string of insulators can almost be eliminated.

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