Restoring Power To A Vast Transportation System After A Substation Failure

David T. Montvydas, P.E

SEPTA

Philadelphia, PA

Steven D Bezner, P.E.

New York, NY

ABSTRACT

During a time of severe budget constraints, the last thing a public transportation system needs is a failure of components in a substation. The Southeastern Pennsylvania Transportation Authority (SEPTA) has a 650 volt direct current (dc) traction power system for its heavy rail and subway-surface trolley systems. While SEPTA's forces have done an excellent job at keeping the system maintained and operational, component failures can and do occur with catastrophic results.

SEPTA's Market Street Substation provides 650V dc power to the Market Frankford Subway Elevated (MFSE) line and Subway-Surface trolley system. The Market Street Substation is an essential part of the SEPTA system with nearly 10,000 MWh of electrical energy flowing through the each year with a peak power level of nearly 2.6 MW. In March 2011, the SEPTA system experienced a major component failure at this substation. The failure destroyed five (5) dc circuit breakers, the remote terminal unit (RTU) and many control cables within the substation. The resulting power outage stopped service on the MFSE line and five different subway-surface trolley lines. The power needed to be restored but the damage was extensive. The breakers that failed are no longer manufactured. Replacement parts are no longer available. In the short term, power needed to be restored to the MFSE and subway-surface trolley lines to keep passengers moving. For the long term, at a minimum, a new breaker lineup was needed. In this paper, an explanation will be provided of how the traction power for the MFSE and trolley lines was returned to service in just twenty-four (24) hours. In addition an explanation of the logistics and hurdles of finding and delivering breakers from a retired substation and the technical issues with modifying, testing, installing and commissioning these breakers is discussed. This paper will explain the process and problems that resulted in a restoration of normal substation service in February 2012.

THE INCIDENT

SEPTA's Market Street Substation is a key traction substation for the Market Frankford Elevated Line and the Green Line Trolley System. The Market Street Substation provides a peak power level of nearly 2.6 MW to the systems and nearly 10,000 MWh of electrical energy each year. In the early 1970s, the original switchgear (circa 1920) was replaced with refurbished English Electric HSK open face circuit breakers. Because of SEPTA's diligent maintenance, this equipment has been kept operational for almost forty years.

On March 15, 2011, at 2:30 am, while preparing to de-energize portions of SEPTA's Market Frankford Subway Elevated (MFSE) line for overnight maintenance, SEPTA experienced a major breaker failure at the Market Street Substation. As a result of the failure, service on the MFSE Line and Green Line came to a halt. Upon inspection, it was discovered that the failure destroyed five (5) dc circuit breakers, the remote terminal unit (RTU) and many control cables within the substation.

RESTORING POWER TO THE SYSTEM

Power needed to be restored as soon as possible. With five breakers out of service neither normal nor contingency operations were possible. The only alternative was to reconfigure the power system to get service up and running. Once normal service was restored, replacements for the failed breakers and RTUs were needed to get the substation back to its normal operation. Finally, the reason for the failure needed investigation.

The MFSE Line and Green Line begin normal service at 5:00 am. With extensive damage to breakers that are no longer manufactured, and have no replacement parts readily available, this would be a difficult task. Utilizing the redundancy of the MFSE power system and some quick reconfiguration, power was sectionalized around the substation to get the MFSE system up and running for regular load line at 4:27 am. By sectionalizing and back feeding the DC feeders from adjacent substations, partial service was restored to the western sections of the Green Line network. However, a portion of the street level and the entire underground level of the Green Line would be suspended. An estimate for return to service was still not available.

SUBSTATION RESTORATION

The cleanup within the substation could now begin. All of the destroyed and affected buses and breakers were disconnected. All of the control wiring and damaged RTU components were removed. Airlines and vacuums were brought into the substation. Air was utilized to blow the soot and debris out of, and off of, all the remaining equipment within the substation. The soot and debris were swept up and vacuumed. The equipment was wiped down to remove the remaining dust and soot particulates. Once the cleanup was complete, troubleshooting and repair of the RTU, AC equipment, rectifier-transformers and rectifiers was done. Resistance testing of cables and testing of breakers was also performed. Cables were also reconfigured to redirect power and feed the underground sections of the Green Line network.

By 2:27 pm, less than twelve hours after the initial failure, all testing was completed and the power for most of the street level and the underground section of the Green Line network was re-energized and put back into regular service. At this point, the RTU and SCADA control were still out of service. Everything in the substation was under manual control only. By pursuing the same aggressive cleanup, repair and reconfiguration along with back feeding from adjacent substations, the final section of the Green Line was put back in service at 8:35 PM – just over eighteen hours after the failure.

REPLACEMENT EQUIPMENT REQUIRED

Replacements for the failed breakers and RTU were needed to get the substation back to its normal operation. With the system operating but the possibility of new DC circuit breakers a minimum of a year from being delivered, alternative solutions needed to be evaluated and decided upon. For expediency, efficiency and cost, the best solution was using "spare" equipment. The spare equipment was salvaged from remote switch rooms that had been retired. Though unused and in need of cleaning and testing, this set of breakers was the best bet for SEPTA to get the Market Street Substation back to its former state of operation.

INSTALLATION

The process for getting the substation back to its former state of operation included the following:

1. Evaluate the layout of the spare equipment in the substation: A plan for the location of the new equipment was evaluated and completed by April 2011. A plan for the location of the new RTU and relocation of the control wiring was completed by May 2011.
2. Rehab the spare equipment: Breakers were delivered to the substation by April 2011. Cleaning and testing of the equipment was completed by May 2011.

3. Design and procure bus duct and switches to isolate and sectionalize the spare switchgear: Design, procurement and delivery of the bus duct was completed by July 2011. Installation of the bus duct was completed by September 2011.
4. Replace the control wiring and RTU: Replacements for the control wiring and the RTU were completed by October 2011.
5. Replace the power cabling and accessories: Purchase, fabrication and installation of cable, cable racks and supports were completed by October 2012. Over 2000' of 2000 mcm cable and 1000' of 1000mcm cable between the existing cables/busbar and the new switchgear lineup were installed. This work was completed in February 2012.

The items with the longest lead time were the end housings for the switchgear. These were procured from an electric housing manufacturer that has a history of doing work with SEPTA. The design was completed and approved in two months. The new bus duct and switches were delivered one month later. The lengthiest duration from failure to construction was the delivery and installation of the power cables, control cables and accessories. Although purchase and delivery of the cables and accessories is routine, the installation of these into an underground substation was tedious and laborious. Outages in the substation were also needed to safely install and terminate the new cables and accessories. These outages were only possible during overnight hours to prevent service disruptions. The substation in its new configuration was put online in February 2012.

MITIGATION

An investigation of the breaker failure was needed to determine a cause and to take a course of action. The breaker that started the chain reaction was destroyed by a fault current estimated to be over 100,000 amps. Investigation and SCADA logs point to a mechanical portion of the breaker failing as the root cause. This type of breaker was designed with a spring loaded mechanism that releases in two stages during a fault. One of the release mechanisms failed. This mechanical failure would not allow the breaker to clear the fault and lead to a false indication on the breaker. This resulted in a dead short through the breaker leading to its explosion and the destruction of the other four breakers and associated control equipment. This failure will lead to a major overhaul of the substation's switchgear as funding allows.

As a public transportation agency, the main goal is always to keep passengers moving. The ability to get the system back in service after eighteen hours is a testament to the efforts of SEPTA's Power Department. To restore the substation to its normal operations in eleven (11) months is further evidence of this. Future funding to replace outdated equipment will go a long way towards prevention of this type of failure in the near future.