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Electrical distribution system for the Cantera Península Community (Santa Elena and Condadito Final sectors)

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Abstract

The primary objective of this project is improving the quality of life of the Península de Cantera residents. Our collaboration in this improvement deals with infrastructure, specifically with the electric power service. For this project, we followed the proposed goals of the Integral Development Plan for the Cantera Península community.

Our design and study covers the area of electric power distribution, which embodies all the equipment beginning at the point of connection to a primary feeder (13,200 volts) and ending at the customers' service points. To minimize costs, whenever possible, we used existing equipment. This work has been divided into three main phases:

- Analysis of the actual conditions of the existing electrical distribution system.
- Short term recommendations.
- Design of a new distribution system for long term implementation.

Sinopsis

Sistema de distribución eléctrica para la comunidad de la Península de Cantera (Sectores de Santa Elena y Condadito Final)

Este proyecto de diseño se realizó para mejorar la calidad de vida de los residentes de la Península de Cantera. Nuestra colaboración a esta mejora es en el aspecto de infraestructura, específicamente en el servicio de energía eléctrica. Para el diseño nos regimos por las metas que propone el Plan de Desarrollo Integral de la Península de Cantera.

Nuestro estudio y diseño cubrió la distribución eléctrica, lo cual comprende desde el punto de conexión de voltaje primario (13,200 voltios) hasta el punto de conexión de los abonados. El diseño contempla usar al máximo el equipo existente para bajar cuanto sea posible los costos del proyecto.

Este trabajo se ha dividido en tres fases principales:

- Análisis de las condiciones actuales del sistema de distribución eléctrica.

- Recomendaciones a corto plazo.
- Diseño de un nuevo sistema de distribución para implantarlo a largo plazo.

Introduction

In November 1994, students registered in the Capstone Design Course for Power System Engineering received the assignment of developing a design to improve the electrical distribution system of the area known as Península de Cantera. This project is part of the Polytechnic University's participation in the Península de Cantera project. The electrical distribution system was divided into three sectors which were assigned to three different Capstone Design groups.

The Península de Cantera project is a combined effort made by private industry, government agencies and residents. The activities include the refinement of the substructure, housing and recreational facilities to aid in the success of the social and economic objectives described in the plan.

The Polytechnic University of Puerto Rico joins this project by assignment of students from the electrical and civil engineering capstone design courses. These students should develop studies and submit design proposals. Those proposals should adjust to the proposed objectives by the Cantera Integral Development Plan ("Plan de Desarrollo Integral de la Península de Cantera").

The problem in this area is the lack of planning and maintenance of infrastructure and other social and economic conditions. The actual electrical system of this locality is based on improvisation. Failure to observe the minimum safety requirements of the Puerto Rico Electric Power Authority (PREPA) has turned the actual electrical system into an unsafe one. It is mostly composed of insecure, overloaded and deteriorated equipment. House construction without the proper permits has also caused another problem. The right-of-way of distribution lines has been clearly violated, to the extent that transformers and primary lines are only inches away from some of the the houses, which are mostly wooden. Another critical problem in the area is the proliferation of criminal activity aggravated by a poor lighting system.

Our work takes into consideration such aspects to design and improve the electrical system. Our design must also meet the requirements of the regulating agencies, such as PREPA, the National Electrical Code (NEC) and the National Electrical Safety Code (NESC).

Procedures

A. Analysis of the electrical system's present conditions

To study in depth the present conditions of the electrical system in our assigned area, we had to generate drawings of the existing equipment with a full description of how they were built. Field inspections were needed to generate these drawings. A description of how this process was carried out follows.

1. Field data gathering

For this activity, we inspected all the poles in the area to learn about their general conditions (bent, rotten, etc.). An identification number was assigned to each pole for its location in our drawings. The pole inspections consisted of verifying all of the wiring, including primary (4.16kV, 13.2kV, and others), secondary (120/240V), and telephone cables. Low wire clearances or live parts were annotated. All these data were recorded on forms prepared to speed up the process.

We also verified whether the poles had lighting fixtures and whether they were in working condition. In addition to verifying whether the poles had transformers, we also checked which dwellings were served from each transformer. This was done by tracing all the secondary lines coming out of the transformer, which was a difficult process, due to the entangled connections found.

This way, however, we could illustrate on the drawings the dwellings served by a specific transformer; thus the suggested procedures for new transformers, lighting fixtures or any other equipment would be simplified. This type of inspection also helped us in the drafting of the actual path for the primary line.

When this procedure was completed, we had in our hands an inventory of practically every piece of equipment in the present electrical system.

2. Calculation of the loads for the study

Knowing how many dwelling units were connected to each transformer, we then had to check whether the transformer was overloaded. This involved the calculation of the power consumption of all the houses connected to each transformer. In some cases, it was clear that a transformer was severely overloaded because of the high number of homes connected to it.

To develop these calculations we verified the following:

a. Assumption of a typical house load.

To verify transformer loading in terms of power consumption, we assumed a load for an average house. We assumed that each of the dwellings had the following electrical equipment:

- Lighting and miscellaneous equipment.
- A refrigerator
- Electric range (in 40% of dwellings)
- A water heater
- A small air conditioner

Calculating the load of a house with this equipment, on the basis of the National Electrical Code (NEC), and then multiplying this load by the number of houses connected to the transformer does not give an accurate approximation of the real load on the transformer. This is so because the load calculation listed on the NEC is made to select the appropriate feeder conductor and service equipment for a dwelling unit. This is not the real power that the house will consume because all the equipment will not be used simultaneously. In addition to this, the average power consumed per house is even lower because the houses do not have the same equipment operating concurrently either. This concept is known as load diversity. Thus, the best way to approximate the average load of a dwelling at the transformer level is by performing a diversified demand study.

To perform the diversified demand study, we used a special graph of maximum demand characteristics for various residential loads. In this graph, the Y axis represents the average maximum diversified demand in kilowatts per house [kW/load]. The X axis represents the number of loads or houses connected to the transformer. The corresponding demands of each piece of equipment are then added, a total which gives the average demand per house. A correction was made when approximating the air conditioning load, since the air conditioning load listed on the graph was a central 4-ton unit, and what we assumed was a small room air conditioner.

After carrying out this procedure for each transformer, we found out that the average power consumption per house was 3 kVA. This average load might be lower, since about 60 percent of the dwellings have gas ranges and 110V service, which reduces the average load to half the load of a house equipped with an electric range (1.5 kVA).

b. Load per transformer summary

In this procedure the load connected to each transformer was studied. We compared the capacity of the transformer with its connected demand, which consists of the residential and street lighting load. A load larger than the stated capacity of the transformer indicates an overload condition.

c. Addition of the total load

This consists of a calculation of the total power that the existing three-phase feeder is supplying to the area. With this calculation we wanted to check whether any line, primary or secondary, was overloaded.

B. Short term recommendations

We identified the equipment required to correct the problems found in the preceding activity on a short term basis. This included transformers, secondary lines, lighting, and poles that were identified as overloaded or in poor conditions. Suggestions for installing lighting fixtures in places where they were needed were also listed. A sample sheet of recommendations is included in Appendix 1.

C. Design of new distribution system

A design of a new electrical power system was necessary after evaluating the serious problems in the area. We decided to develop a radial type distribution system because of its simplicity and economy (Appendix 2). This is the standard distribution system employed by PREPA for residential loads. Other types of distribution systems, such as the loop type and the primary network type, provide a much higher system reliability, but at the expense of increased costs due to the extra equipment needed (additional wire, poles, fuses and switching units would have to be used along with the equipment already needed for the installation of the radial type system). Besides, these systems are used in areas where continuity of service is important, for example, in hospitals and military installations.

As required by PREPA, all new or reconstructed distribution systems shall be configured in a wye connection with a common neutral. This system is called a common neutral system because the neutral conductors are shared in the primary and secondary of each distribution transformer. Our design was based on this distribution configuration.

The first step in the process of designing the new distribution system was studying the available alternatives, which were underground distribution and overhead distribution. For overhead distribution, there are two possibilities:

to follow the path of the present distribution line or to span the lines through the community boundary with the Caño Martín Peña. In this area, a recreational bikeway is being proposed by residents.

1. Underground distribution

Having the three-phase feeders and one-phase laterals running underground, the aesthetics of the area would be greatly improved. However, though underground distribution systems are considered safer than aerial distribution systems, the construction of underground distribution in areas where flooding is possible might pose several safety hazards on residents. For example, if a flood occurs, distribution transformers, being pad mounted, would be possibly submerged in water, causing dangerous situations. In addition to the safety factor, continuity of service would be adversely affected. Also, material costs, as well as labor costs, are much higher when constructing underground systems. We found out that underground construction costs were twice as much as overhead construction costs per mile of distribution feeder. The reason for this is the high cost of underground electrical equipment and the extra man-hours needed for the construction. In a flood prone area or in damp terrain, the costs are even higher. Investment on water pumping equipment for the excavation of utility trenches is necessary when working on under these conditions.

2. Aerial distribution

Distribution through the Paseo Lineal

Advantages

The aerial distribution through the Paseo Lineal provides better right-of-way compliance and improved aesthetics inside the neighborhood. With the relocation of residents living near the Caño Martín Peña, there is enough space for the location of utility poles throughout the path of the Paseo Lineal with enough width to comply with PREPA's minimum right-of-way of 10 feet.

All the wiring would be out of sight from the neighborhood streets.

Disadvantages

The type of terrain near the proposed Paseo Lineal is mainly packed-fill, which is not suitable for the installation of concrete poles. This would make necessary the use of more expensive types of mounting bases for the poles to withstand 150-mile-per-hour winds, as required by PREPA.

Wires spanning through the proposed Paseo would affect the aesthetic quality of this project.

The construction of the new distribution system through this area would be delayed because the construction of the Paseo Lineal is scheduled for the third stage of improvements as stated in the Integral Development Plan.

Three-phase feeders and one-phase laterals would have to be longer, increasing the overall costs of the project.

Distribution based on the existing path

Advantages

The wires would be running through almost the same path with minimum changes, making it possible to carry out a faster transition process from the existing 4.16 kV level to the proposed 13.2 kV level (fewer man-hours would be spent on the process).

Equipment already in use, such as wooden poles, would be better used and taken advantage of.

Using the present path as a base for the new system, fewer one-phase laterals are needed, and the ones needed would be shorter. We would take advantage of the path to the maximum in this manner for installing distribution transformers.

The advantages stated above would reduce the overall costs of the project. Although these savings cannot be calculated with precision, we can estimate a substantial economy on the man-hours required to complete the construction of the system. The reason for this is that in this manner, tasks that take considerable time and money, such as the displacement of transformers and service conductors to other locations, would not be necessary.

Disadvantages:

There are places where there would be problems with the line right-of-way. A special permission by PREPA would have to be granted, provided that a special kind of wire insulation is used. This type of permission is given by PREPA where compliance with the right-of-way is not possible. In the Old San Juan area, for example, this permission was granted.

On the basis of these alternatives, we decided to use the path of the present primary line for our design. Several modifications are required to comply as much as possible with the right-of-way.

The three-phase main feeder was carefully routed in a way such that it could be near the residential load centers. This way, we had to use fewer one-phase laterals. Where one-phase laterals were needed, they were kept as short as possible, with enough length to reach the distribution transformers. On the other hand, primary lines were also routed so they would span through the main streets (for example, Santa Elena street), in order to comply with the right-of-way, keeping the line on one side of the street and avoiding street crossings. This was a PREPA recommendation to simplify right of way compliance. In some line sections, however, this could not be done because of space limitations. To comply with the right-of-way we were forced to trace the line on both sides of the street.

Shielded wire was used for the single phase laterals so PREPA could grant the special permission to locate the laterals where rights-of-way compliance is not possible. This type of insulation was also selected as a safety measure for the residents.

After the proper transformer for each load area was selected, we proceeded to specify in which of the three phases the transformer would be connected. Since most of the transformers were connected to the single phase laterals, we added the total capacities of the transformers connected to each lateral and used this total to carry out the balancing. The balancing was completed according to PREPA standards.

Poles

As specified, concrete poles shall be used where possible. So we decided to use concrete poles for every section of the three-phase primary line. These poles were selected high enough to accommodate other services such as telephone, cable TV and lighting. Since there are many two-story dwellings in our area, we had to use 50-ft poles. With this pole height it is possible to comply with the minimum vertical clearances required by the NEC and PREPA. A uniform spacing for primary line poles was kept as much as possible to provide good lighting quality for long streets such as Santa Elena street and the proposed new avenue. Pole guy wires are subject to field inspection of the area surrounding the pole installation location.

Distribution transformers

The selection of proper transformers to serve the load demands of the area was one of the key steps in the improvement process of this design project. On the basis fn our analysis of the present conditions, we selected transformers of various ratings, but mainly of 37.5 and 50 kVA capacities. Some units of 75 kVA were used where it was absolutely necessary because of space limitations. Transformers smaller than 75 kVA were selected to guarantee that, in the event of a transformer failure, fewer consumers be affected.

To keep the voltage drops of the secondary lines to a minimum, the transformers were placed as near as possible to conglomerated dwelling units, but bearing in mind the clearances required by the NESC. The location of poles depended mainly on the voltage drop studies made for different wires. Transformers could not be placed farther than these maximum calculated distances.

The selected PREPA standard for transformer installation on a concrete pole is standard No. T-1. For the standard to be adequate for our distribution system, the primary fuse holder must have a 15 kV voltage rating.

With our load estimate for individual houses of 3 kVA, we determined the maximum number of houses that can be connected to a transformer, depending on its capacity.

Secondary lines and equipment

To select the necessary secondary equipment, the work team opted from three alternatives:

- Add new equipment.
- Replace a defective piece of equipment with a new item having the same specifications.
- Use equipment already in use.

Secondary line selection was based on voltage drop studies, in which the maximum wire length for different wire gauges were determined. The maximum distances for wires based on transformer full load capacities and selected wire gauges (#2/0 ACSR) were calculated by assuming a unity power factor.

All secondary wiring was selected to be triplexed with cross-linked polyethylene (XLP) insulation, because of its safety and aesthetic attractiveness compared to separate wires. Where applicable, PREPA standards K-1, K-2, K-4, K-5, K-6, K-7, and K-7-1 for secondary triplex wiring must be used. These standards are given as a guide, since the reconstruction of dwelling units and their future locations are not known. However, a suggested secondary line path was prepared and estimated in the project's budget.

To maintain the cost to a minimum, we recommend using existing wooden poles still in good condition for the distribution at low voltage levels (120/240 V). These could be used for secondary lines and lighting only. The wooden poles replaced should be replaced with concrete poles, H-3 type, 45 ft tall. This is to follow PREPA's trend of avoiding the use of wooden poles. As with the primary line poles, the height of the pole was selected to meet with the vertical clearances required and to provide space for lighting, telephone and cable TV wires. Wooden poles type 35-foot KC-9 were specified where concrete poles could not be installed.

Lighting

One of the important aspects of this design project was based on providing a safe environment for the residents of Península de Cantera. It is for this reason that we have paid special attention to this matter. Our design is the result of a thorough study to provide the best possible lighting system for a minimum cost.

Satisfying the residents' needs and taking into consideration the requirements of the "Autoridad de Carreteras," we decided to select from one of two alternatives.

To illuminate the streets and avenues with the standard high pressure sodium luminaries, using the existing lighting system as a base. Where the illumination level was under the accepted lighting parameters, or where the lack of lighting was reported by the residents, more lighting fixtures of the Cobra II type would be used.

- To use a special solar-and battery-powered lighting system, which has been successfully implemented in some sectors of the United States. In this case, the initial costs were not economically justifiable because one of the most important constraints of our project was the economic factor.

On the basis of these alternatives, we decided to use the standard lighting system, which has a practical and economic advantage over the solar powered lighting system. First, cost of the materials for the standard system was considerably lower than that of the solar-powered system. The latter includes in each of the luminaries a solar cell, which is still expensive, even after being widely used for numerous applications during recent years.

Appendix 1

Table

Pole Id.	Bent	Rotten	Triplex wiring required	Lighting
SE-P-125				
SE-P-126				
SE-P-127				
SE-P-128				
SE-P-131				NW
SE-P-132				
SE-P-134				
SE-P-135	X			

Legend

NW = Not working
REQ = Required

1. Vegetation is covering electrical equipment and should be trimmed.
2. Structures present under the pole.
3. Low clearance.
4. Anchors holding the pole are loose.
5. Relocation of the pole is necessary.
6. A pole was replaced by a new one, but the old pole has not been removed or cut.

Appendix 2

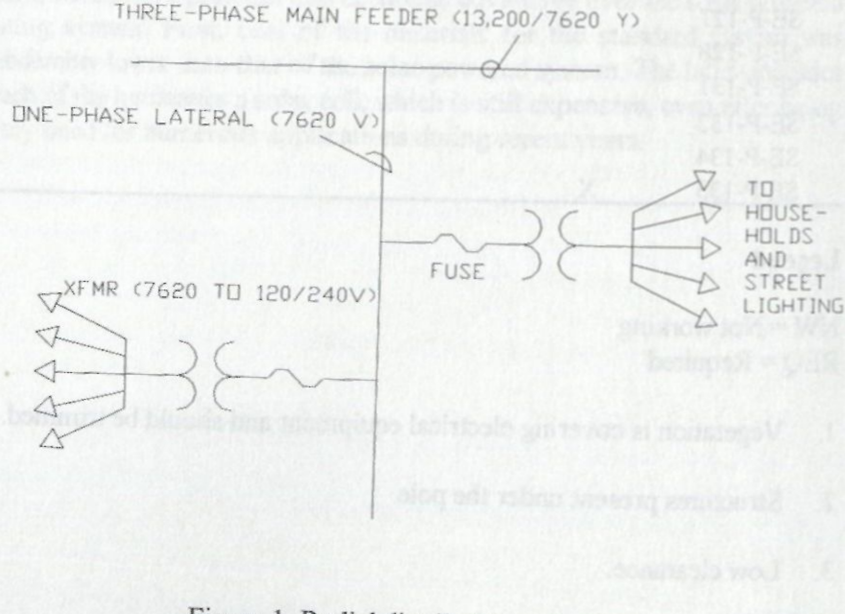

Figure 1. Radial distribution system