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SynchroTeq – 3-Pole Transformer Switching

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Executive Summary

This report was produced by Enspec Power LTD; it details the application of the SynchroTeq device for transformer switching using 3-pole operated circuit breakers. The document outlines the application and theory of controlled transformer switching and then presents a number of commissioned and operational site examples. In conclusion, the document demonstrates how the SynchroTeq can mitigate inrush currents during the energisation of transformers and provide site compliance with voltage dip limits.

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1 Introduction

When a transformer is energised it may draw a large transient current from the supply connection point. This large current may lead to voltage dips in excess of allowed standards and limits. Due to this it has been common practice to install a Pre-insertion Resistor (PIR), that is placed in circuit during the transformer energisation to reduce the inrush current and thus voltage dip. However, a PIR requires an extra circuit breaker, has a significant footprint and can be expensive. The SynchroTeq is a controlled switching device that can provide equal or better inrush mitigation to that of a PIR without the need for an extra breaker or costly install. This document will cover the theory, installation and performance of the SynchroTeq when applied to transformer switching using a 3-pole breaker and will end by presenting a number of operational SynchroTeq installations.

2 SynchroTeq Transformer Switching Theory

When a transformer is de-energised, the magnetic core will contain a certain amount of residual magnetic flux. This residual flux is dependent on the voltage across the transformer at the time of de-energisation and can intensify saturation leading to a high transient inrush current and thus voltage dip on re-energisation. The possibility or magnitude of saturation and thus inrush current is dependent on the point of re-energisation (angle) in relation to this residual flux. This effect can be seen graphically in Figure 2-1 below.

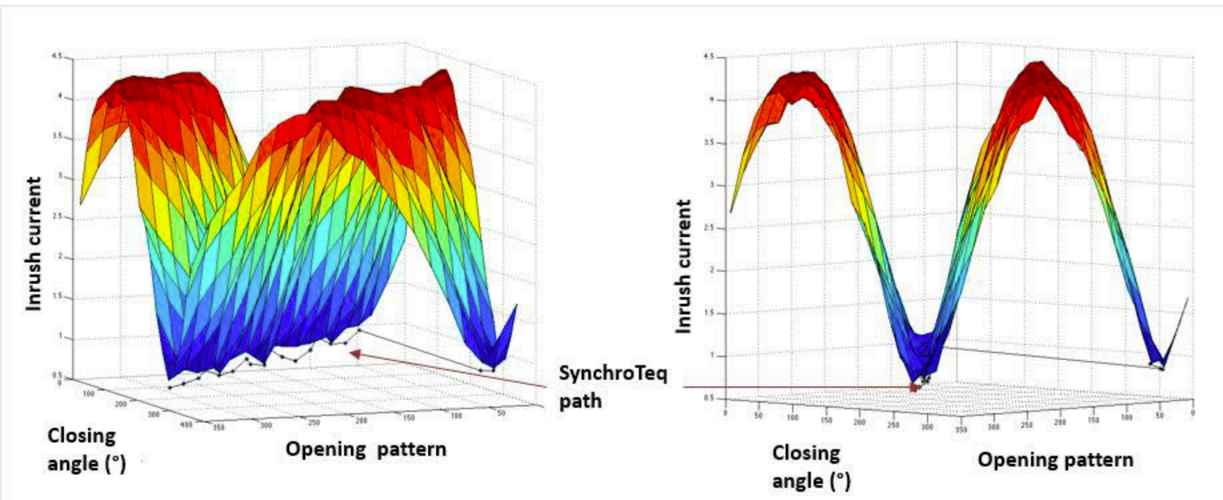

Figure 2-1 - Inrush Current due to Opening and Subsequent Closing Angle

The above Figure 2-1 shows the inrush current obtained across all possible closing angles for each possible opening angle. As can be seen, there is a best and a worst-case closing angle for each opening angle. When switching a standard transformer arrangement there is equal possibility of hitting a bad point as a good point, and thus a possibility of a high inrush current. The SynchroTeq works by monitoring and calculating this residual flux, with knowledge of the residual flux it can calculate the optimum closing angle. This is seen graphically in Figure 2-1 above as 'SynchroTeq path'. The SynchroTeq then becomes an interface between the open/ close commands (manual, remote or protection) and the Circuit Breaker. Using the calculated residual flux and knowledge of the Circuit Breaker operation time, the SynchroTeq can target this optimum closing angle, thus mitigating high inrush currents. This process can be seen graphically in Figure 2-2 below.

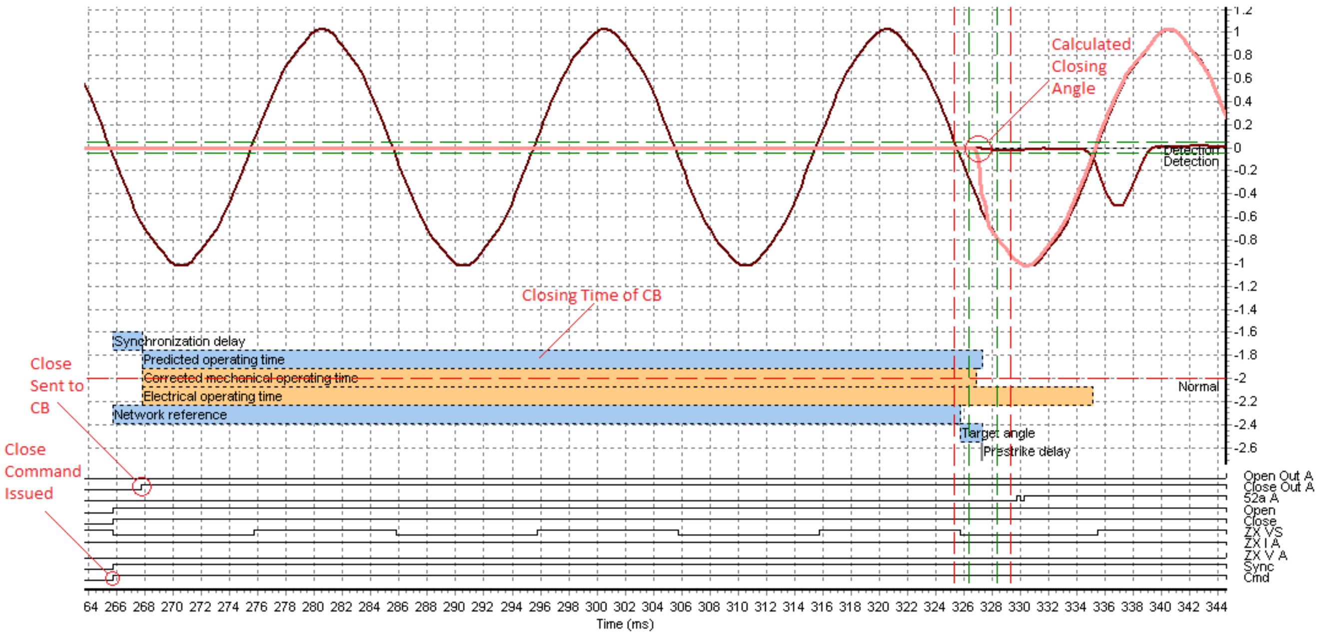

Figure 2-2 - SynchroTeq Controlled Close Operations (Phase A)

The above Figure 2-2 shows a closing operation carried out via the SynchroTeq (Phase A). In this example the calculated closing angle, based upon the calculated residual flux, is around 220 degrees. Firstly, the close command for the CB is issued to the SynchroTeq, the SynchroTeq then waits until the target angle is the CB closing time ahead (predicted operating time), and then the close command is sent to the CB. The result here is the CB closing at the desired angle with minimum inrush current.

The SynchroTeq can mitigate inrush current using any modern CB. The CB can be a 3-pole gang operated device or a 3-pole individual pole device. When operating via a 3-pole gang operated device, the SynchroTeq cannot close the CB at the optimum point for each phase, in this instance it calculates the optimum point for all three phases to keep inrush current to a minimum.

3 SynchroTeq Application

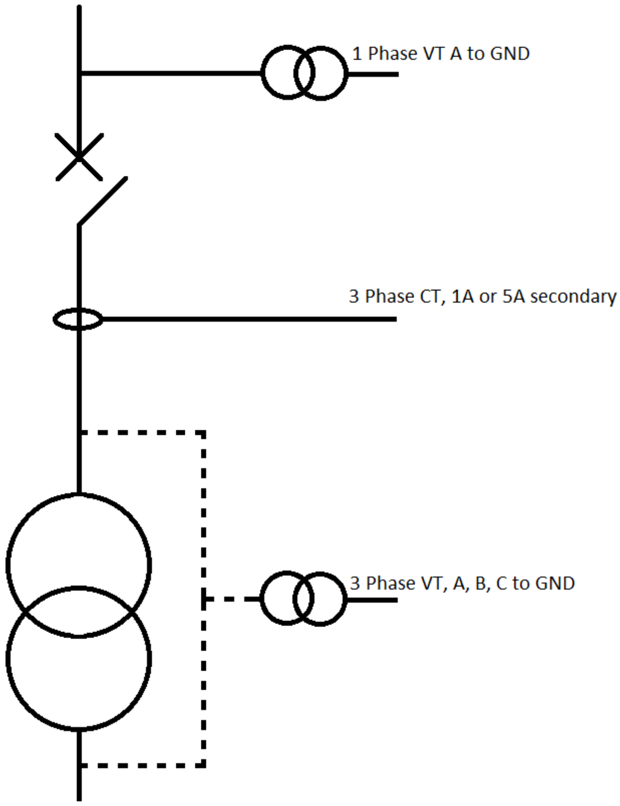

Figure 3-1 - SynchroTeq Signal Requirements

The above Figure 3-1 shows the signal requirements for transformer switching with a SynchroTeq device. The single-phase VT is used for voltage synchronisation, the CT's are used to measure inrush current and the three-phase VT allows the SynchroTeq to calculate residual flux. The three phase VT can be taken from either side of the transformer. The SynchroTeq then forms an interface between the circuit breaker open/ close commands and the circuit breaker itself.

4 Actual Application and Results

4.1 UK Solar Farm

The following results are for a SynchroTeq MVX installed on a UK solar farm. The SynchroTeq was used to control the simultaneous energisation of the sites 2MVA and 1.77MVA 11/04kV transformers, via an 11kV 3-pole operated breaker. A diagram of the site layout can be seen below in Figure 4-1.

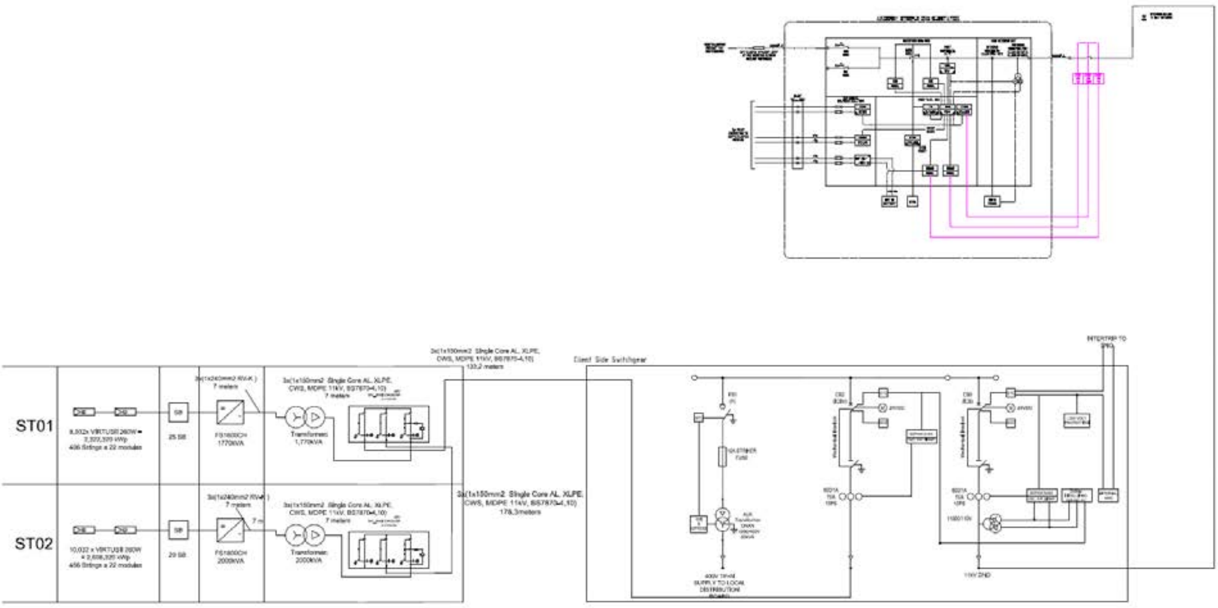

Figure 4-1 - Site SLD

The SynchroTeq MVX was mounted in the client substation and controlled the energisation of the main CB. The initial P28 studies for the site highlighted a 50th percentile voltage dip of 8.2% for the simultaneous energisation of the site's transformers, this can be seen below in Figure 4-2.

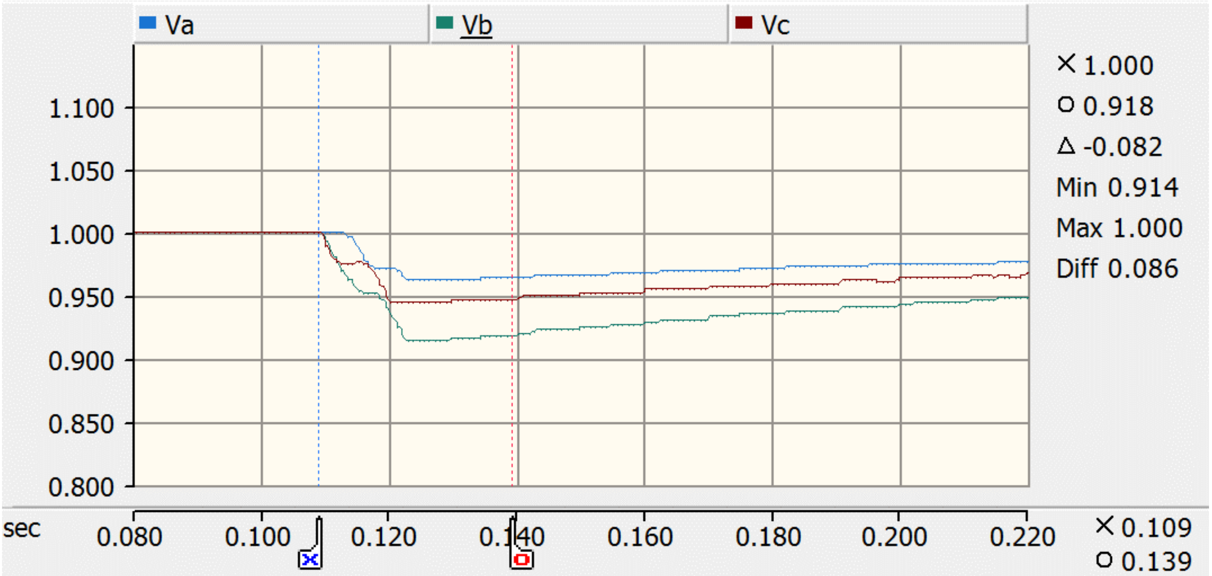

Figure 4-2 - PCC Voltage Dip for Whole Site Energisation

The DNO for this site stipulated a maximum voltage dip at the PCC of 6% due to the whole site energisation. The below Figure 4-3 shows the result of the SynchroTeq MVX commissioning.

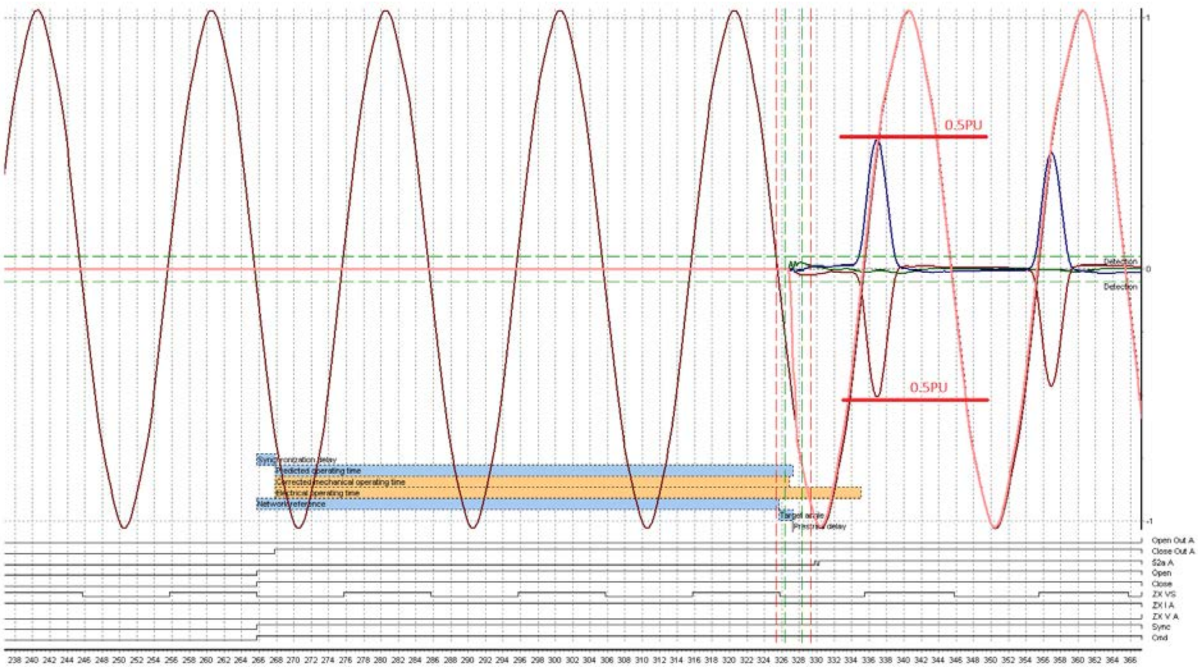

Figure 4-3 - Commissioned SynchroTeq Inrush Current

As can be seen from the above figure the resultant inrush current was 0.51PU (101A).

This resultant inrush current was then used to obtain a new voltage dip using the original P28 simulation model.

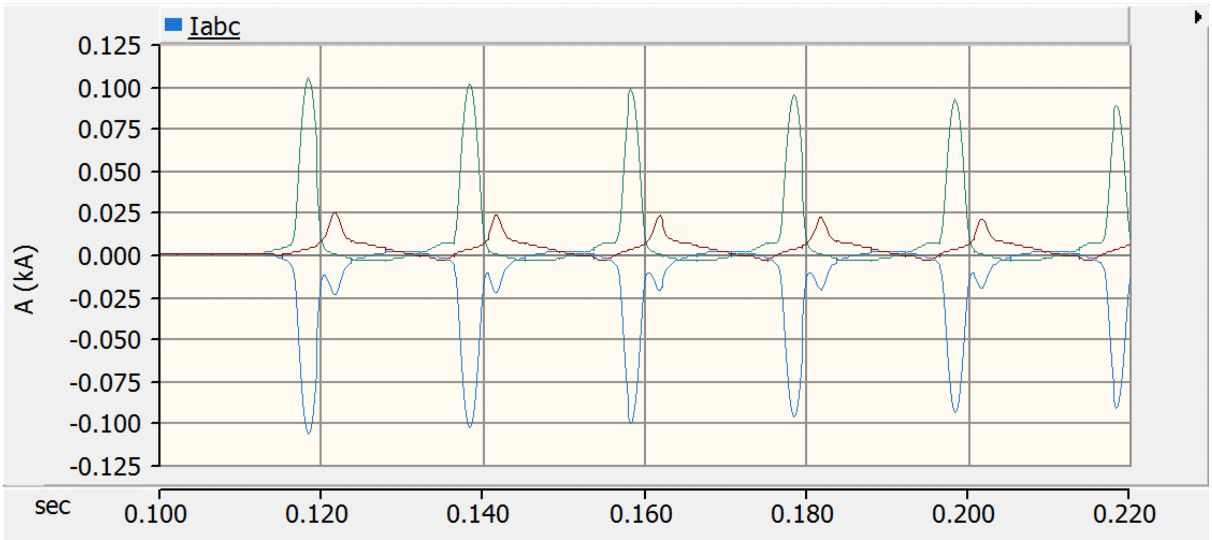

Figure 4-4 - SynchroTeq Resultant Inrush Current in P28 Model

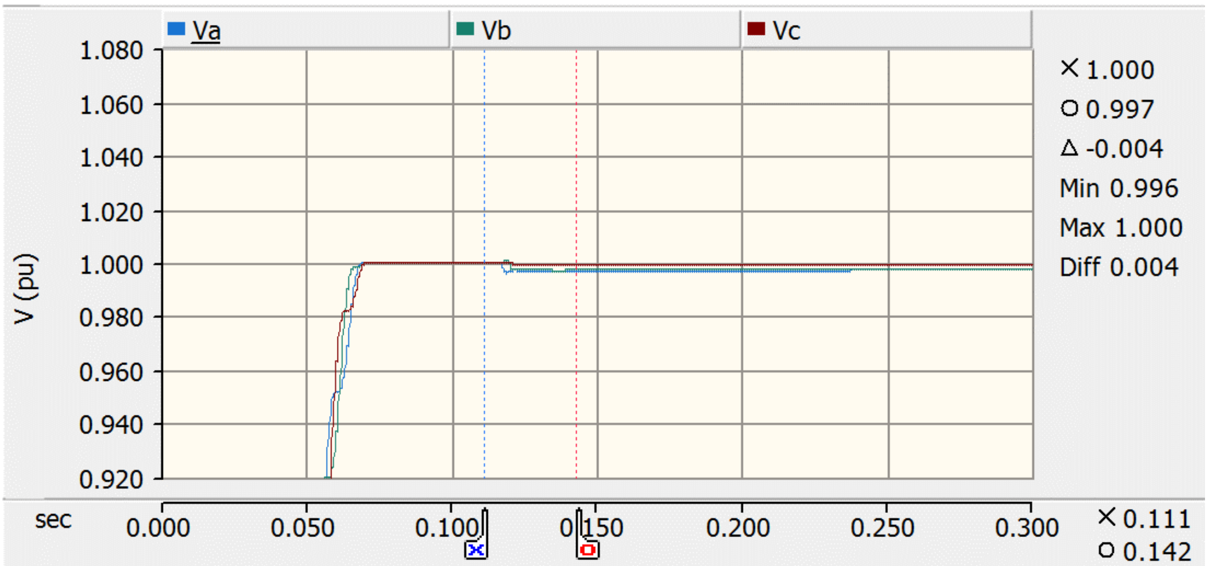

Figure 4-5 - Simulated Voltage Dip Based on SynchroTeq Inrush Current

As can be seen from the above figures, simulation of the resultant inrush current led to a PCC voltage dip of 0.4%. As the switching is now controlled by the SynchroTeq this level of inrush current will result from every future energisation, making the site fully P28 compliant.

4.2 GE Transformer Testing Facility

The following results are for a SynchroTeq MVX installed at GE's transformer testing facility. The SynchroTeq was used to control the energisation of the sites 2.4 MVA 11/6.6kV cast resin transformer via a 3-pole breaker. GE were experiencing issues when energising the transformer for testing purposes, sometime the inrush was so high that the site would trip out completely. Enspec were contracted to offer a turnkey solution, carrying out the supply, install and commissioning.

Figure 4-6 - SynchroTeq Retrofit Installation

The above Figure 4-6 shows the retrofit installation. Enspec supplied the SynchroTeq in a standalone wall mountable enclosure and brought all of the required interface connections out of the existing switchgear and into the panel. Once installed and tested Enspec carried out the on-site commissioning to fully characterise the circuit breaker timing.

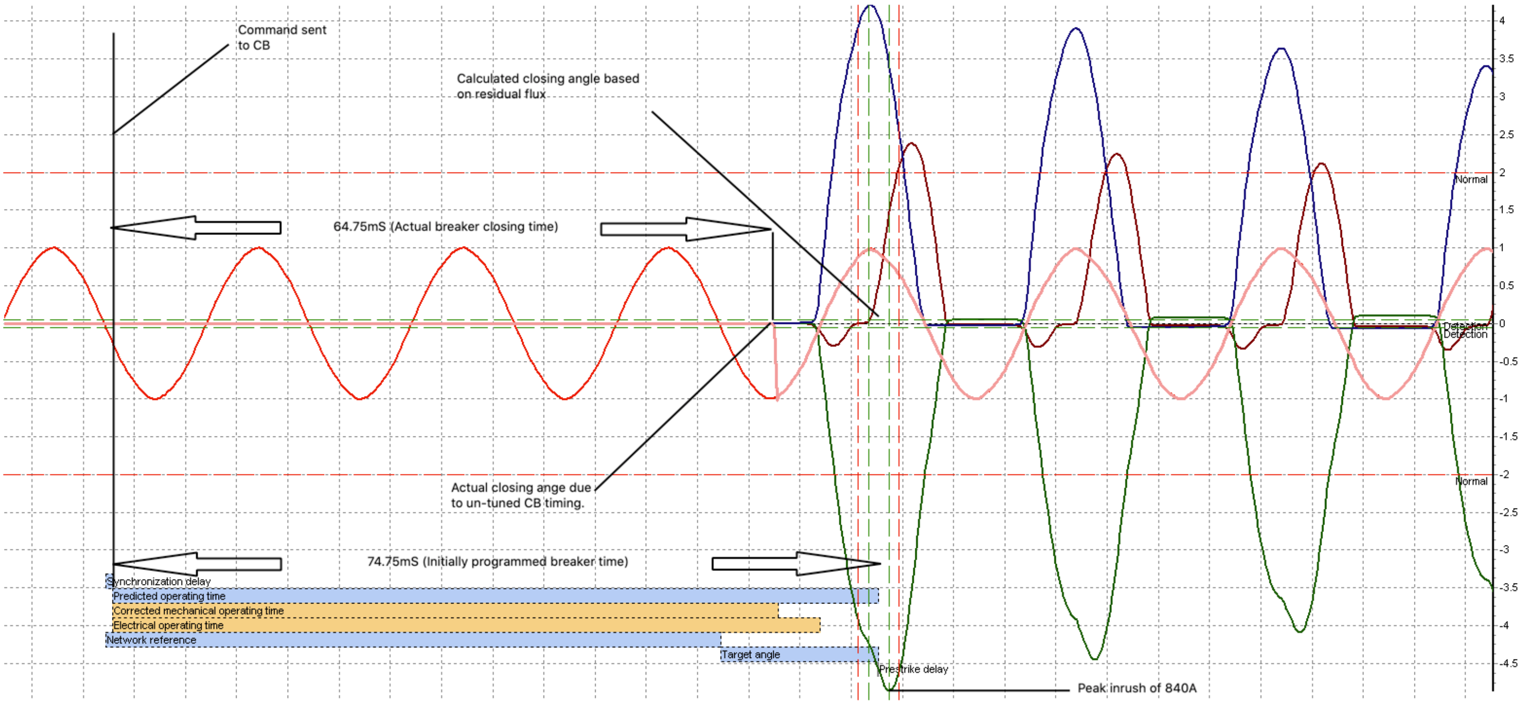

Figure 4-7 - First closing operation

The above Figure 4-7 shows the first closing operation done via the SynchroTeq. The timing was not yet correctly characterised and as can be seen the SynchroTeq target was missed. This resulted in a peak inrush current of 840A. This operation was used to correctly measure the timing of the CB and the application file was updated accordingly.

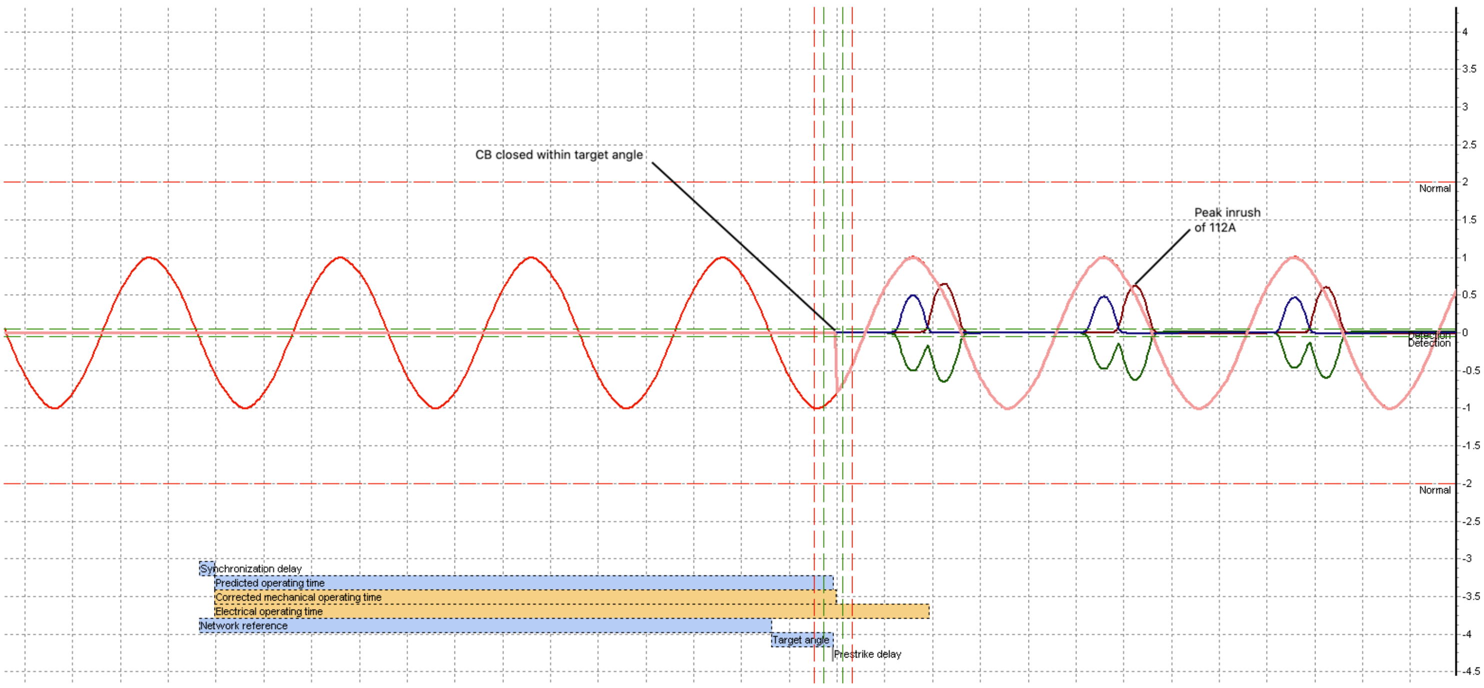

Figure 4-8 - Commissioned Waveform

The above Figure 4-8 shows the commissioned waveform. Here the current conduction began at exactly the target angle calculated by the SynchroTeq, resulting in minimum inrush current less than 1PU. The final peak value of inrush current was 112A meaning an over 8-fold reduction in peak inrush current.

4.3 SSEN LEAN Project

The SynchroTeq MVX was used for Scottish and Southern Energy Networks (SSEN's) LEAN project. This project was to switch out one of a pair of distribution transformers during periods of low loading to reduce no load losses in the network. SSEN wanted to ensure that this regular transformer switching would not cause power quality issues on the network so engaged Enspec Power to supply Point-on-Wave relays to mitigate inrush currents and voltage dips.

Figure 4-9 - SSEN 15MVA transformer

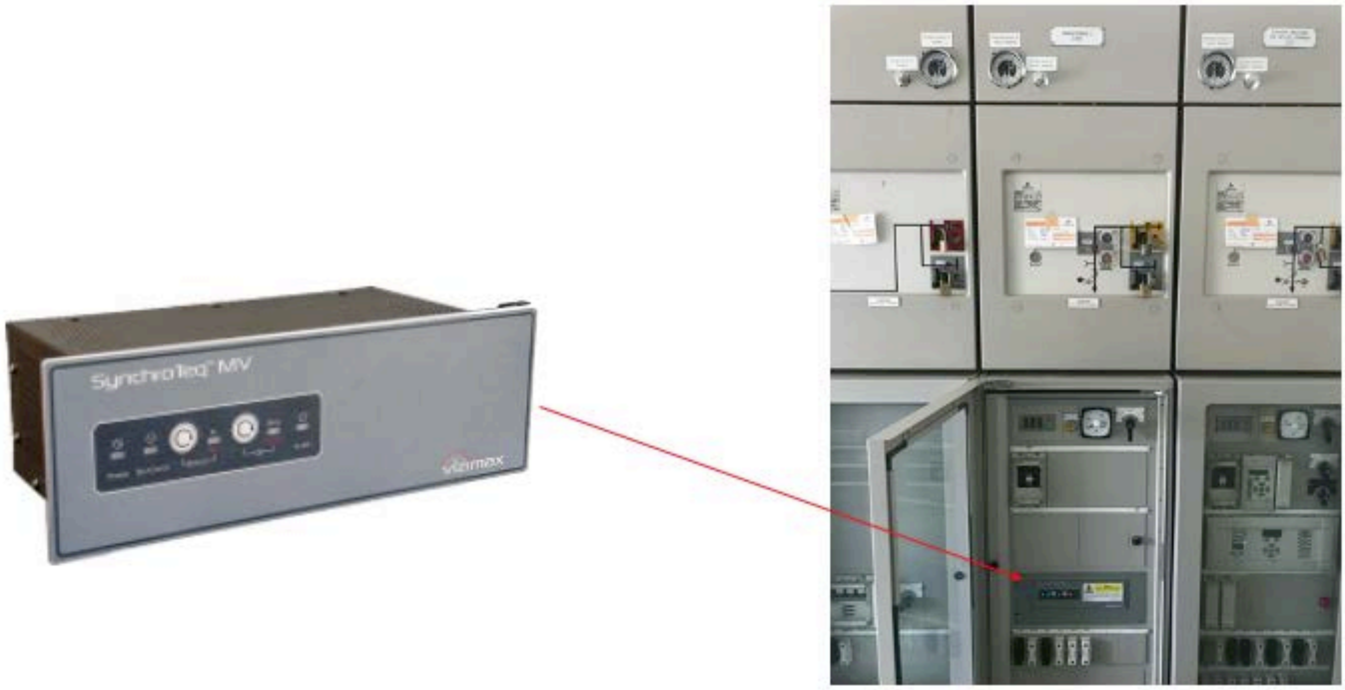

Figure 4-10 - SynchroTeq Installed within Switchgear

The above Figure 4-9 and Figure 4-10 show one of SSEN's 15MVA transformers and the SynchroTeq installation within the switchgear panel. The SynchroTeq was used to control the energisation of the 33kV 3-pole operated Alstom CB.

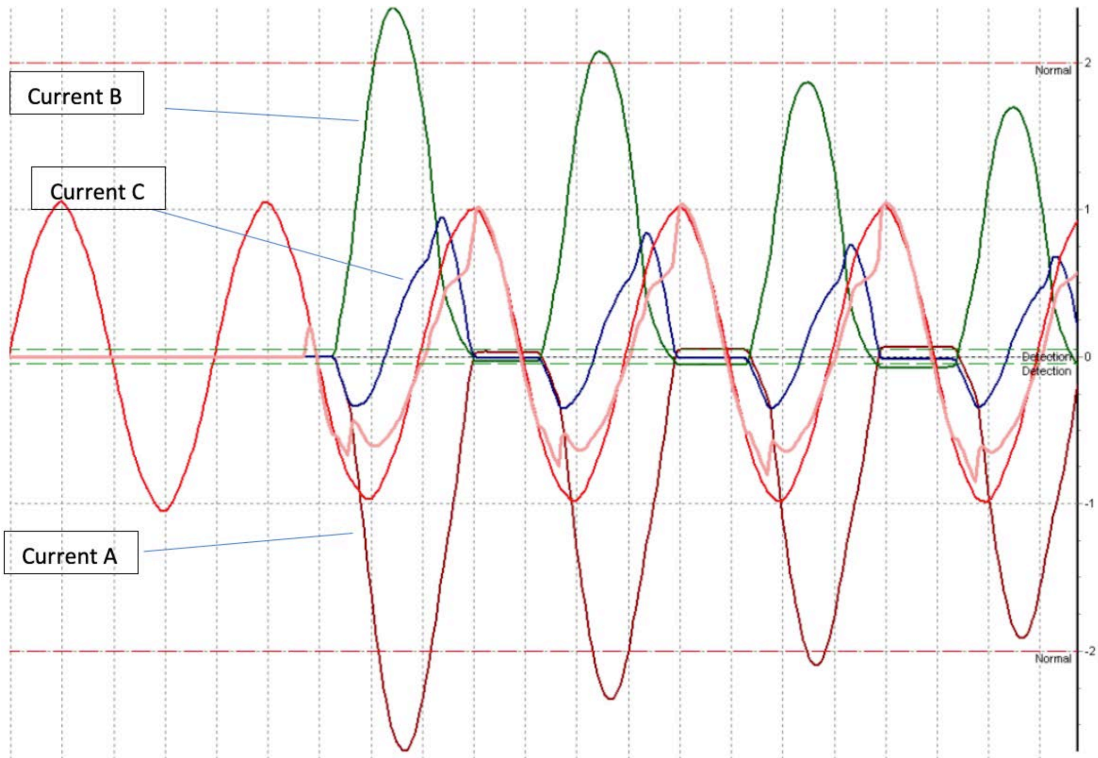

Figure 4-11 - Transformer Energisation before Commissioning

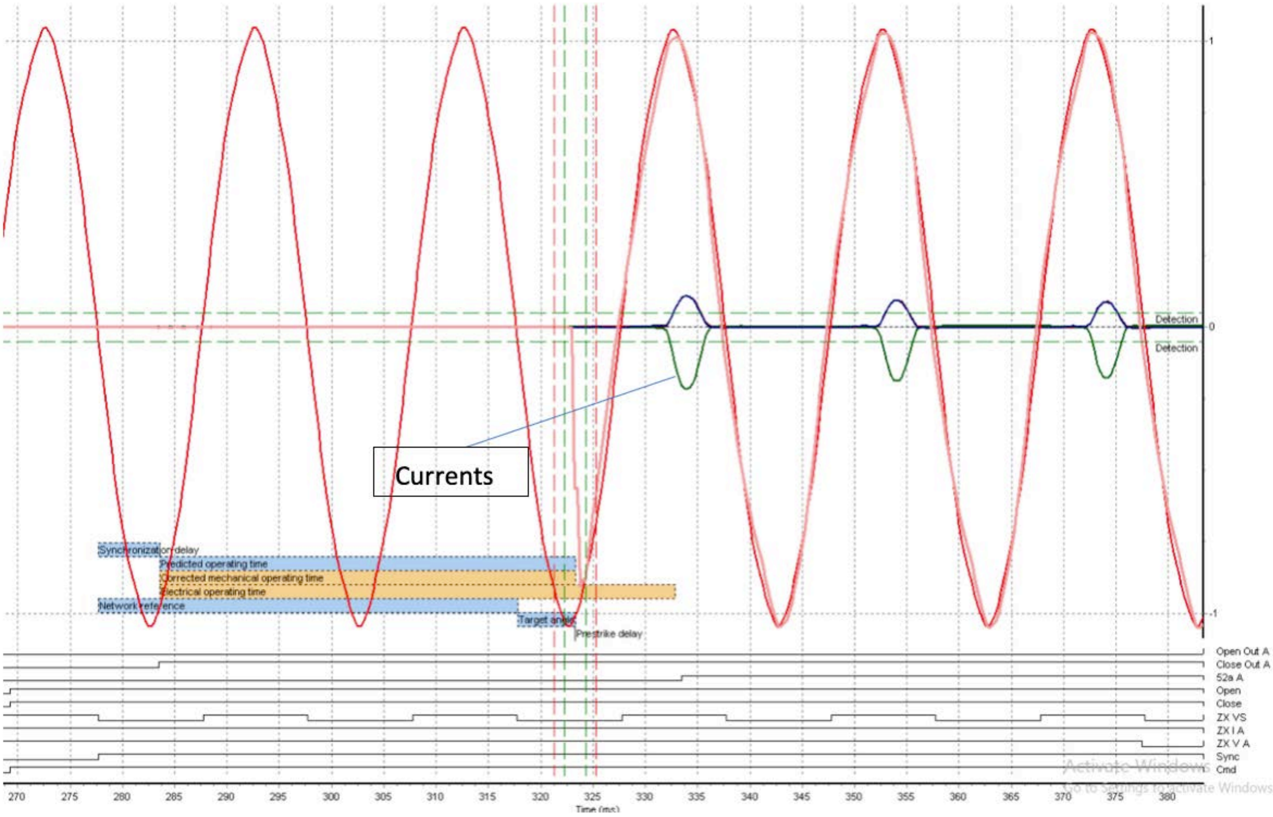

Figure 4-12 – Transformer Energisation after Commissioning

The above Figure 4-11 shows the waveform captured before the SynchroTeq was commissioned. A peak 2.4 PU inrush current was recorded along with a noticeable collapse of the voltage waveform as a result of the inrush.

The above Figure 4-12 shows the waveform captured after the SynchroTeq was commissioned. The inrush current was greatly reduced to a maximum of 0.25 PU and the voltage waveform remained unaffected. The below graphic shows the maximum inrush current obtained from either of the transformers at the distribution substation over the period of 2 months.

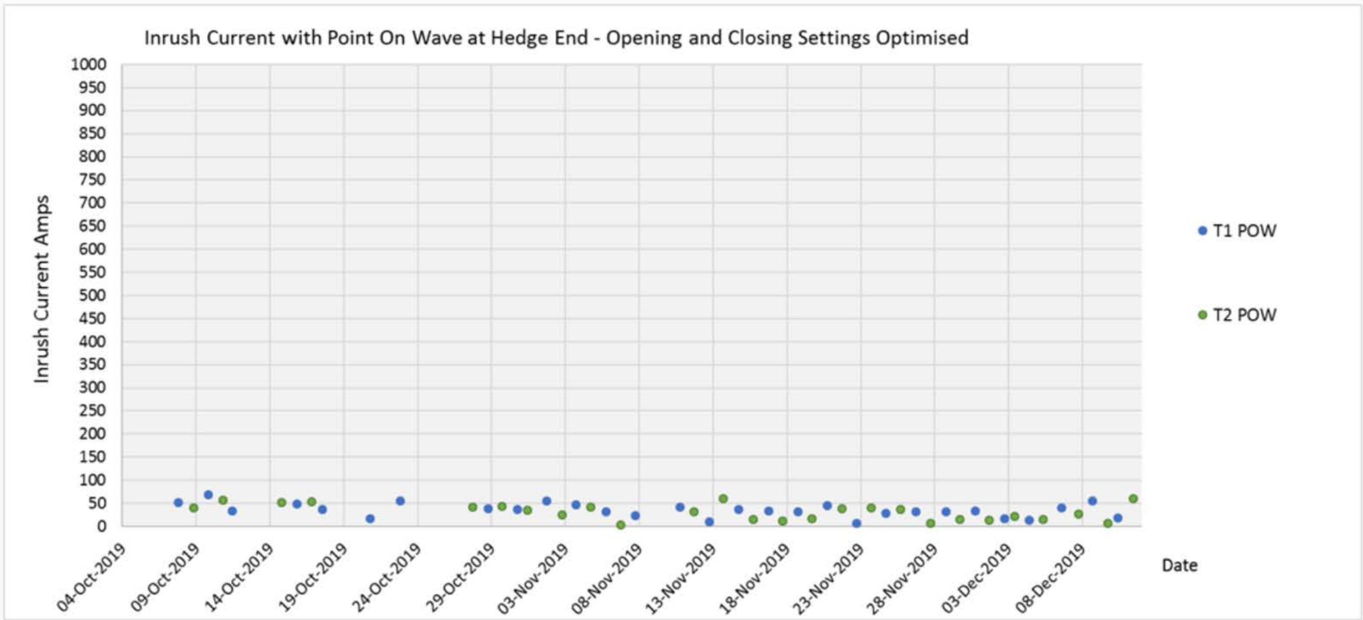

Figure 4-13 - Inrush Current Data with SynchroTeq in Service

5 Conclusion

In summary, it has been shown that by using the SynchroTeq device, inrush current caused by transformer energisations can be significantly reduced. Three installed and commissioned cases have been presented that show the potential of the SynchroTeq to ensure P28 compliance when initial system studies predict potential for large voltage dips.