Lehigh Navigation Coal Company

Electrical System

A turn of the Twentieth Century Mini-Grid

by Jim Stone, PE

Foreword

The Lehigh Navigation Coal Company's (LNC) electrical system was a large, robust, 25 cycle, mini-grid that served high horsepower motor loads. LNC's mini-grid was powered from a single, multi-unit, generating station because adjoining electric utilities operated 60 cycle systems. Delivery points were spread over an area that included Bethlehem, almost 50 miles to the south. The result was a complex microgrid that required significant planning, design, and operating support. LNC's 25 cycle overhead powerlines crisscrossed the Panther Valley from Tamaqua to Nesquehoning.

The LNC's main incoming station was the Hauto Navigation Substation, located due south of the Hauto Power Plant on Route 54. The main source of fuel for the plant was locally mined anthracite coal. The Hauto Navigation Substation had circuit breakers protecting both incoming source lines and outgoing load lines. The nominal voltage was 11 kV, the same voltage used to distribute power throughout the mini-grid.

At its peak, the mini-grid stretched from the Hauto Valley to the Nesquehoning Colliery, to Black Rock Fan House and the Summit Hill Strippings, to fan houses on Sharp Mountain as well as the Number 14 Colliery. It then looped back toward Coaldale, back over the mountain and to the Hauto Valley. From its single point of service, the LNC mini-grid served five coal mines and support facilities. At peak production, maximum load was about 40,000 horsepower.

The LNC electrical system is a historical example of a mini-grid that existed before today's integrated power grid was developed.

1905

During its heyday, the LNC was the largest mini-grid in eastern Pennsylvania. The first venture of the LNC into the power business was in 1905 when a power station was constructed at Lansford, PA. The generating equipment included direct current generators used to furnish power to a local trolley system, and quarter phase alternators to supply surrounding towns with power for lighting, etc. The AC generators were a 700 KVA, 2300 volt, 25 cycle, 3 phase unit and a 400 KVA, 2300 volt, 25 cycle, 3 phase unit.

In 1912, LNC started construction of the Hauto Power Station and placed it in commercial operation in 1914. With an initial capacity that consisted of three 10,000 KW, 25 cycle, 11 kV generators, the mini-grid was expanded to include the cement mills in the Lehigh Valley and the Bethlehem Steel Plant in Bethlehem, PA.

1917

Capacity expansion set the stage for the LNC to become a major producer as well as a consumer of electric energy. In 1917, the LNC sold shares of stock in the power plant. Eventually, LNC's power plant and supporting electrical system became Pennsylvania Power and Light Company (PP&L). At this time, LNC included a power factor and a demand clause in power contracts. The demand interval was based on hourly usage.

LNC utilized synchronous motors at mines to mitigate the power factor clause and to improve voltage at their mines. At the Lansford Colliery, two 650 HP compressors were used with one idling as a synchronous condenser to improve power factor. A 660 KVA capacitor at Alliance Colliery and a 600 KVA capacitor at Cranbury Colliery were paid for in less than two years due to the reduced power factor penalty.

A single line diagram of the main feeders from the Hauto Navigation Station to the major colliery loads is illustrated in Figure 1. This shows simplified routing of the power lines to colliery substations. Electrical power was generated at the Hauto Power Plant for use by the coal company and other customers. The one line diagram only shows the major colliery locations and does not shown radial lines from colliery substations to mine ventilation fans and other remote loads. Also, this one line does not show circuit breakers, transformers and major loads but merely shows lines routes. The lines were designated Hauto – Tamaqua #1, Hauto – Tamaqua #2, etc.

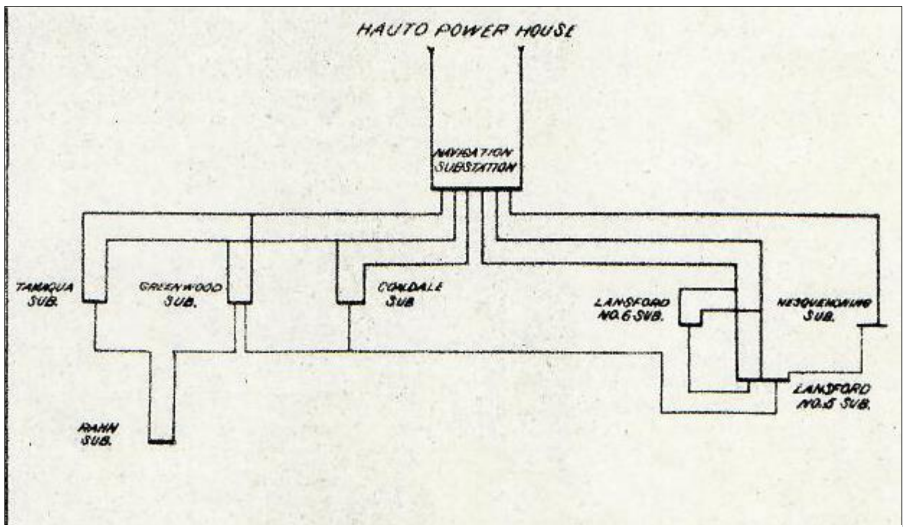

Figure 1: LNC 11,000-volt distribution system single line diagram.

1930

Growth of electric power usage was rapid and by 1930 the company had 17 miles of two circuit, three phase, 11 kV transmission lines and 23 miles of one circuit, three phase, 11 kV transmission lines. Substations located at collieries were housed in buildings constructed of brick or formed concrete. Each substation building housed switchgear type circuit breakers, main step-down transformers (11 kV/2.3 kV), and major loads such as the supply for mine hoists, DC supply for underground haulage and main air compressors for drills inside mines (Figures 2, 3 and 4).

Substations and Major Electrical Equipment

Overhead line conductors were 4/0 stranded copper supported on steel towers with through wall bushings at substations. Incoming and outgoing substation terminations included a set of lightning arrestors and a set of choke coils to minimize the probability of lightning surges traveling into building and damaging equipment. 11 kV circuits inside the building consisted of open air bus work supported on porcelain insulators.

Figure 2: Exterior of the Hauto Navigation Substation looking south. Two incoming overhead feeders from the Hauto Power Plant are on either end. The Hauto Power Plant was to the north of this building.

Figure 3: Interior of the #10 Substation looking at the south wall. 11 kV circuit breakers are in the background; overhead bus work; 2.3 kV circuit breakers are along the east wall (left); main 11 kV / 2.3 kV transformers are on the left. The rotary converter in the foreground supplies DC for underground haulage.

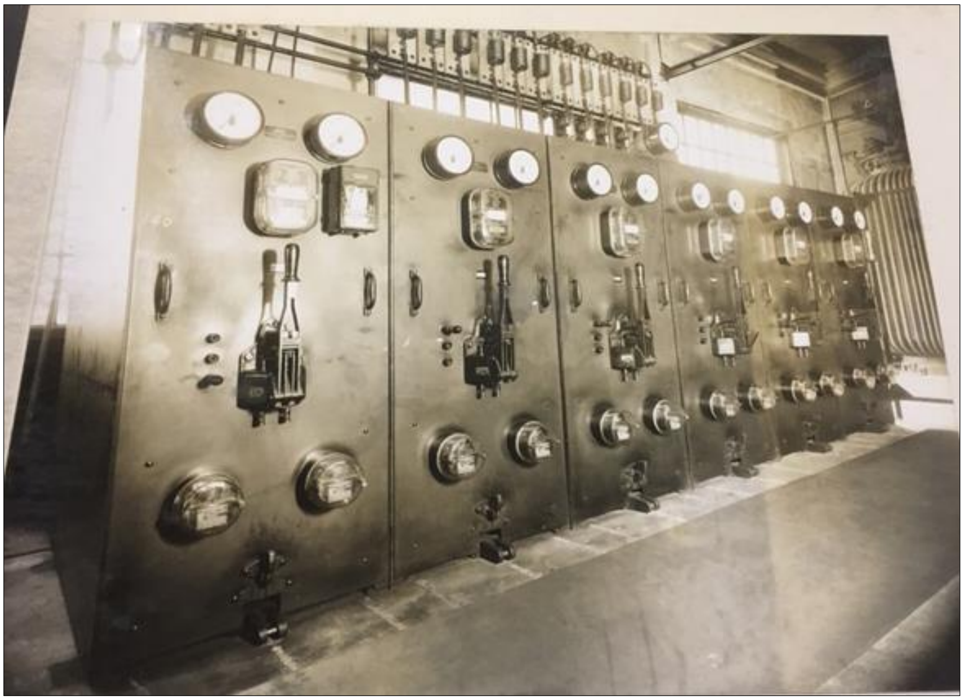

Figure 4: View of the 2.3 kV circuit breakers along the east wall at #10 Substation. Circuit breakers are draw out construction. Choke coils are located above circuit breakers.

Step down transformers for major loads, were powered at 2.3 kV, were included in each substation. The transformers were oil filled and suitable for outdoor use. In major substations, 11 kV circuit breakers were utilized for incoming feeder, outgoing feeder, and main transformer protection. The typical substation design included three single phase oil filled transformers banked together as a three-phase bank.

These main transformers would serve as the source to large motor loads. 2.3 KV would be routed inside the substation building to oil circuit breakers and then routed outside on overhead conductor runs to the mine hoists and nearby mine ventilation fans. Air compressors in the substation building and the underground mine de-watering pumps utilized 2.3kV motors as well. When 440 volt power was needed, other step down transformers were installed. 2.3 kV and 440 volt systems were ungrounded, delta connected systems. Delta connections were preferred so that a single phase to ground fault would not impair ventilation, dewatering, and haulage. The one line diagram for the #10 Substation is included as Figure 5.

At this time, it was common to use one large step down transformer bank and feed the circuits at a lower voltage on wooden poles to the loads. The practice in coal breakers of this era was to install one motor and to connect belt drives to crushers, conveyors, and shakers. For example, the #6 Breaker in Lansford, was built in the early 1920s, had 20 motors with a combined rating of 2,975 hp. Present day design is to use a motor for each individual load.

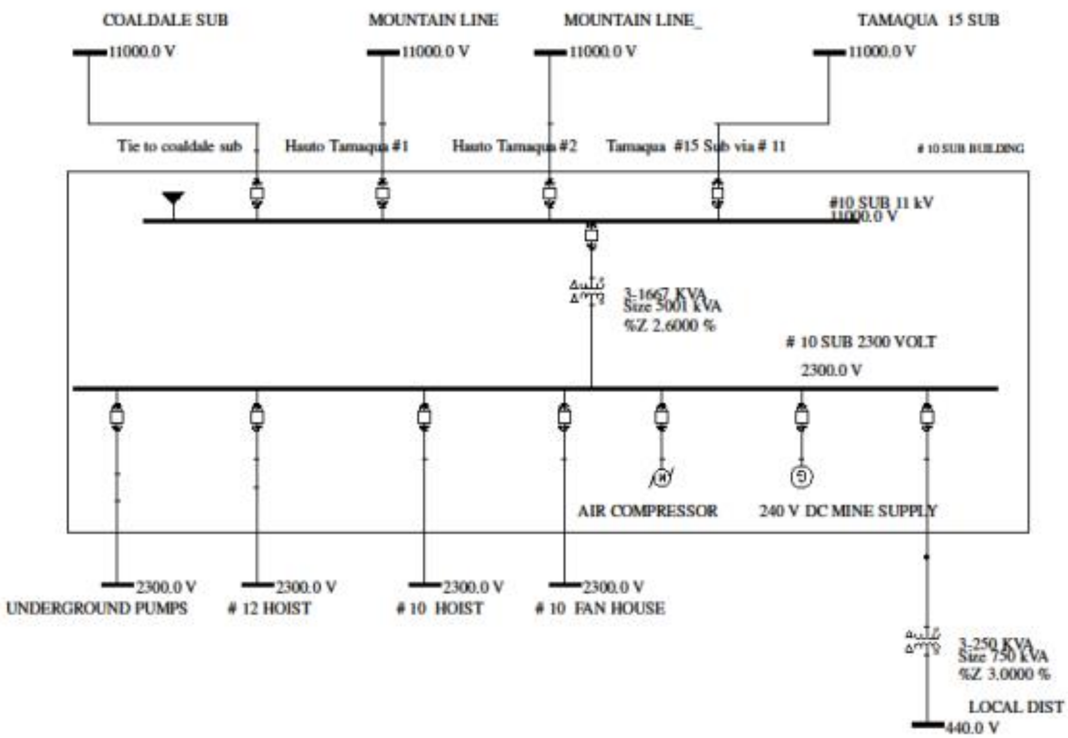

Figure 5: Single line diagram of the #10 substation.

The Hauto Navigation Station used single phase circuit breakers that were ganged together for three phase operation. Protective relays and the controls were mounted on a slate panel on the front with the circuit breaker located on the back side of the slate panel. A unique feature of the circuit breakers at the Hauto Navigation Station was that the circuit breakers were mounted on a roll out truck so that the circuit breakers could be disconnected from their circuits and moved as a visible disconnect from the live circuit (Figure 6 and 7). This design is a precursor of the modern draw out circuit breaker as used in typical metal clad switchgear.

A maintenance pit was provided, to lower circuit breaker oil tanks, for access to contacts during maintenance and repair of circuit breaker contacts. It was more common in that day for indoor applications to use stationary circuit breakers for the higher voltage rather than draw out circuit breakers. Oil circuit breakers have now been supplanted by air magnetic, vacuum and gas insulated circuit breakers.

The Hauto Navigation Station ran twenty four hours a day, seven days a week. It served as the source of electric power to the operation and, as the single line diagram shows, provided multiple paths to switch among the various lines so that each colliery could be fed from multiple sources.

Figure 6: Interior of the Hauto Navigation Substation. The circuit breakers are on the north wall facing the Hauto Power Plant. The two incoming feeders are on the ends corresponding to the11 kV single line.

1945

One of the newer company substations was the upgraded Coaldale Substation, which was rebuilt in 1945. The 11 kV indoor circuit breakers were metal-clad switchgear using circuit-breakers of adequate interrupting capacity to meet the needs of the Pennsylvania Power & Light Company system as part of the new installation**.** The circuit breakers at the new substation were cable/conduit fed via a "pothead" from the outside open bus steel structure into the building, as opposed to bringing in the bare conductors thru porcelain bushings thru the wall. The 11 kV open bus work in the building was eliminated as a safety improvement. This was a big improvement in the safe operation of LNC's electrical facilities. At this time, the fault current supplied by PP&L had increased to more than the interrupting rating of the existing 11 kV oil circuit breakers.

This first generation of the metal-clad switchgear still used oil circuit breakers at the time. This type of equipment was common in major industrial and petrochemical facilities. This equipment at this station was in service well into the 1980s. Part of the reason for the modernization of this substation was the installation of a replacement hoist on the number 7 shaft. The hoist was rated at 1750 HP and reported as the "industries most powerful hoist." The remainder of the mine hoists at the LNC collieries ranged between 1000 and 1250 HP. As precise speed was not needed and DC machines would be prohibitively expensive, the wound rotor induction motor was the natural choice for this application. This was the type of motor used for the hoists from the time of conversion from steam power to the last hoist used by the company.

Figure 7: Hauto Navigation Substation draw out circuit breaker "truck". There are three individual circuit breaker oil tanks in which the arc is interrupted. Only the first is visible because of the angle of the photo. Protective relays, projection mounted on the front of the slate panel, are part of the draw out circuit breaker assembly.

After the Coaldale Substation modernization DC used for mine haulage was produced using mercury arc rectifiers. Mine locomotives required 240 volt DC. In the early years, rotary converters were located in substation buildings. Rotary converters were similar to motor generators, but instead of having two rotors and two stators, rotary converters had one rotor and one stator. An important difference is that the rotary converter is not electrically isolated while a motor generator set is isolated. Rotary converters are bidirectional, synchronous machines. Rotary converters used by LNC that converted AC voltage to DC for mine haulage service were as large as 500 HP.

Mercury arc rectifiers had a dedicated three winding transformer with phase shifted secondary windings for harmonic control and to minimize the ripple of the rectified AC. The mercury arc rectifier was the precursor of the solid-state diode rectifier. This scheme provided a twelve pulse output waveform essentially the same as present day sources for large variable frequency drives. The transformer serving the rectifier was in this substation into the 1980s.

With evolution of electric industrial technology, mercury arc rectifiers became the method to supply DC in the late 1930s and early 1940s. This greatly reduced the amount of maintenance and complexity needed as opposed to a rotary converter. Rotary converts are still in use in several applications although mostly used as frequency changers such as from 60 to 25 cycles.

Fan houses used for mine ventilation were sometimes close to the main shaft areas, but many were located at remote areas. Since some of the fans could be well over 350 HP, the voltage of the fan motor was 2.3 kV. (New York City subways, built in the early 1900's, used 200 hp, 208 volt ventilation fans that are still in use today.) Ventilation fan motors were mostly squirrel cage induction motors with reduced voltage starting. For remote locations, an 11kV feeder from nearby power lines was installed and a step down transformer powered the fan motor.. The fan house had a building to house the motor and motor controls, but the transformers were located outside on a pad adjacent to the building. As early as 1930, the fans were being operated as remote unmanned sites, a big departure from the days of steam or earlier electrification. Since the fan shafts were routes to the underground facilities, the shafts were also be used as convenient route for a remote source of DC to help improve the voltage drop on the DC haulage feeders.

Air compressors were mostly located at substations; compressed air for drilling operations was transmitted to the mine workings by a borehole or down the shafts. A large air storage tank was adjacent to the substation buildings. Air compressor motors were synchronous, low speed, serving a piston type pump. The motors ranged in horsepower between 50 to 650 HP.

Significant dewatering was needed for underground mining and LNC had motors of several hundred horsepower at pump stations located on various levels for dewatering. One example was the fifth level pump house at the #10 Colliery which had three 650 HP motors. The cable that fed this pump house was a 2.3 kV cable, 800 foot long, installed in the #12 shaft. This cable was three phase, 800 MCM stranded copper, similar to an interlocked armor type cable. The cable weighed 16,544 pounds and was supported on the top of the shaft by one single support. At the time, this cable was the largest cable used in a coal mine in the USA. Cables of this type were typical, and to this day some of these cables are visible at shafts.

The Later Years

After the LNC stopped mining operation in the valley in 1954, Pierce Mining started the Coaldale Mining Company which operated the #8 Colliery and the #9 Mine. About the same time, The Panther Valley Coal Company was established and re-started the Lansford #6 Colliery and the Nesquehoning Mines. These two operations were about all that was left of the extensive coal company facilities. In late 1957, the #6 Colliery and the Nesquehoning Mines were acquired by the Coaldale Mining Company and shortly thereafter, they were shutdown.

Greenwood Mining constructed a new coal breaker at the site of the old # 14 Breaker in the 1960s and much of the machinery from the old shuttered #8 Breaker. Moreover, there was a good deal of old electrical equipment available at the mining operations; it was promptly put in service for use in the new company operations as needed. The new company used strip mining exclusively so the electrical facilities for underground mining became unnecessary.

At this time, 11 kV distributions to #6 Collieries and Nesquehoning operations were abandoned. The tie line from Number 5 substation to Coaldale was removed; the Coaldale Substation and the Greenwood Substation became a switching station. Tamaqua #15 Substation was bypassed. The only lines that remained in service were the Tamaqua and Coaldale lines.

Greenwood Mining Company used electric power shovels with 2.3 kV main motors. The supply used a flexible portable cable from a substation to the machine. In those days, and in the early days of Greenwood Mining Company, 2.3 kV and the ungrounded system was acceptable for the source of power to the electric power shovels. During the 1960s, with more stringent electrical requirements by the Mine Safety and Health Administration (MSHA), resistance grounding was required. This naturally translated to a 4.16 kV system.

In the 1960s, PP&L decided to close the Hauto Power Plant which was the source of 25 cycle power not only for the mining operation but also for a part of the Bethlehem Steel Plant in Bethlehem, PA. The end users of the 25 cycle power were given a choice to either be paid to convert their facilities to 60 cycles or to allow PP&L to install rotary converters, to allow their facilities to continue to power the sites at 25 cycles. Bethlehem Steel chose the latter and Greenwood Mining chose the former. The last rotary converter used at Bethlehem Steel was rated at 25,000 HP.

Conclusion

The electrical equipment used in the facilities described in this article are long gone and the design of heavy power usage has evolved and diverged from these early practices. The concepts, however, and the fundamental application of electric power remain the same. Considering the challenges that the previous generations of electrical personnel have overcome to successfully produce robust systems should provide historical perspective and inspire the development of robust micro-grids for remote areas and robust mini-grids for small towns and surrounding areas.

With a little imagination, sewage treatment plants can be compared to dewatering stations, coal mines can be compared to industrial plants, and past success stories can be compared to today's expectations.

This article has been edited from a detailed description of the Lehigh Navigation Coal (LNC) Company electrical system as it was from the turn of the twentieth century through the 1970s. While working as a docent at Number 9 Coal Mine and Museum in Lansford, PA, Jim researched photos, articles, and drawings and summarized recollections of miners and electricians who worked for LNC when the system was operated as a large microgrid between Bethlehem, PA and Hauto, PA. To receive the complete document, contact Jim (jstone@powersytems.com).