SESSION PAPER 22-101
PARIS 2002

TRANSMISSION LINE EMERGENCY RESTORATION PHILOSOPHY AT LOS ANGELES DEPARTMENT OF WATER AND POWER

by

R. J. SCHWEINER K. E. TWOMEY
Los Angeles Department of Water and Power

K. E. LINDSEY*
Lindsey Manufacturing Co.

(United States)

INTRODUCTION

An essential question for any utility is whether to maintain their in-house emergency capability for line restoration or whether to depend on subcontractors and outside sources for this service.

Every utility should consciously address and decide which plan is the most realistic for their particular situation. In doing so a number of factors come into play such as: the size of the utility, the availability of subcontractors who can be depended upon during emergency, whether there are other utilities willing to enter into mutual assistance plans, and of course, cost-benefit of the plan.

This paper describes how the Los Angeles Department of Water and Power (LADWP) has chosen to maintain its in-house capability as the solution to this concern, including what they see as the critical success factors to maintaining their in-house capability.

Several incidents of overhead transmission line (OHTL) failures and emergency restorations are presented demonstrating these critical success factors.

KEYWORDS

Availability – Economic Loss – Emergency Restoration – Overhead Transmission Line

1.0 INTRODUCTION

The Los Angeles Department of Water and Power (LADWP) established at the beginning of the 20th century is the largest municipally owned utility in the United States. LADWP provides electricity to approximately 1.4 million electrical customers in a 1202-square-km area. Business and industry consume about 70 percent of the electricity in Los Angeles, but residences constitute the largest number of customers. In addition to serving these consumers, LADWP lights public streets and highways, powers the city's water system and sells wholesale electricity to other utilities.

LADWP supplies power from many sources, including its own hydroelectric and fossil-fueled generating stations and contracts for hydroelectric power from the Pacific Northwest. Coal is the largest single source of power supply in Los Angeles at 45 percent. Natural gas now supplies about 20 percent of the city's energy; hydroelectricity accounts for 12 percent; nuclear, 9 percent, and the remainder comes from purchased power, including biomass, solar and cogeneration. LADWP has a net dependable capacity of approximately 7000MW, and an annual peak demand of approximately 6000MW.

1.1 LADWP'S OVERHEAD TRANSMISSION GRID

The LADWP overhead transmission grid consists of approximately 8,800 circuit km of 115, 138 and 230kV transmission as well as both 500kV AC and DC transmission lines. The Bulk Power Business Unit of LADWP is responsible for all construction and maintenance of these lines. Of approximately 15,000 transmission structures maintained by LADWP, over 90% of them are steel lattice type structures. Much of the 8,800 circuit km of transmission is within the metropolitan Los Angeles area; however, the LADWP Bulk Power Business Unit also maintains 935km of 500kV DC transmission lines from Los Angeles to the Nevada-Oregon border and 772 km from Los Angeles

* P.O. BOX 877, AZUSA, CA 91702

to northern Utah. The major 230 and 500kV OHTLs maintained by LADWP outside their service territory are shown in figure 1.

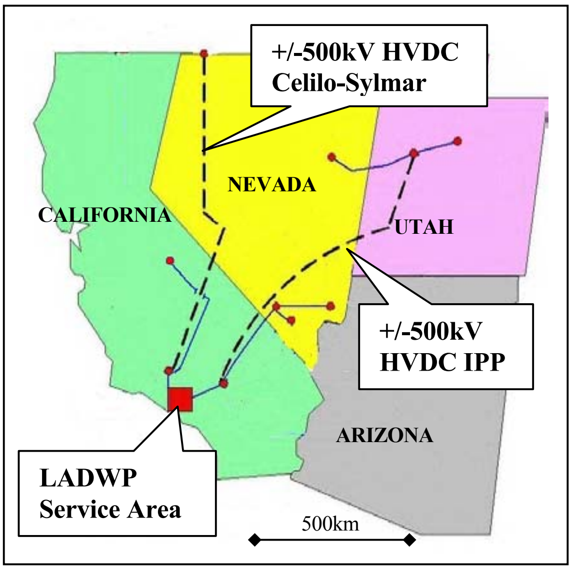

Figure 1
The service area and the 230 and 500kV OHTLs maintained by LADWP

1.2 ECONOMIC IMPACT OF A TRANSMISSION LINE FAILURE

In the current deregulated environment of California electrical energy production, the loss of a critical transmission line could be catastrophic.

LADWP currently has a typical peak native load of approximately 5,500 MW (these are customers that LADWP is committed to serve). LADWP has a peak generating capacity of approximately 7,000 MW. Of their large bulk 500kV AC and DC transmission system, the 500kV lines range in capacity from 1,800 to 3,100 MW. The loss of one of these lines could require purchasing 1,000 MW of power on the current deregulated market during peak hours. At the time of the writing of this paper, the current cost of electric energy on the summer spot market in California is approximately US$350/MW hour. The need to purchase 1,000 MW in this market to prevent outages could cost US$350,000/hour. In addition, the loss of any transmission line could prevent LADWP from selling excess power to the neighboring utilities and again force additional economic hardship on not only LADWP but other utilities as well.

In recent years, LADWP has experienced several failures of their critical transmission lines due to a variety of causes. In each of these cases LADWP has been able to respond quickly and effectively to restore these critical lines. The next section will discuss what LADWP believes are the critical success factors for this performance.

2.0 CRITICAL SUCCESS FACTORS FOR RAPID RESTORATION OF A DAMAGED TRANSMISSION LINE

2.1 MANAGEMENT SUPPORT

The Transmission Construction and Maintenance Organization (TC&M) reports to the Director of the Bulk Power Business Unit who in turn reports to the power system Assistant General Manager of the Los Angeles Department of Water and Power. The TC&M Organization is responsible for all maintenance, capital improvement jobs and emergency response when there is a transmission line failure.

LADWP management has decided to have the in-house line crews of TC&M perform capital improvement jobs as opposed to using subcontractors. Conventional wisdom views outside contractors as more economical than in-house crews. However, LADWP management has made a decision to stay with in-house transmission construction and maintenance crews. This management decision is one of the biggest success factors for rapid restoration of a damaged overhead transmission line (OHTL).

2.2 TRAINED IN-HOUSE PERSONNEL

The TC&M Organization consists of three superintendents that share overall management duties. One superintendent is responsible for fleet, secondary land use and purchasing coordination, the other two are field superintendents Under these two superintendents are eight (8) line foremen and two (2) labor supervisors. The line foremen direct 37 transmission patrolmen, 12 line maintenance assistants and two (2) heavy equipment operators. In the mid 1980s, the size of the transmission patrol staff was larger averaging approximately 80 transmission patrolmen. Over the years, this number has been reduced to its current number. All transmission patrolmen are journeymen linemen that were first trained in distribution work and then advanced to the transmission department.

Transmission patrolmen get approximately 80 to 100 hours of classroom and field training per year at TC&M's training facility (see figure 2). However, much of the training is on the job training, since TC&M crews perform capital improvement jobs, such as, transmission line modifications, fiber optic installations as well as normal maintenance including live line maintenance on all transmission lines voltages. The TC&M line crews can and do build towers and string conductor on a regular basis.

The 37 transmission patrolmen can work unsupervised because of their extensive training and experience. These transmission patrolmen can be dispatched from their home, which can save considerable time since the transmission patrolmen can proceed directly to a trouble site. Transmission patrolmen are normally rotated around the entire service territory of LADWP so that they are familiar with the entire service territory.

Figure 2
This LADWP training facility enables TC&M crews to train in all phases of construction and maintenance. Various DC, AC and temporary towers are erected.

One aspect of planning, crucial to the successful handling of an emergency, is communication between the various elements of the emergency response team. A "single point contact" concept is used during emergency situations to insure that all communication between each department is direct and that the responsibilities are clearly defined. Using this concept, a single individual within each department is assigned to handle all inter-company contact in any major functional area. In addition, once a task is assigned to an individual, it becomes the obligation of that individual through completion—thus establishing a clearly defined path of responsibility. This approach dramatically improved the efficiency of the inter-company communications, an area that, if not properly coordinated, can become a major problem in the hectic environment of an emergency situation.

2.3 CONSTRUCTION EQUIPMENT

One of the most critical aspect of emergency restoration is effective communication between all of the parties involved. One of the most important pieces of equipment is communications equipment. The foremen and supervisors have been equipped with new satellite phones to improve communication between field and TC&M headquarters where most of the materials and equipment are kept. The satellite phones take care of dead spots in LADWP's service territory that normal cell phones and low band radio are unable to serve.

Another major piece of equipment for emergency response is helicopters. LADWP has two Bell 206 Long Ranger helicopters that are primarily used by TC&M for: transportation of men and materials to remote job sites, staging materials in rough terrain, and as safety standbys for construction personnel at job sites. During transmission line emergency restoration, they are used to locate the damaged site and find the actual trouble location, weather permitting.

Because TC&M line crews do most of the capital improvement jobs at LADWP, they are very familiar with the equipment and tools that are available to them because they use them on a normal, daily basis. Without this normal use of the construction tools and equipment, some material might not be operable when required in emergencies. A free flow of ideas is encouraged from the transmission patrolmen and foremen on new tools and equipment. As a result, many new tools are developed for a particular type of work that is required by LADWP.

Some specialized construction equipment; such as winch trucks are strategically placed throughout the service territory. However during emergencies local equipment, such as backhoes and cranes, are typically rented from a variety of sources in Los Angeles and outlying areas. This equipment is readily available at this time.

Most important, specialized transmission line construction equipment such as: puller pilot winder, with steel pulling line, all wheel drive tri bundle bull wheel tensioners for both 2 and 3 bundle conductors (see figure 3) and fiber optic bull wheel tensioners for pulling overhead ground wire and fiber optic cable are maintained by TC&M since they are not readily available from other sources. This equipment must be maintained in good working order for effective emergency response. In addition, other specialized equipment suitable for various terrains found along the OHTL right-of-ways (such as: all terrain rubber track vehicles for working in snow conditions, and all wheel drive 2 ½ ton trucks with front winches) are also maintained by TC&M.

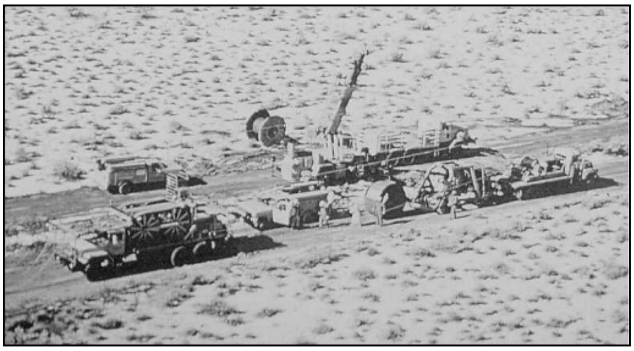

Figure 3
An all wheel drive tri bundle bull wheel tensioners for 2 bundle conductors is used to string 2312kcmil conductor during restoration of the DC Intertie.

2.4 EMERGENCY MATERIALS

In order to perform any unplanned emergency work, critical materials must be on hand and available. LADWP typically carries standardized wire sizes in appropriate quantities including all terminations and splices. For example, LADWP stocks over 30km of 2312kcmil ACSR Thrasher conductor which is a standard 500kV conductor.

Most of LADWP's 230kV transmission lines were built between the 1950s and 1960s. In performing normal maintenance or replacement during emergencies, it is almost impossible to replace the older hardware from this era; therefore, TC&M has standardized new hardware and insulator assemblies for the 115, 138 and 230kV voltage classes. This standardization has resulted in considerable savings in time and money for routine maintenance and for emergency restoration.

Since LADWP has a variety of different types of transmission towers, extra permanent tower steel for various types and classes of towers are stored close to the transmission lines where they will be needed. The majority of the transmission structures on the +/- 500kV HVDC Celilo-Sylmar (DC Intertie) transmission line are a guyed steel tower. Spare guyed steel towers are located at various yards along this transmission line. The majority of transmission towers for the 500kV DC Intermountain Power Project are heavy self-supporting steel towers and likewise these towers are located at yards along the transmission line right of way.

In addition to this permanent tower steel available, a quantity of light weight modular aluminum restoration structures (ERS) made in accordance with IEEE Standard 1070[1] are maintained at TC&M headquarters. These lightweight structures are used whenever permanent steel is not readily available. The polymer insulators for emergency restoration and the hardware and guying components are maintained in 20ft storage containers for security and for easy of transportation to job sites.

3.0 RECENT EXAMPLES OF OHTL EMERGENCY RESTORATION BY LADWP

3.1 GENERAL RESTORATION PROCEDURES

When an overhead transmission line failure occurs the first job is to find the trouble location. Weather permitting, helicopters are sent to find the trouble location and to report back. When the helicopter is sent, either a transmission patrolmen or a foreman from TC&M is sent along with the helicopter in order to report back.

The first priority is to ensure the safety of the general public and the workers at the jobsite and to prevent further damage and/or cascading of the transmission line. Transmission patrolmen are sent directly to the jobsite in order to ground any conductors and to start snubbing operations of the downed conductors. Snubbing equipment consists of a variety of anchoring equipment, winch trucks, conductor splices and grips. In addition preplanned layouts of conductor puller and tensioner sites are sent to the site so that the work can be started on placing anchors for the pullers and tensioners

Typically two foremen are sent to the jobsite to marshal equipment and to communicate back to TC&M headquarters. One foreman is responsible for mobilizing all required emergency materials to the trouble locations. The second foreman is responsible for mobilizing all equipment and other logistical support such as hotels, food and lodging for the TC&M crews.

Next, all necessary critical emergency materials such as conductors, splices, insulators, hardware and structures are mobilized. If sufficient permanent steel is not available or if there is foundation damage, the modular lightweight IEEE Standard 1070 ERS structures are brought to the jobsite along with the 20ft storage container containing all the polymer insulators, hardware and anchoring for these modular temporary structures.

After the line is stabilized and the area around the line is made safe for the general public and the workers, the next priority is to restore the line either permanently or temporarily considering the economic factors at that time. In today's economic environment, the fastest possible restoration scheme is usually the most desirable. At later dates during power plant maintenance, temporary towers can be taken down and permanent structures are rebuilt and the line restored to its original permanent condition.

Since the mid 1980's TC&M crews have had to restore several major OHTL failures. Most of these failures have been on the +/- 500kV HVDC Celilo-Sylmar (DC Intertie) transmission line. Other failures on 230kV transmission lines have been due to a variety of causes such as earthquakes and lightning strikes on wood poles. The next section will briefly discuss some of the failures on the DC Intertie and failures due to the 1994 Northridge earthquake.

3.2 FAILURES ON THE DC INTERTIE

Between 1984 and 1986 the DC Intertie was uprated with several of the guyed suspension towers raised 2.1 to 6.4m. This was done by adding mast sections and lengthening guy wires without moving guy footings. On three different occasions sabotage has brought down these guyed towers. But the most extensive failures began in January 1988 when sixteen guyed and one self supporting tower collapsed due to high winds and cascading. Both of these incidences have been discussed previously and will not be discussed here [2], [3].

In February 1989 eight more guyed and two self supporting towers collapsed again due to high winds and cascading. From 1990 to 1992 the DC Intertie line was upgraded by reguying, moving footings and replacing defective hardware. This upgrade has effectively prevented any further cascade type failures. However, isolated failures have still occurred. All of these failures were quickly restored by TC&M crews. The following is a brief summary of each failure and their restoration.

3.2.1 1989 STORM DAMAGE

At 1:20 p.m. on Saturday, February 4, 1989, high winds again damaged the DC Intertie. Eight guyed towers, one self-supporting angle and one self-supporting suspension tower were destroyed. The 2312 kcmil conductor and static wires in those 11 spans were too damaged to be reused, requiring the installation of approximately 16 km of 2312 kcmil conductor and 8 km of static wire.

The Owens Gorge transmission line encountered structural damage to six towers. The 954 kcmil conductor was down on seven spans and required replacement of approximately 5 km of 954 kcmil conductor. The damage to the Owens Gorge line was caused primarily by the falling of the DC Intertie structures and conductors.

TC&M personnel immediately activated their emergency response plan. After the initial single point contacts for the support functions were established, the Supervisors started the transporting of material and equipment to the soon-to-be established marshalling yard at Indian Wells. A remote command post was set up at Indian Wells to control: material and equipment delivered from Los Angeles; supply and personnel needs; lodging; meals; crew assignments; timekeeping; and progress logs.

By 3:30 p.m. on February 4, the available on-duty Transmission Section personnel in Valley, Victorville and Los Angeles were to report to TC&M for instruction. The Transmission personnel were into the first day of the scheduled days off, and approximately 50 percent of the transmission line series personnel were off shift. However, by 9:00 p.m. of that day, all Transmission off-duty supervisors were called out to travel and report to the Indian Wells damage site.

The major tasks were divided into two areas: the Owens Gorge line restoration and the DC Intertie restoration which included the assembling and erection of eight in-stock guyed suspension towers, as well as anchor installation, pad development, and erection of three IEEE Standard 1070 ERS structures to replace the two self-supporting towers.

The Owens Gorge- transmission line was “Okayed for service” on the evening of Sunday, February 11, and the DC Intertie on the following Thursday, February 16.

The permanent restoration of the DC Intertie was contingent on delivery of self-supporting tower steel, and the availability of DC Intertie. During the week of March 27, the northern crew transported the tower steel to the Indian Wells site and assembled the tower for erection, completing the restoration (see figure 4).

Figure 4
Permanent restoration of a self-supporting DC Intertie tower. The de-energized conductors are supported in the ERS, and the Owens line is shown at the right.

3.2.2 1995 STORM DAMAGE

On December 12, 1995, at 7:53 a.m., a guyed suspension tower of the DC Intertie collapsed under heavy wind. This tower had a height of 36m from the base to the crossarm elevation and was one of the towers that collapsed in 1988 as part of the wind cascade failure that took down seventeen other towers.

The tower was permanently replaced using spare guyed tower components stored in the Mojave Yard. Approximately 100m of subconductor were replaced, and the remaining conductor was repaired by sanding and adding sleeves. The replacement tower was assembled, erected, and secured by the night of December 13. On December 14, all other restoration work was completed, and the line was available for service by 4:00 p.m.

3.2.3 1998 AIRCRAFT COLLISION WITH TOWER

On September 20, 1998, at 4:38 p.m., a twin-engine Cessna sliced through conductors and hit and destroyed a self-supporting tower on the DC Intertie. The aircraft burst into flames along the right-of-way just 20m from a housing development.

LADWP crews immediately responded. They grounded and snubbed the conductor to prevent further damage (see figure 5), and a roadway under the line was barricaded for public safety. As a similar self-supporting tower was not available, LADWP crews installed a temporary IEEE Standard 1070 ERS structure. Due to the close proximity of residential houses, a steep down guy angle was required. This was quickly analyzed using the emergency restoration structure structural analysis computer programs.

Crews work around the clock using night lights. Conductor hardware and insulators were replaced on the adjacent tension tower and new conductor was spliced in and sagged. Spacers were installed and the line energized within 36 hours after the start of the outage.

Figure 5
Snubbing the twin bundle 2312kcmil conductor with conductor grips and a winch truck. Note the residential area to the left of the damaged tower.

3.3 THE 1994 NORTHRIDGE EARTHQUAKE.

At 4:31 a.m. on January 17, 1994, the 6.6 magnitude Northridge earthquake hit Los Angeles. For the first time in the history of LADWP the entire city of Los Angeles went black. Only one transmission line was operational. A four circuit 230kV transmission tower, that normally brings 1500MW of power from the Castaic pump storage generating station north of the city, was completely destroyed, and several other towers were severely damaged. It was vital to restore one circuit of this line to support the black start procedures for the fossil fuel generating stations. Adding to the difficulty was the damage to several roadways leading to the site.

Within eight hours after the earthquake, TC&M Crews were able to bring in a crane and assemble a vertical string of polymeric insulators and conductor travelers to lift one circuit and allow it to be energized (see figure6).

In order to support the load that was being brought back on line, two more circuits of this critical 230kV line needed to be restored. In order to accomplish this a special double circuit narrow right-of-way ERS structure made from the same IEEE Standard 1070 components was erected next to the energized circuit in the crane (see figure 6). By the morning of January 19, all three circuits were energized.

4.0 CONCLUSION

The ability to quickly react to any transmission line emergency at LADWP is due in large part to management's decision to maintain a skilled, trained in-house workforce and to provide them the necessary equipment and materials to perform the job. The responsibility given to the staff and crews of TC&M has promoted an esprit de corps in that organization which fosters cooperation among the personnel of the TC&M Group.

Granted, this type of capability will not be feasible for every utility. However, every utility and transmission line asset owner should address its own needs by a careful review of emergency service contracts, available emergency equipment and stocks of emergency materials, and most importantly their plans for dealing with emergency situations.

Figure 6
One circuit at the left is supported by the crane; two other circuits are supported by an IEEE Standard 1070 ERS.

5.0 REFERENCES

[1] IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components, IEEE Std 1070-1995, ISBN 1-55937-592-2.

[2] J. C. Pohlman, K. E. Lindsey, L. N. Agrawal, A. K. Kapur, Practical Steps for Increasing Availability of Existing Overhead Lines, (CIGRE Paper 22-105, Paris 2000).

[3] S. A. Rutty, et. al., "Planning Ahead Proves Invaluable to the Rapid Restoration of the Pacific DC Intertie and Owens Gorge Transmission Lines", (11th IEEE/PES Transmission and Distribution Conference, New Orleans, Louisiana, April 2-7, 1989).