Case Study-Estram Light Train
Eskisehir Turkey
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Eskisehir Light Train- Correcting Capacitive Power Factor

Eskisehir, a city in the Anatolia region of Turkey is located in an area inhabited since at least 3500 BCE- the copper age. Today Eskisehir is known not only as a region steeped in history, but as an industrial centre were the use of copper is still quite prevalent; though not in a way even the most imaginative of the earliest Anatolians would have ever dreamed. The ubiquitous use of copper in electrical systems in general and for the transmission of power to light rail systems in particular is a fact of life for designers of electrical distribution systems.

The public utility must supply all customers in the city with ample power and stable voltage. Any utility has an interest in encouraging customers to conserve energy, actively and passively. The passive aspect of energy conservation, by keeping the power factor close to unity, is usually enforced with a surcharge for poor power factor.

New electric train appears to the Power Utility as a giant capacitor- attracting penalties for low power factor

The inauguration of a new efficient light train system in the city of Eskisehir running on non polluting electricity surely contributed much to the general populace, though creating a challenge to the power utility. The burden of compensating for low power factor is passed on by the Utility to the customer by levying a penalty if the customer does not improve his power factor. The utility is compensated monetarily for the necessary infrastructure upgrades required to supply this customer with more electric current than he actually needs.

For the purpose of graphing, the power factor ranges from 0 for a purely inductive load to 1 for a "perfect" load where current is drawn in phase with the voltage, and up to 2 where the load is purely capacitive.

The challenge to the utility, and the operator of the light train, is that the poor power factor created by the light train distribution system is capacitive, not the usual inductive power factor associated with the operation of motors and discharge-lighting. The distribution system, with a positive catenary (upper rail) and a negative track, is in fact a giant capacitor connected to a 750VDC power source.

Capacitive power factor is not just a matter of wasted current; the capacitance increases the voltage of the feeder, creating a serious voltage instability problem.

The Problem

The light train electrical distribution system begins with medium voltage 34.5kV utility lines feeding double secondary 2.5MVA transformers 34.5/0.6/0.6 kV. As can be seen in Figure 1, these transformers feed 3 phase 2MW rectifiers. The rectifiers feed a positive catenary and a negative track for the trains. The operating voltage between catenary and track is 750VDC.

Correcting capacitive load for power factor embodies new and different challenges

When measured from the utility point of common coupling, the power factor reached over 1.9 (0.1 capacitive) when few trains were running, averaging 1.5 (0.5 capacitive), and seldom dropping below 1.1 (0.9 capacitive) when many trains were running. A high capacitive power factor in and of itself is not necessarily a problem when little power is being used, however these values translate into an average of 400 kVAR capacitive, as can be seen from the simultaneous sampling of power factor and power in Figure 2. The power utility levied penalties of tens of thousands of dollars as per their defined rates of service.

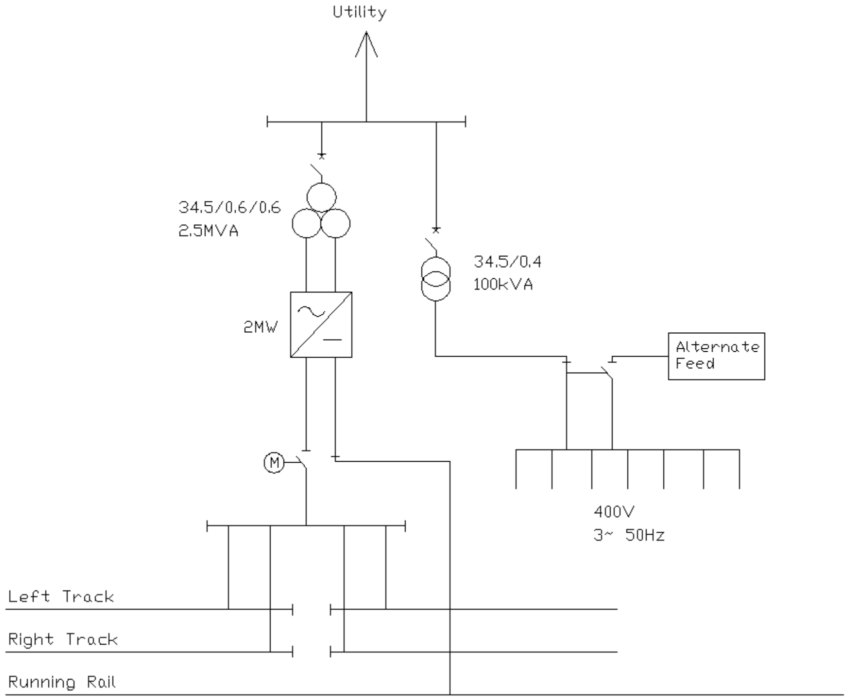

Figure 1: The Electrical Distribution System Feeding the Train Station

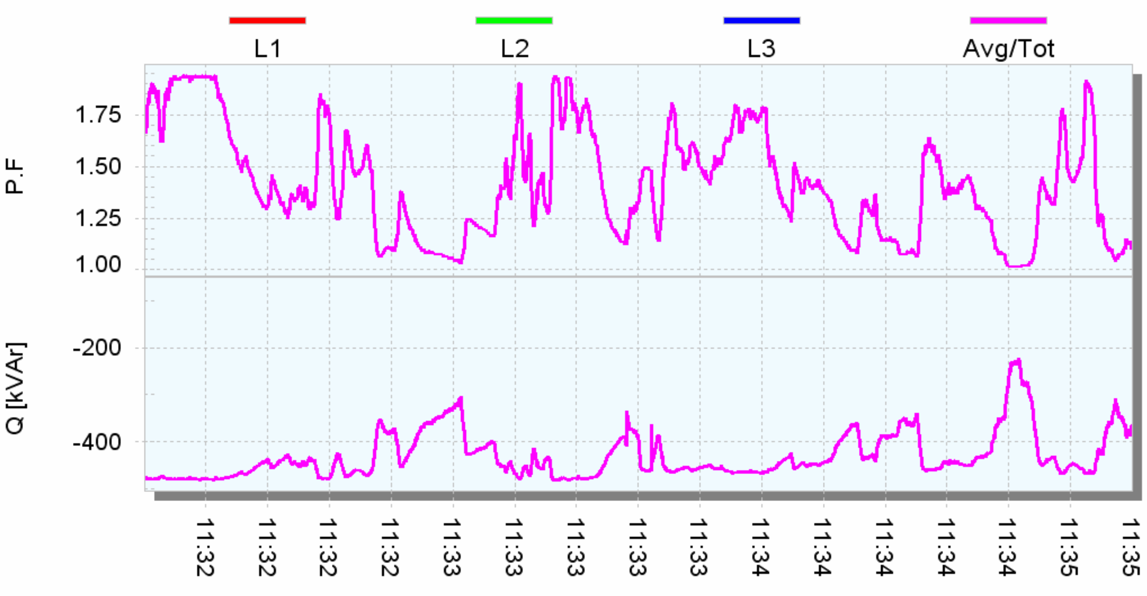

Figure 2: Capacitive Power Factor at PCC with Utility

Another aspect of the problem is that of voltage stability. All instances of poor power factor have negative impact on voltage stability. In the usual instance of poor power factor, the reactive power is inductive; any impact on voltage would be a drop in voltage value. In our system, the impact on voltage is a raise in voltage value when the capacitance is high. This high voltage creates a power quality problem that is potentially more destructive to parallel consumers than the problem created for the utility by increased current.

The Solution

Simply put, the solution is to connect inductive loads in parallel to the capacitive system. No industrial concern operates with out some form of power factor correction. As stated previously, the overwhelming majority of installations requiring power factor correction are dealing with an inductive system corrected by the addition of capacitors. In our case, the system is capacitive, requiring the addition of inductors.

Capacitive loads can raise system voltage, creating power quality problems for the Utility

Most systems employ automatic power factor correction, sensing the power factor by constantly monitoring the current and voltage, calculating the power factor and switching capacitor banks as required. As seen in Figure 2, the power factor is quite dynamic, ranging from 1.1 to 1.9. Automatic switching of inductors is most definitely called for. However, at this point, our analogy to inductive systems must be analyzed more carefully. When switching capacitor banks, care must be taken in designing the switch gear due to the high inrush current experienced when switching a capacitor. These switching events create high wear on the switch gear and the capacitors.

The switching of inductors is no easier; the high inrush currents of a coil are of a substantially different nature than those created by capacitors. Industrial concerns the world over have turned to Elspec for advanced solutions for correcting the "standard" inductive power factor. For over a decade, Elspec has led the world in power factor correction of inductive systems with the invention of the Equalizer power factor correction unit. The Equalizer solves the problem of switching capacitor banks by switching the banks on zero crossing of the voltage sine wave, typically completing the circuit within half a cycle.

No wonder then, when the engineers looking for a solution to the highly capacitive power problem turned to Elspec to design a similar system for this application.

A world leader in correcting inductive load power factor, Elspec has the answers for dealing with capacitive loads, switching the corrective load at zero sine crossing within half a cycle

The solution entailed the installation of an Elspec Equalizer power factor correction unit equipped with iron core reactors instead of the usual capacitors. Based on measurements taken from the site, it was decided to install two Equalizer units with iron core reactors –one 450KVAr the other 550KVAr- on each of two of the three utility feeder stations. Figure 3 displays the method of installation.

The Equalizer, with its iron core reactors, is installed on the low voltage side, correcting the power factor through a 1000 KVA transformer in parallel to the station low voltage distribution panel. The current measuring sensors are connected to the medium voltage side, close to the point of common coupling with the utility. The voltage sensors are connected on the low voltage side of the transformer. By correcting on the low voltage side, the Equalizer takes advantage of the inherently simpler requirements for switch gear. Measuring current on the medium voltage side ensures that the correction will be accurate.

Correcting on the low voltage saves money on switch gear, but does require special consideration. The transformer installed by the train company for the Equalizer was of type Delta\Wye 11, meaning that the primary and secondary are out of phase by 30 degrees. Elspec overcomes this problem, by utilizing their proprietary firmware that calculates the corrections necessary to inject the reactive correction on line in phase with the medium voltage point of common coupling.

Switching iron core inductors instead of capacitors, the Elspec equalizer is engineered to correct the power factor quietly, with no damaging transients, ensuring long life for all the switch gear involved.

The switching of iron core reactors instead of capacitors for correcting capacitive instead of inductive power factor is not just a matter of mirroring the technology, as alluded to earlier. The switching characteristics of capacitors and reactors are very different, and the reaction of the grid to the two types of corrective loads is different. The Elspec Equalizer is capable of cycle by cycle correction, with switching on zero crossing. This capability allows the Elspec engineers to program the equalizer to optimize switching in every situation from pure capacitance to pure inductance, keeping power factor at the required level while ensuring long life to all switch gear and panel elements.

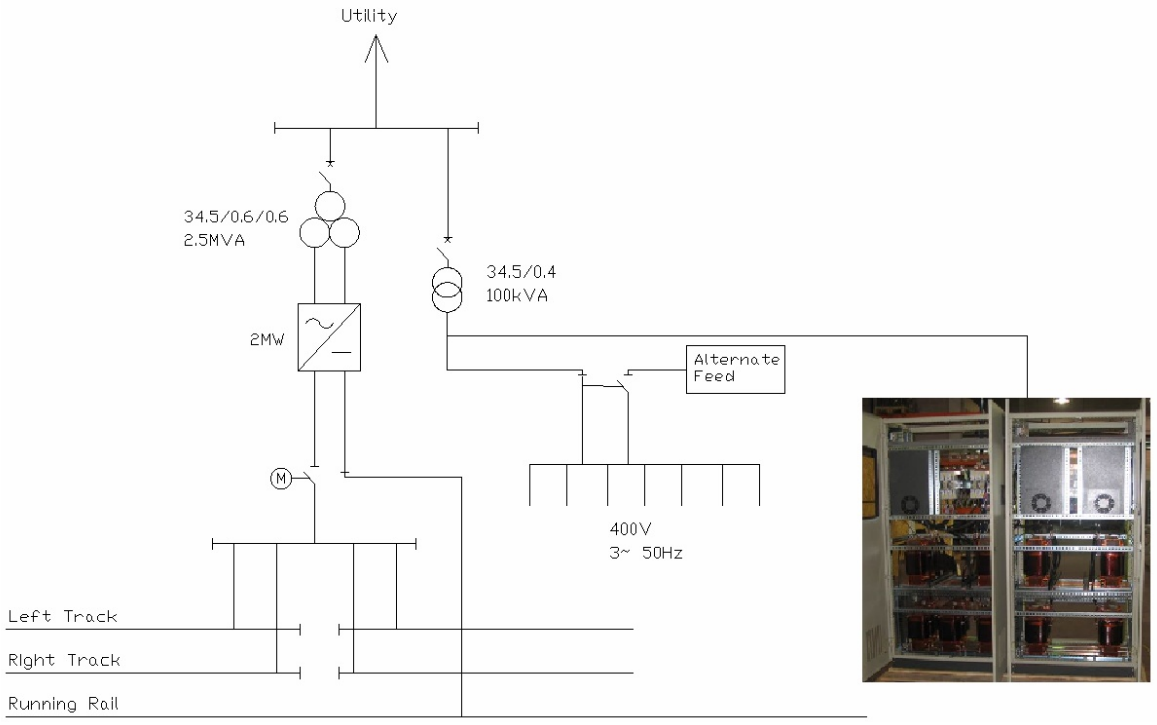

Figure 3: Elspec Equalizer added to the Train Station

Figure 4 demonstrates the success of the Elspec Equalizer in correcting the power factor. An analysis of the sampled parameters shows that the power factor is corrected to within a hundredth of unity. The current represented in the graph is from the high voltage side. The reactive capacitive power has dropped from 400kVAR to an average of around 10 Kvar.

The Elspec advanced electronic switching of the inductors ensures long life for all switch gear in the same manner that Elspec increases the life of capacitive correction systems.

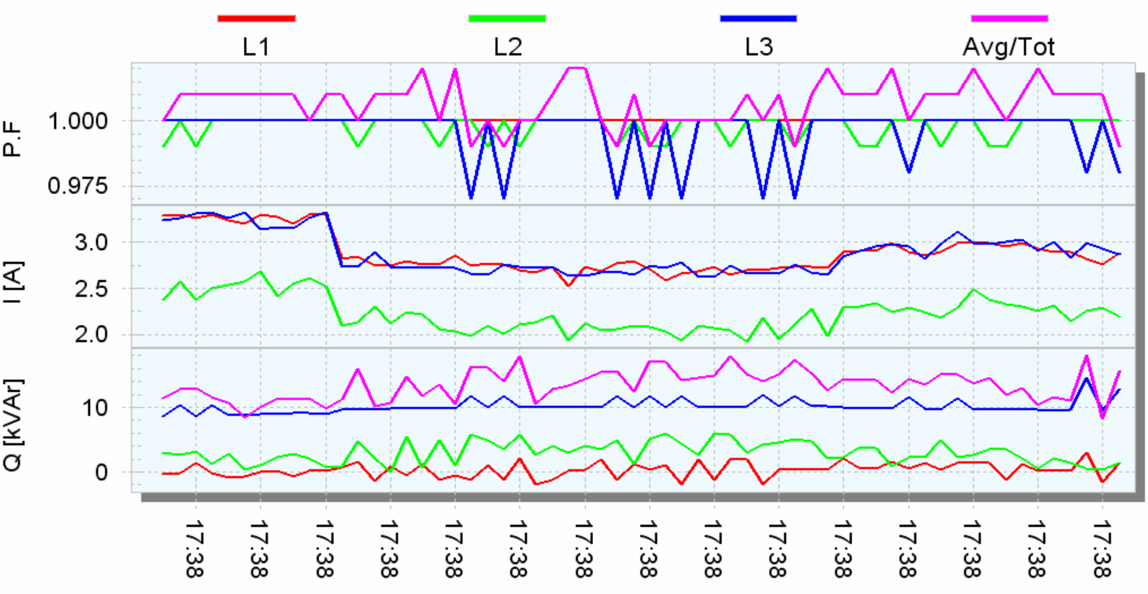

Figure 4: Measurements after Installation of the Elspec Equalizer

Major Benefits:

- Power factor correction of a capacitive load system
- Transient free correction
- Correction within half a cycle
- Mitigation of voltage swells due to high capacitance
- The end to paying penalties due to poor power factor

Power factor is a measure of the phase difference between the current and the voltage; defined as the cosine of the phasor angle between them. In an ideal situation, the current and voltage are in phase, the angle is 0°, and the Power Factor is unity. As a load becomes inductive, the angle increases in the positive direction with the power factor decreasing to 0, as the angle becomes 90°. As a load becomes capacitive, the angle increases in the negative direction, with the PF decreasing negatively until reaching 0 at -90°. These renditions of power factor are used universally in electrical calculations. However, when attempting to graph these values, a different rendition of Power Factor is required, since Unity is the axis of divergence, arriving at the value from either side through -0.99 or +0.99. Therefore, for the purpose of graphing power factor, we use a scale that ranges from 0 for a purely inductive load to 1 for a "perfect" load where current is drawn in phase with the voltage, and up to 2 where the load is purely capacitive.