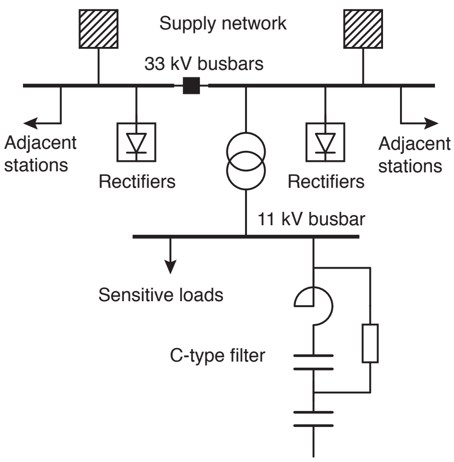
Introduction

Mass rail transport systems in modern urban centres require reliable, safe, and high quality electrical energy. Urban rail systems include power supplies to rolling stock and to stations. Rolling stock is commonly supplied with direct current from rectifiers that generate significant harmonic distortion, and this distortion is distributed throughout the network. High voltage distortion can result in communication failures and malfunctioning electrical and electronic equipment, with consequent danger or inconvenience to passengers and rail personnel. High voltage distortion contributes to network losses and can also result in non-compliance with network supply arrangements and reduce equipment life.

This note describes an approach that ensures voltage distortion on sensitive loads is limited to within acceptable levels.

Network

A typical railway substation is shown below. Two 33 kV busbar sections are connected to a supply network. Each 33 kV busbar feeds rectifiers that supply power to rolling stock and is also connected to adjacent substations. This configuration allows for flexible and robust operation of the supply network. The rectifiers are so-called twelve-pulse devices, meaning that harmonic current generated by these rectifiers are predominantly at frequencies determined by $12n \pm 1$, where $n = 1, 2, 3 \ldots$ The substation also contains a step-down transformer to 11 kV. The majority of the load supplied from the 11 kV busbar is sensitive signalling, passenger access systems (escalators and elevators) and other passenger station loads.



Due to the sensitivity of these 11 kV loads to harmonic distortion, a harmonic filter is connected to the 11 kV busbar. The purpose of this filter is to limit the amount of 11 kV busbar voltage distortion.

An alternative approach of connecting a harmonic filter to the 33 kV busbar was rejected in this case due to space and cost constraints. In general harmonic filters are more effective when placed electrically close to harmonic current sources, so the application described here is not ideal in terms of limiting harmonic distortion.

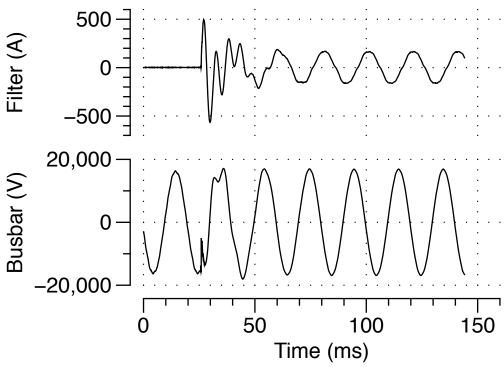
The filter is configured as a C-type filter, tuned to the fifth harmonic. This configuration has the advantage of relatively low losses (the losses in the damping resistor are limited to the harmonic currents flowing into the filter, no fundamental frequency losses are dissipated in the resistor) and because the filter is damped, a fairly wide range of harmonic orders is absorbed in the filter.

Performance test

A short term test was performed to determine the impact of the filter on the network and the effectiveness of the filter in reducing harmonic distortion at the 11 kV busbar. The test involved setting up the supply network in a particular configuration, ensuring that all supplies are within acceptable limits and switching the harmonic filter in, out and in again while recording the current into the filter, into rectifier loads, and 33 kV and 11 kV busbar voltages.

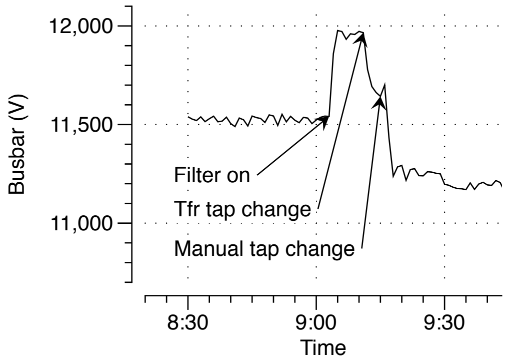
Results

The graph below indicates filter current and busbar voltage when the filter is energised. A switching transient can be expected, and in this case the oscillation is damped and effectively disappears after two cycles.



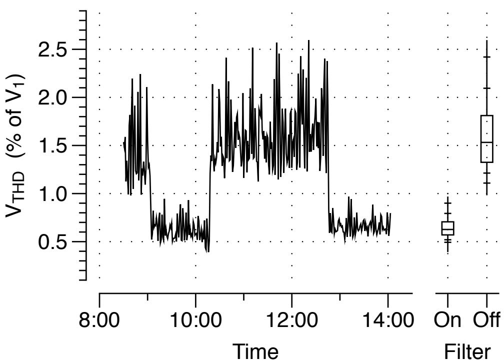
When a capacitive load is connected to a network with mainly inductive source impedance, a per unit voltage rise δV with magnitude approximately according to $\delta V = Q/S_k''$ will occur, where Q is the reactive power output of the filter in Mvar and S_k'' is the fault level at the 11 kV busbar in MVA.

The graph below illustrates a typical voltage trend before and after energisation of a filter bank. The voltage rises predictably according to the above relationship. After a few minutes, an automatic tap changer on the 33 kV/11 kV transformer operates to correct the voltage to setpoint levels. An additional, manual tap operation was also performed in this case due to operator concerns about high voltage elsewhere in the network.

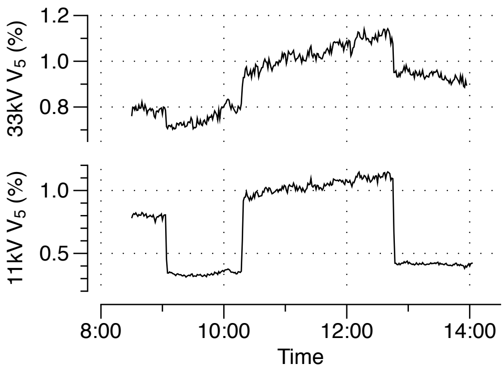


The voltage total harmonic distortion displays wide variation due to short-term, high-load periods associated with traction loads. The effect on voltage distortion is illustrated in the graph below. Without the harmonic filter, voltage distortion averages around 1.5%, reducing to approximately 0.5% when the filter is connected.

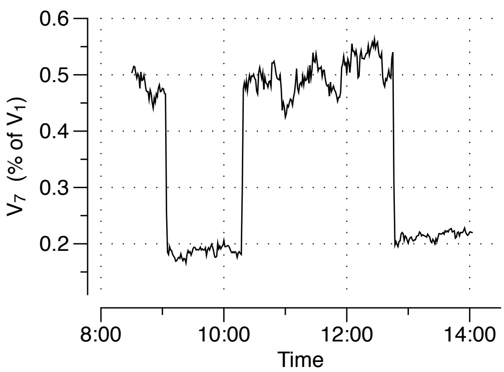
The range of variation in distortion is also reduced when the filter is connected.



The impact of the filter on the 33 kV harmonic distortion can be seen in the graph below. The fifth harmonic distortion at the 11 kV busbar is reduced very significantly when the filter is energised, from approximately 1% to approximately 0.4%. At the same time, the fifth harmonic distortion at the 33 kV busbar is notably reduced but not to the same extent. This is a predictable outcome considering the filter is connected at 11 kV while the majority of harmonic emissions occurs at the 33 kV busbar.



The filter performance is expected to be optimum at the fifth harmonic, as that is the selected tuned frequency in this case. The graph below demonstrates that the filter is also quite effective in reducing the voltage distortion at the seventh harmonic, due to the fact that the filter is damped and therefore absorbs harmonic current across a fairly wide range of frequencies.



Conclusion

The test results presented in this application note were obtained during a short measurement period with the rail network and supply grid in a particular configuration chosen to minimise the risk of high harmonic distortion. Voltage distortion levels without the filter connected are not excessive and would not normally warrant the application of harmonic filtering. Under different operating conditions the voltage distortion is significantly higher and this note illustrates that the harmonic filter is very effective in reducing voltage distortion at the busbar where it is connected.

Optimised Network Equipment can perform the necessary network analysis to design and supply power quality solutions to a range of applications, and as described in this note have proven capability to deliver solutions that are demonstrated to work in practice.