May 17, 2019

A Project to Correct Mill Power Factor

Selection and Deployment of a Second Capacitor Bank

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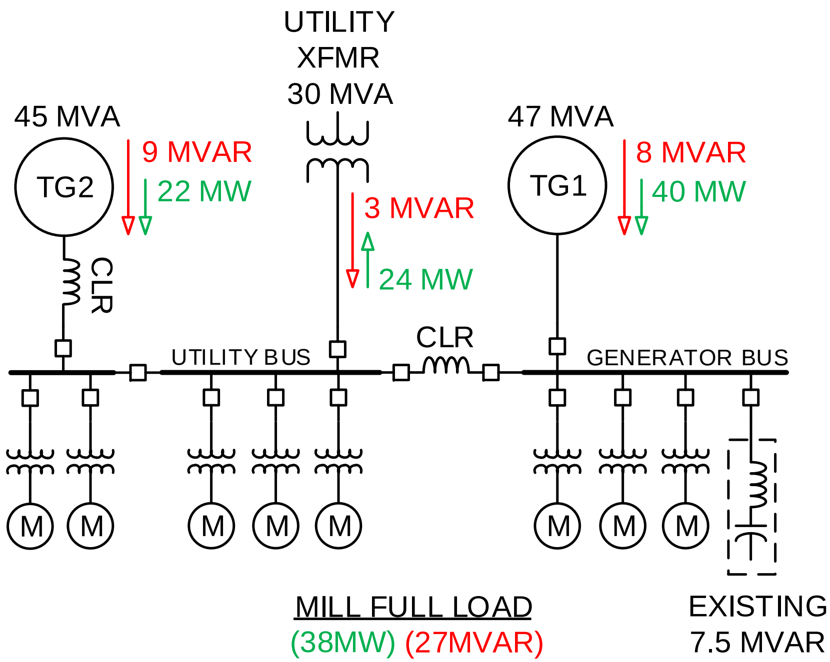
Pulp Mill Profile



SBSK Pulp Mill

Existing Power Flow

- Utility Bus & Generator Bus operate at 13.8kV, with 2.4kV and 480V Secondary Subs
- Mill load at full production → 38 MW/27 MVAR
- Generators supply 17 MVAR reactive power to mill load
- Existing Capacitor Bank supplies 7.5 MVAR reactive power to the mill load
- The mill imports 3 MVAR from Utility
- TG1 provides process steam and is operated as a regulated unit (constant P & V)
- TG2 does not provide process steam and is operated as a condensing unit (constant P & Q)
- ISSUE: TG1 is operating at reactive limit with frequent trips due to overheating of the field

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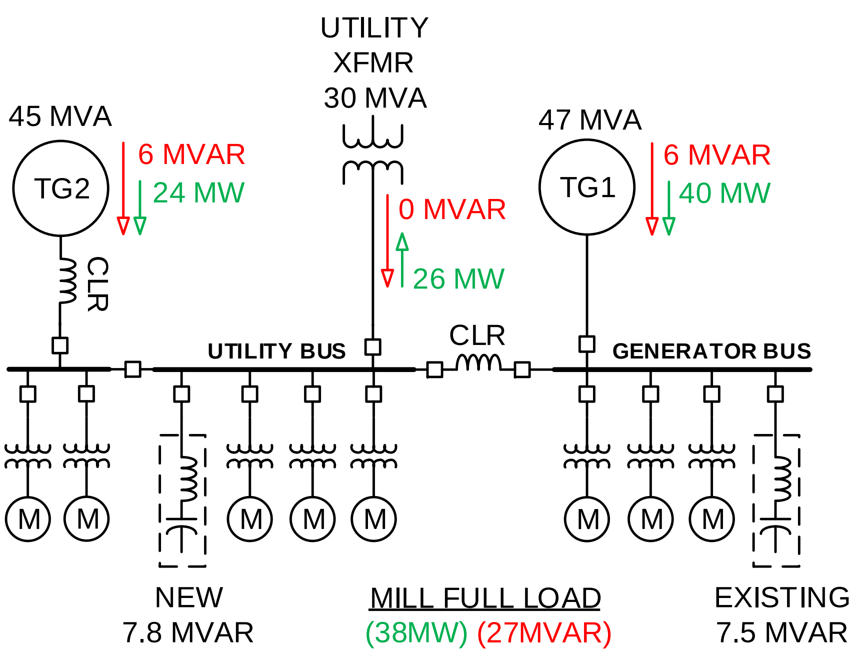
Engineering Scope

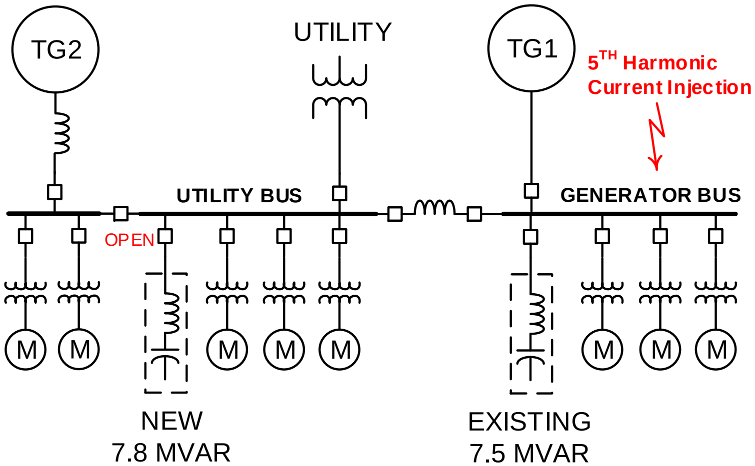


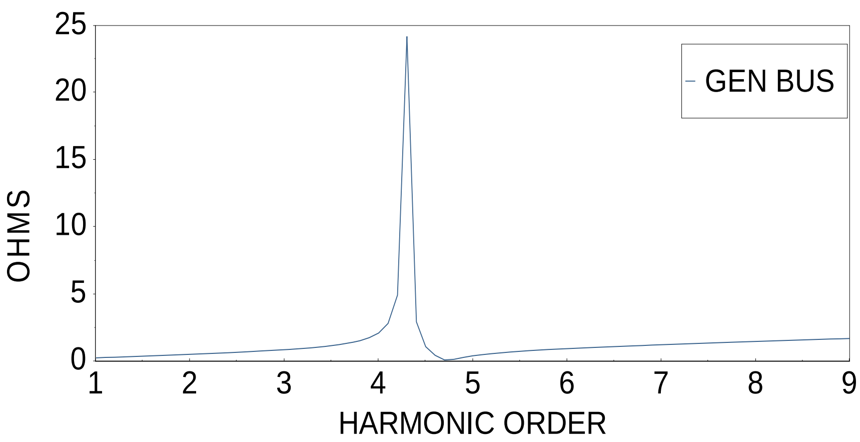
SBSK Pulp Mill

Projected Power Flow

- Specify technical details for new capacitor bank to be connected to the Utility Bus
- Run calculations in both Frequency Domain & Time Domain to investigate the impact of installing the second capacitor bank
  - → Harmonics & Resonance
  - → Circuit Breaker TRV
  - → Back-to-Back Switching Currents
  - → Outrush Current
  - → Bus Voltage Transient
- Develop Cap Bank Switching Procedure for Mill Startup & Shutdown Operations
- Record cap bank inrush current & bus voltage waveforms during startup of the new cap bank

Harmonic Resonance



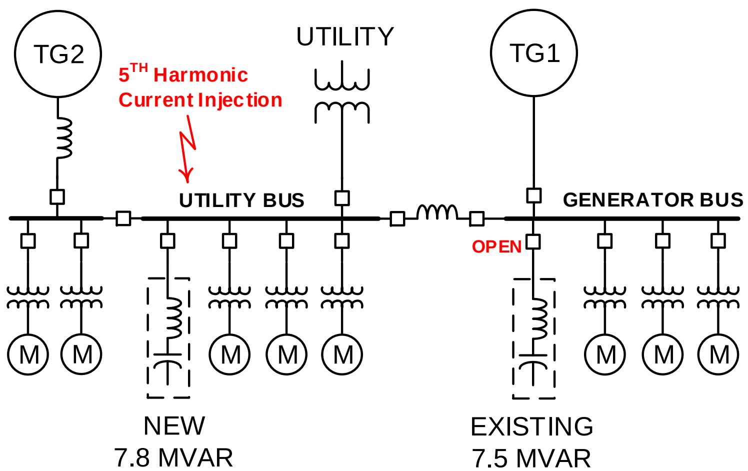


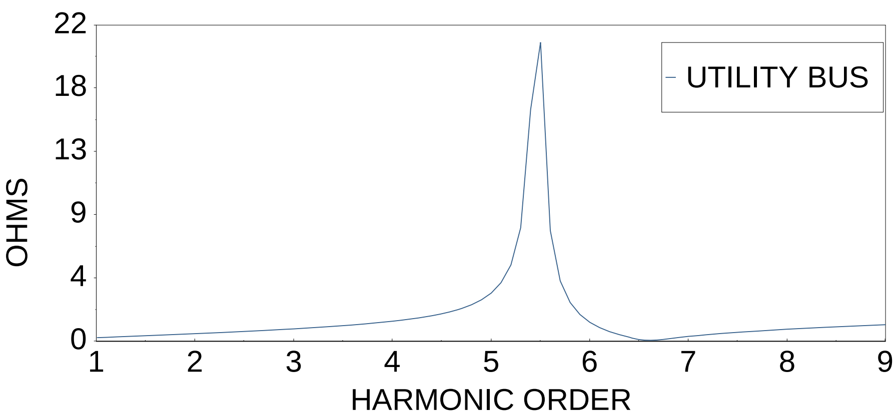
- IEEE 519-2014, *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*, New York, NY: IEEE.

- Existing cap bank on Generator Bus is tuned to filter 5th harmonic currents, tuning point H=4.8

- New cap bank on Utility Bus is designed to filter 7th harmonic currents, tuning point H=6.8

Harmonic Resonance





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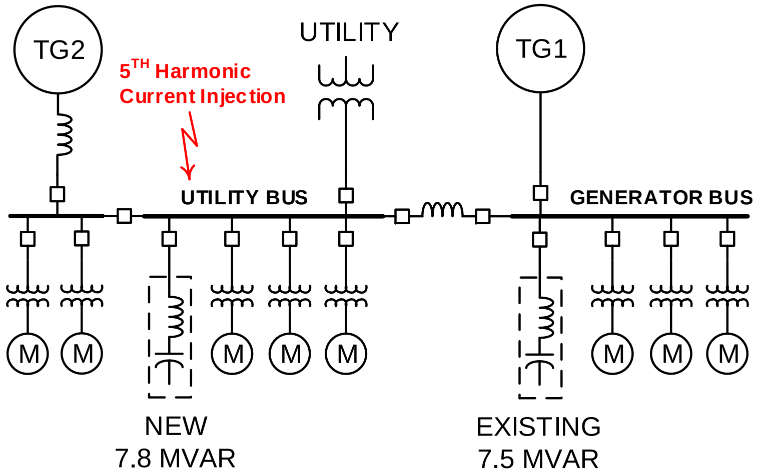
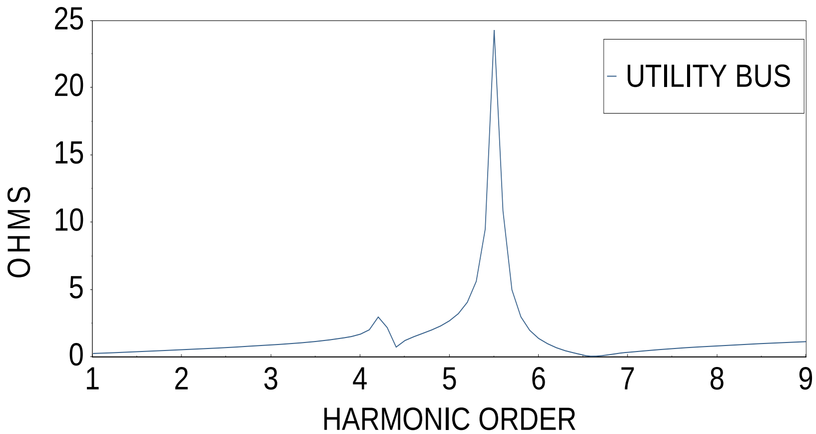
Harmonic Resonance



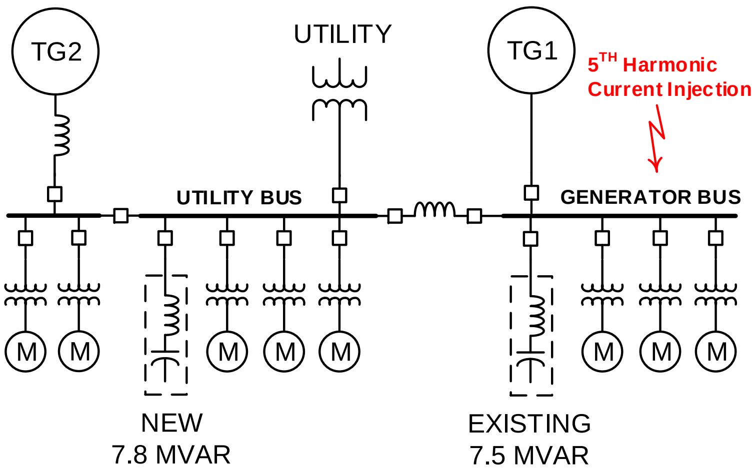


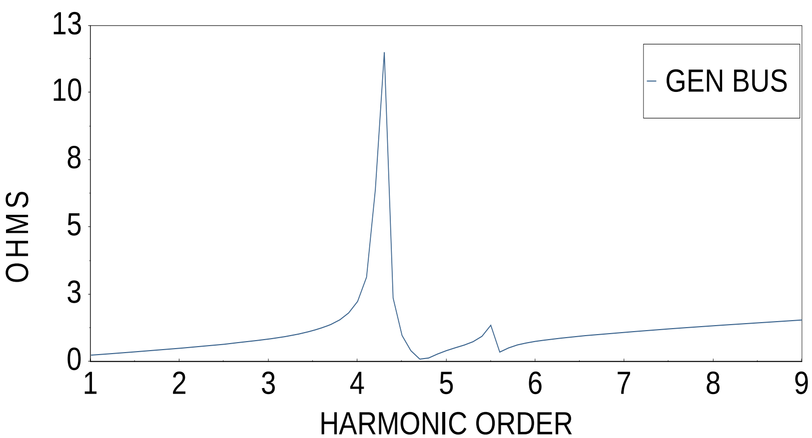
Utility Bus

- Both cap banks in service , Mill at full production
- 5th harmonic current injected on the Utility Bus
- Frequency response of the system shows two resonant points
- Resonant points are close to even harmonic orders

5 Amps X 2 Ohms = 10 Volts

Harmonic Resonance



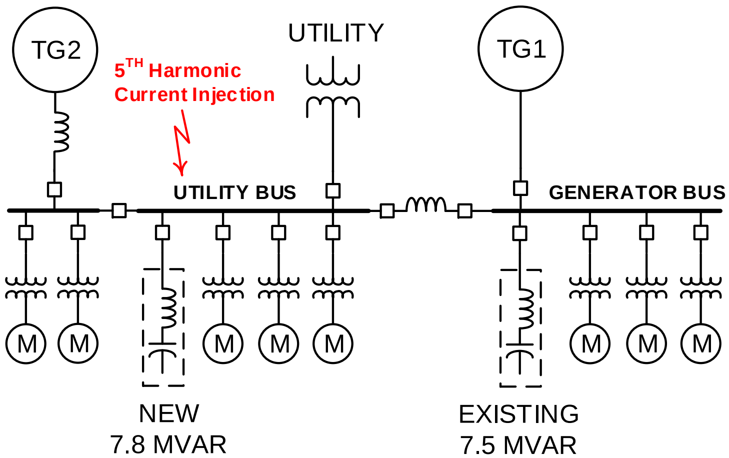


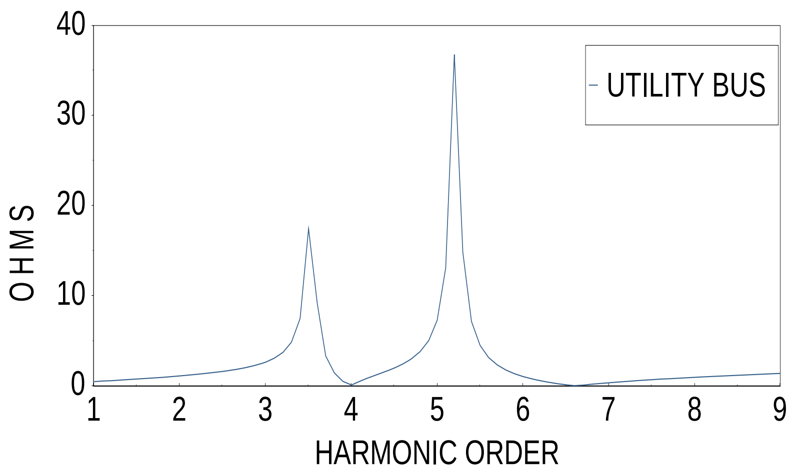
Generator Bus

- Both cap banks in service, Mill at full production
- 5th harmonic current injected on the Generator Bus
- Again, the frequency response of the system shows two resonant points
- Resonant points are close to even harmonic orders

5 Amps X 0.5 Ohms = 2.5 Volts

Harmonic Resonance





- Mill load is reduced to 50% for this simulation
- Resonant impedance increases in magnitude
- Resonant points shift closer to odd harmonic orders – Dangerous Condition!

5 Amps X 15 Ohms = 75 Volts!

Many simulations were required to develop capacitor bank switching procedure for Mill Startup & Shutdown operations

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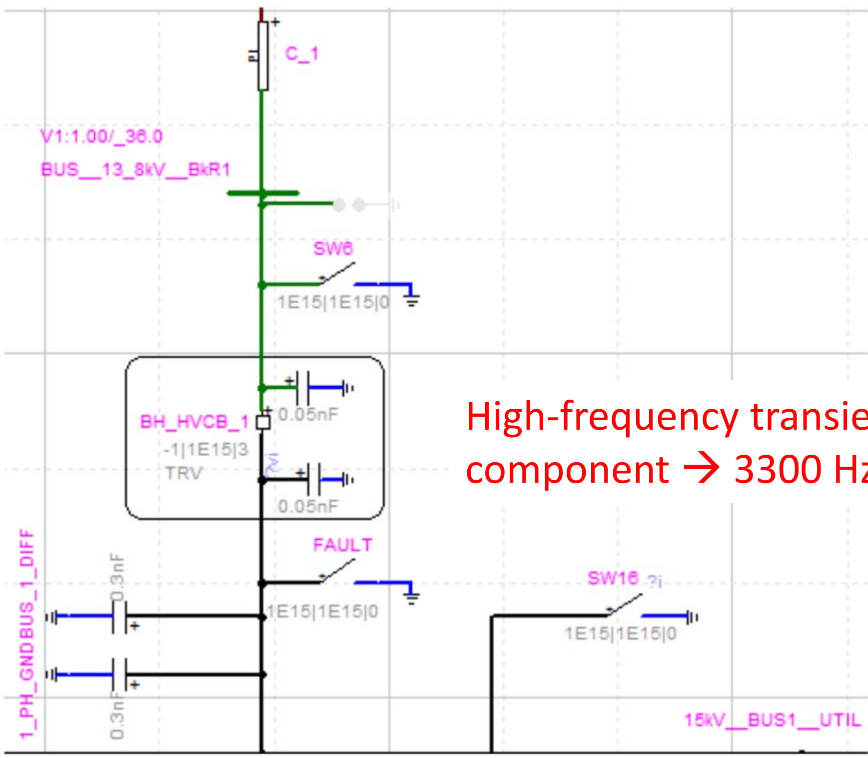
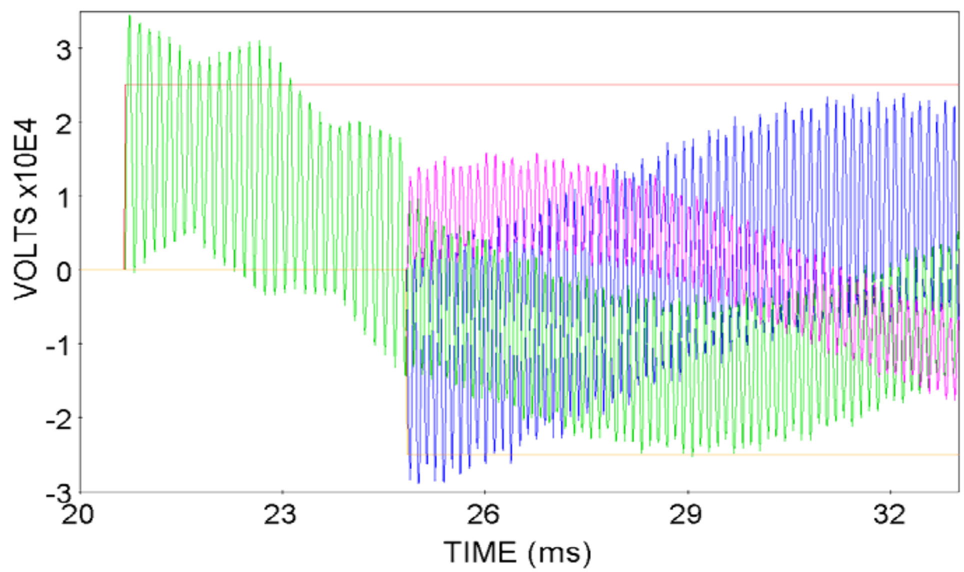
Circuit Breaker TRV

Inherent Voltage → voltage across circuit breaker when interrupting a fault



High-frequency transient component → 3300 Hz

- IEEE C37.011-2011, *IEEE Guide for the Application of Transient Recovery Voltage for AC High-Voltage Circuit Breakers*, New York, NY: IEEE.
- IEEE C37.04b-2008, *IEEE Standard for Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*, New York, NY: IEEE.



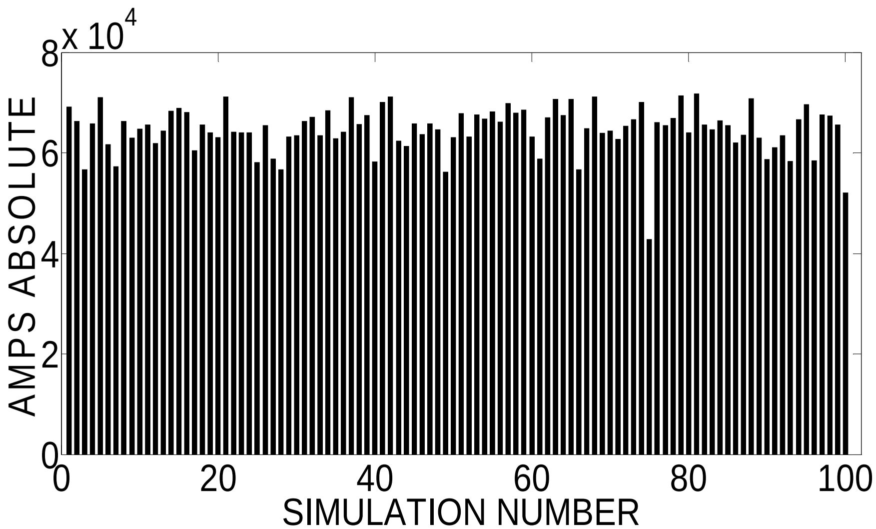
Circuit Breaker TRV

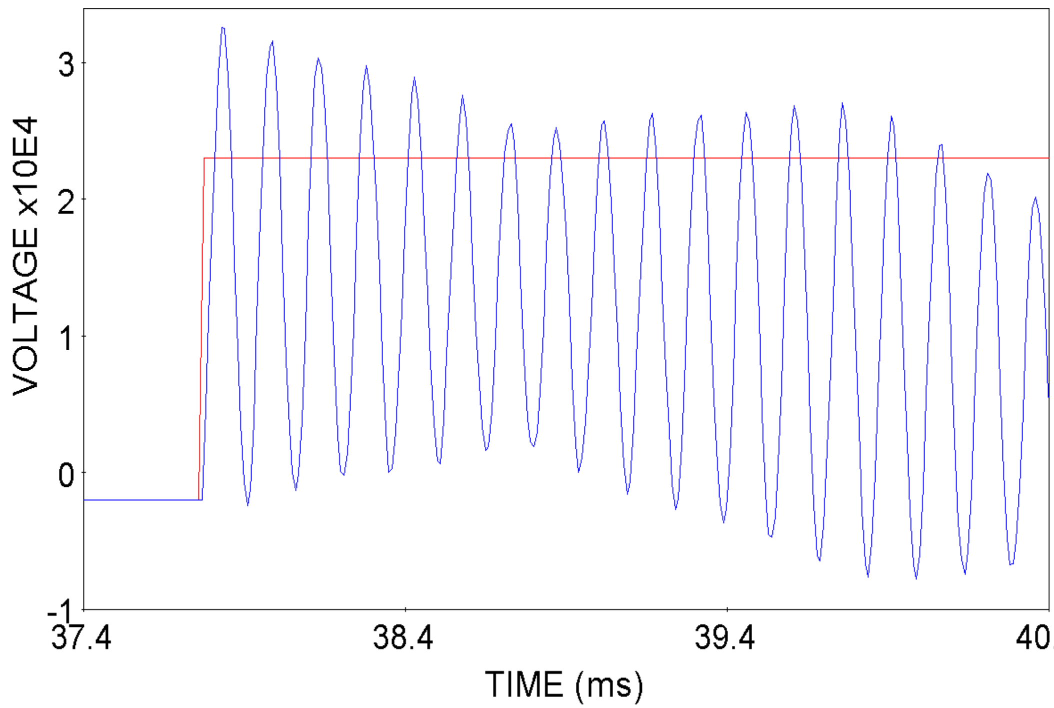
TRV Rating Envelop from IEEE C37.04b-2008

Inherent Voltage exceeds rating envelop on first pole-to-open

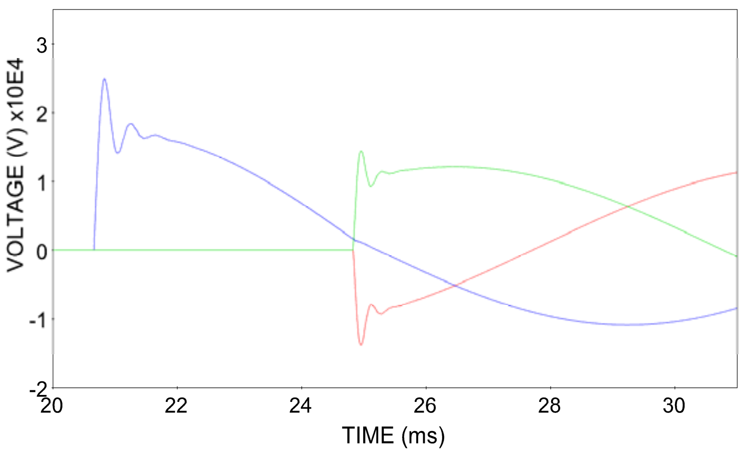
Dangerous Condition! Breaker could restrike and re-ignition of the fault is possible!

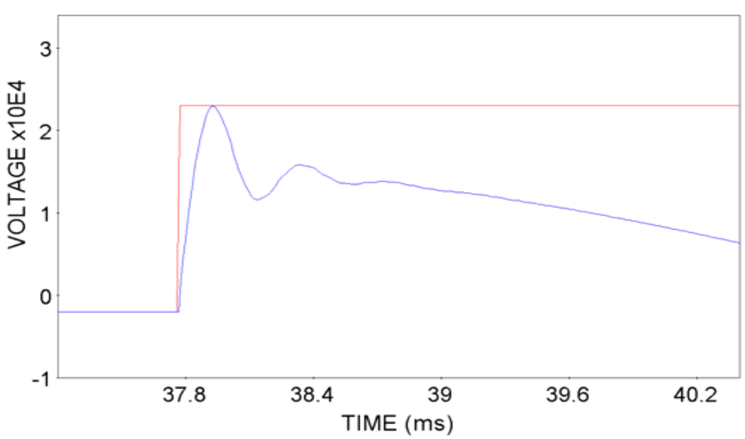
- IEEE C37.012-2014, *IEEE Guide for the Application of Capacitance Current Switching for AC High-Voltage Circuit Breakers Above 1000V*, New York, NY: IEEE



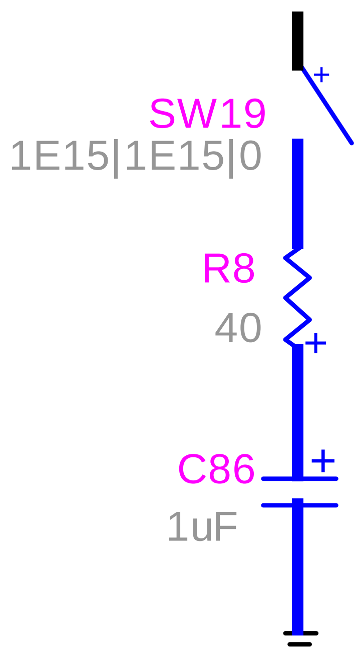


Circuit Breaker TRV



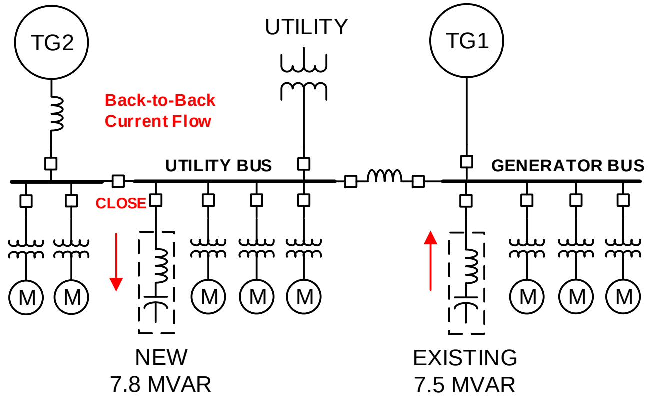


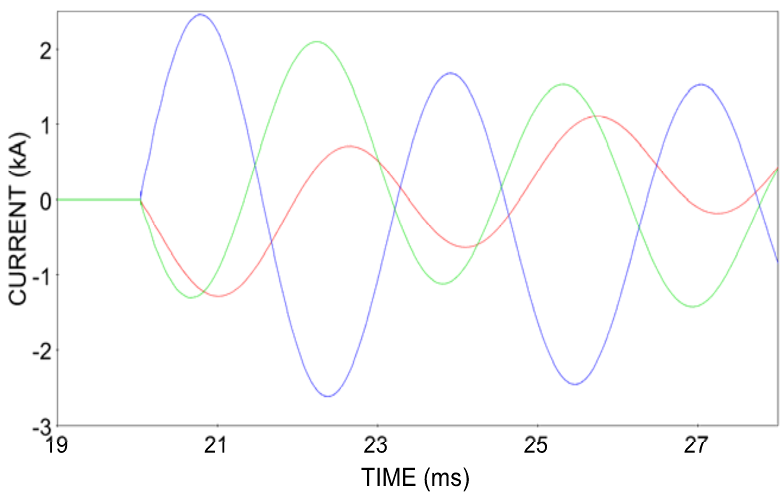
One solution to the TRV issue is to install RC Snubber at the Utility Transformer secondary



Snubber eliminates the high-frequency transient component of the Inherent Voltage

Back-to-Back Switching Current

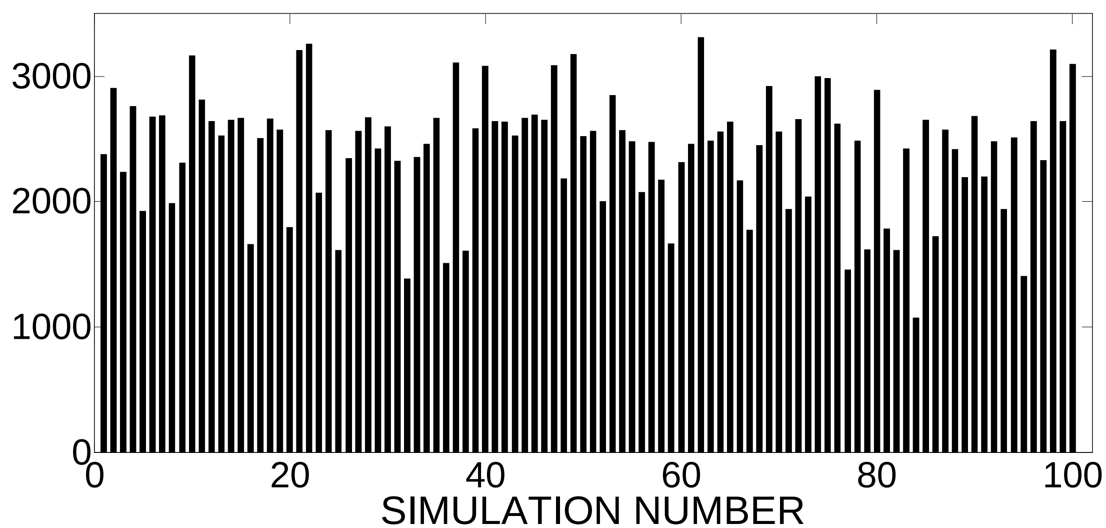




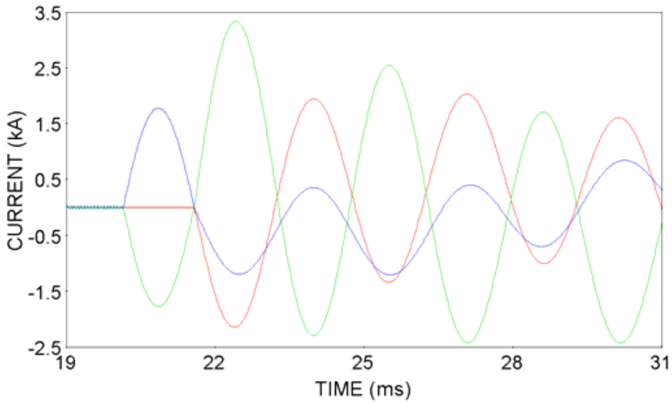
IEEE C37.06-2009, *IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis – Preferred Ratings and Related Required Capabilities for Voltages Above 1000V*, New York, NY: IEEE.

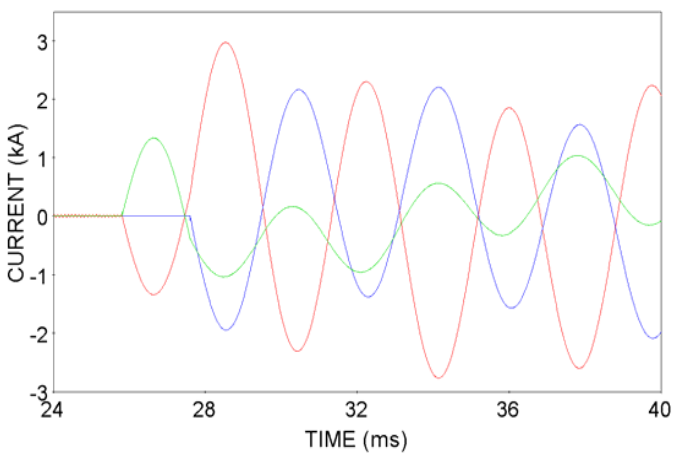
Table 4 in IEEE Standard C37.06-2009 offers preferred ratings and required capabilities for Class S1 circuit breakers when used for switching capacitor banks (Current & Frequency).

Worst-case back-to-back current depends on where the first pole-to-close closes on the voltage waveform. A Statistical analysis is required to capture worst-case.



Back-to-Back Switching Current





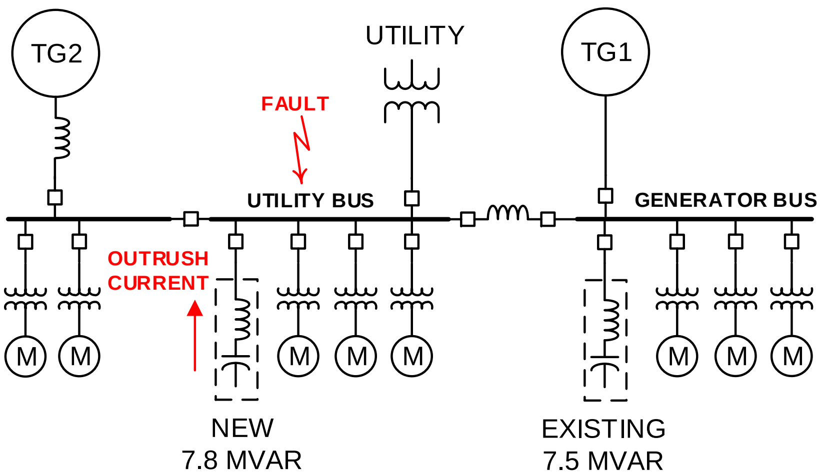
- Worst-case B2B current is 3,400 Amps when energizing **Utility Bus** cap bank
- Worst-case B2B current is 2,900 Amps when energizing **Generator Bus** cap bank

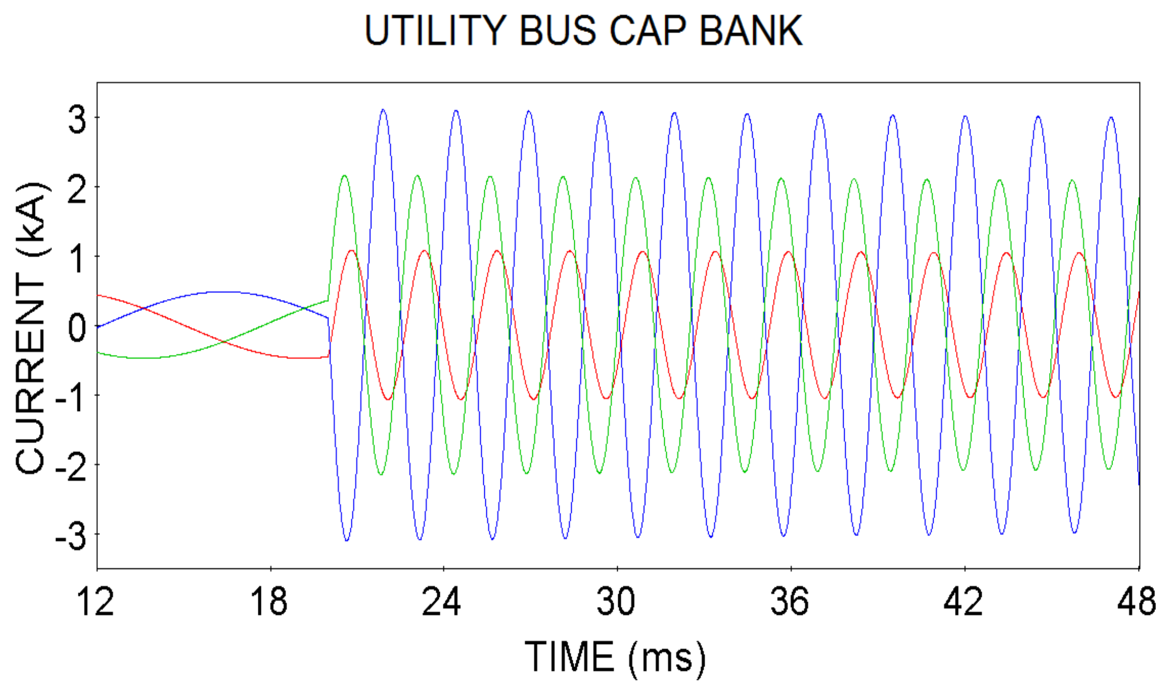
The CLR in the bus-tie reduces B2B currents!

Cap Bank Outrush Current

IEEE C37.06-2009, *IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis – Preferred Ratings and Related Required Capabilities for Voltages Above 1000V*, New York, NY: IEEE.

Frequency of Outrush Current is around 320 Hz

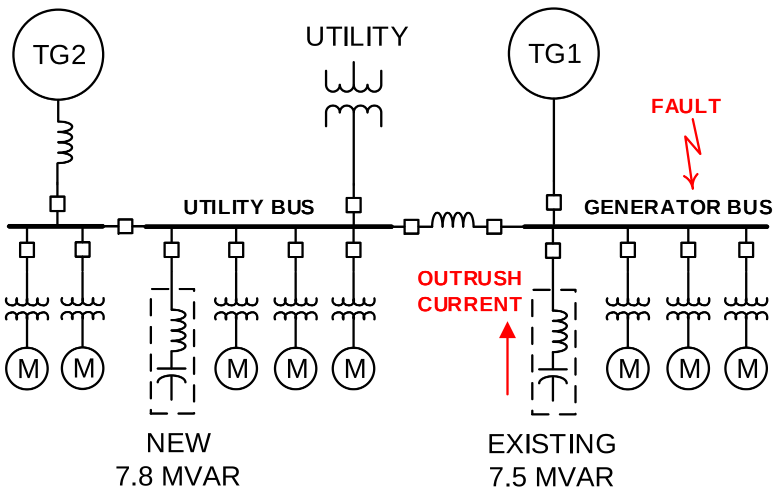


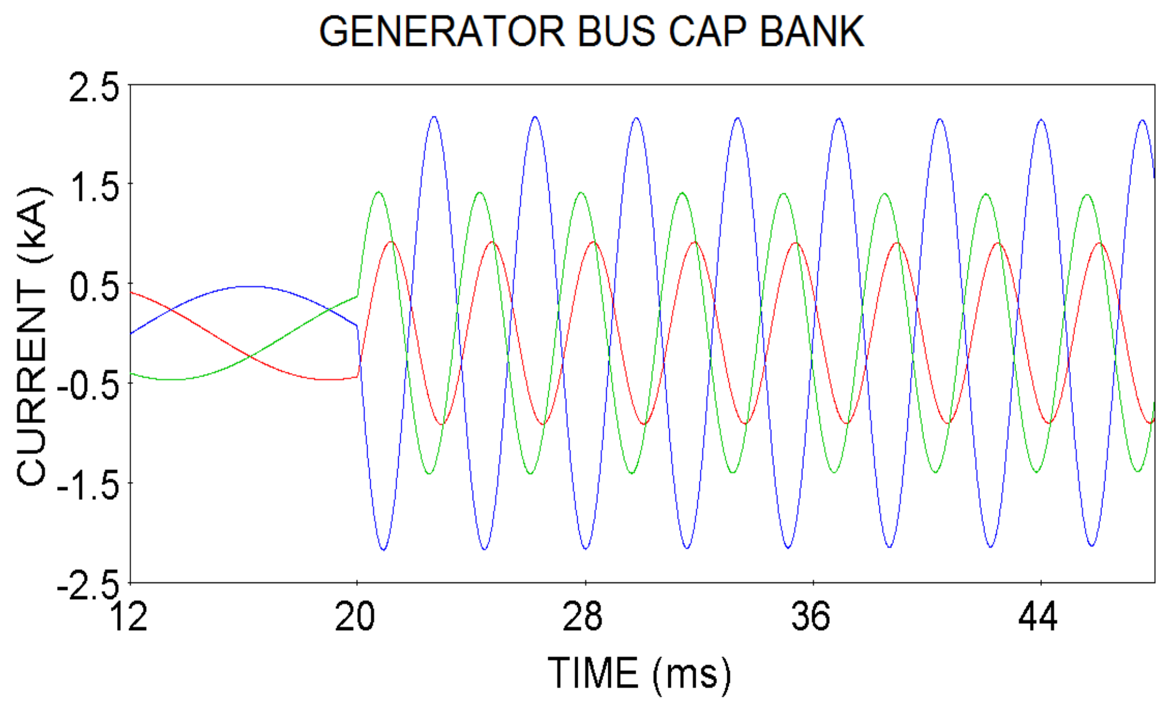


Cap Bank Outrush Current

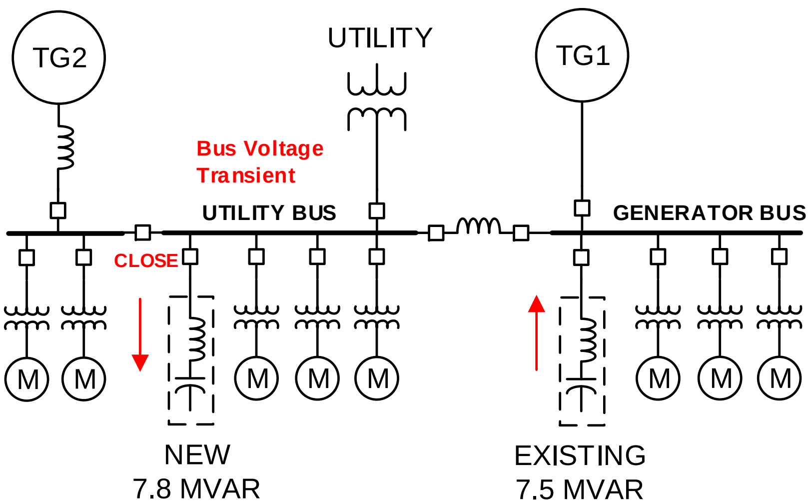
IEEE C37.06-2009, *IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis – Preferred Ratings and Related Required Capabilities for Voltages Above 1000V*, New York, NY: IEEE.

Frequency of Outrush Current is around 270 Hz





Bus Voltage Transient Response



The magnitude of this bus voltage transient is 15,050 Volts peak – that's 1.33 per unit!

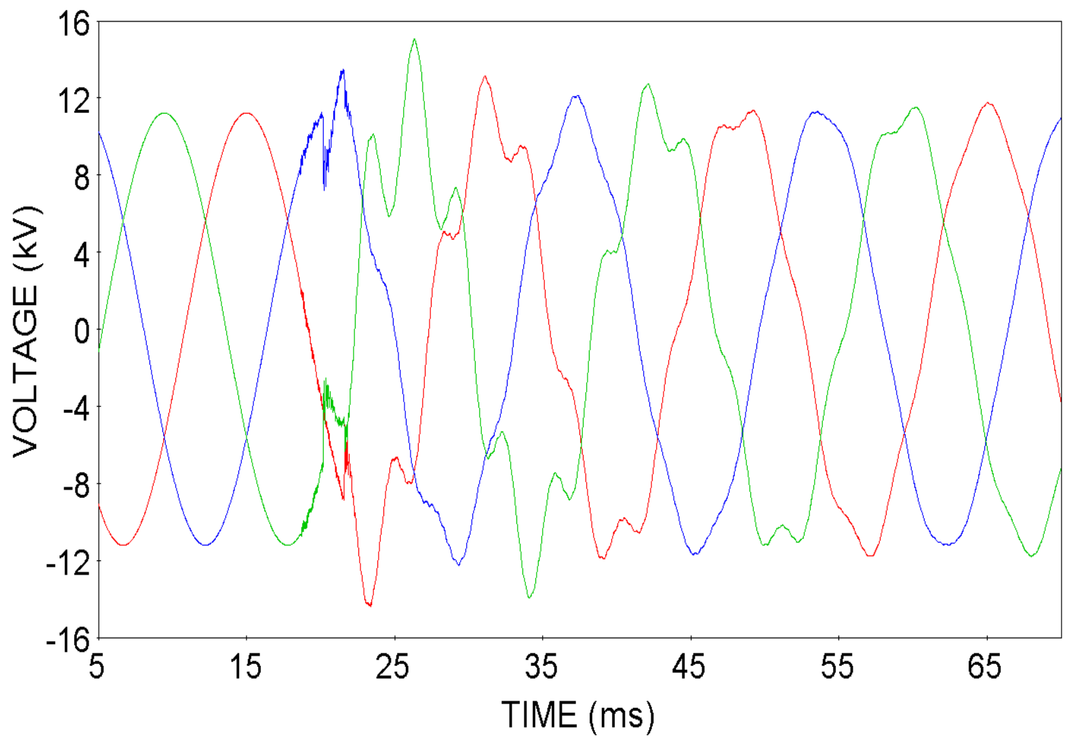
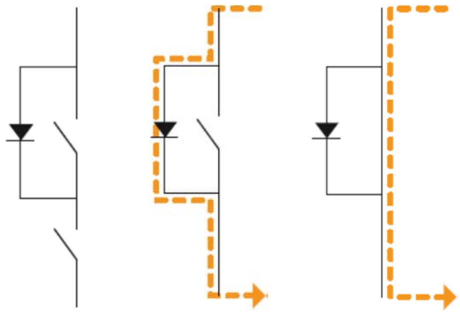
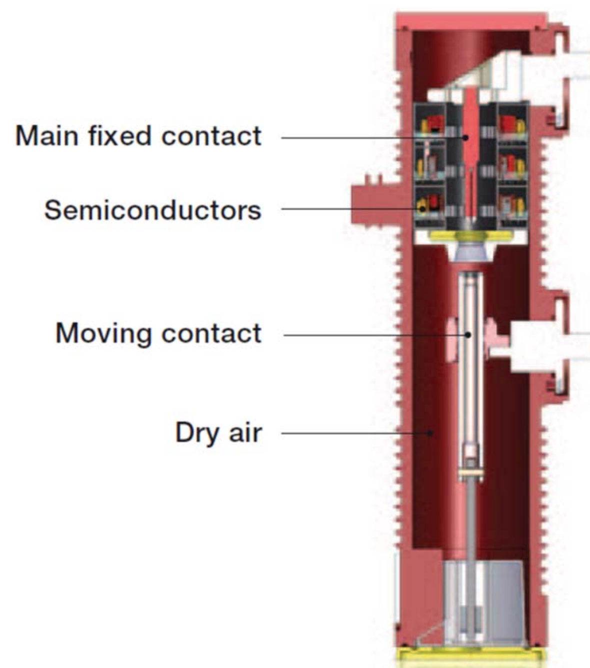


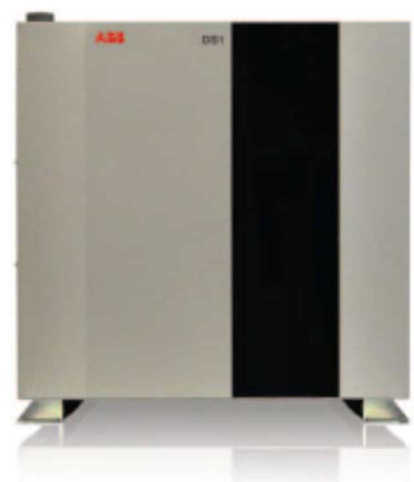
ABB DS1 Transient Free Capacitor Switch





A diode-based transient-free capacitor switch (TFCS) was incorporated into the new capacitor bank design.

The ABB model DS1 synchronizes with the AC system to perform capacitor bank switching operations without disturbing the network.



Capacitor Bank Deployment

Capacitor Bank Deployment

A plan was developed to use three 3-phase power monitors to record voltages during switching.

Meter connected to the breaker on the Utility Bus that would connect to the input of the new capacitor bank.

Meter connected at the Generator Bus breaker which feeds the existing capacitor bank.

Meter connected to the 480V system that was deemed to be the most vulnerable, i.e. the supply to the pulp machine sectional and winder drives which are supplied from the Utility Bus, where the new capacitor bank was to be connected.

There was also a peak-reading clamp-on AC ammeter at the existing capacitor bank breaker in an effort to see any significant back-to-back current flow when the new capacitor was put on line.

Capacitor Bank Deployment

First Startup Attempt

When the day for startup arrived, just ahead of a PMO (scheduled pulp machine outage), the breaker that would supply power to the DS-1 was racked in and failed to close. It was racked back out for inspection and troubleshooting. It had been test-operated several times prior to this event, but was found to have a badly broken stationary secondary control block in the cell. It may have been slightly out of alignment during racking. It could not be readily repaired and so the first startup opportunity passed without anything being accomplished.

Capacitor Bank Deployment

Second Startup Attempt

The next PMO was approximately seven weeks later. The 15kV breaker cell had been repaired and tested. The metering was back in place as described. The breaker on the Utility Bus was closed and the input side of the diode switch was energized. All sequence indications looked correct and the operator very tentatively operated the closing control for the diode switch. NOTHING happened, even though that operation had been successfully tested several times! The “opportunity” passed again and troubleshooting efforts found an intermittently faulty crimp in a temperature switch that was employed to prevent closure of the vacuum contacts in the diode switch if the temperature inside the capacitor bank enclosure was below a certain level.

Capacitor Bank Deployment

Successful Startup

The operator closed the control switch to close the DS-1, the status indicators showed change of state and nothing seemed to happen AGAIN!
All indications were that the breaker and diode switch had closed but there was no obvious significant voltage increase, no indicated current on the control room metering panel, only a very small amount of current detected at the capacitor bank itself and, most telling to the operators, no call about loads tripping off in other areas of the mill. After quelling the initial frustration, the project team reconvened in the control room for a closer look at mill power flow. It told a different story. Bus voltages had risen slightly, MVAR's had shifted off of both generators and the utility tie. The capacitor bank was obviously online as the status lights indicated!

Conclusions

- The ElectroMagnetic Transients Program proved to be a very valuable tool to assess the worst-case possibilities involved in switching operations under a variety of power distribution system configurations
- The concept of including a “zero crossing closure device” to switch the relatively large capacitor bank ON and OFF line proved extremely valuable. The switch options considered included conventional breaker, timed pole-closure breaker and diode insertion and the project team believes the ABB DS-1 diode-based TFCS was the absolute best choice.
- This project was conceived in an effort to improve reliability of mill operation after a significant increase in internal generation, which was followed by a very trying series of forced power outages. The project has been successful in helping to eliminate those forced outages and has also produced the opportunity for a 2-3 MW increase in power sales as predicted by the calculations.

Thank You

ABB

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