



Modelling and Mitigation of Switching Transients from Inductive Load

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Abstract

In medium and high voltage power system networks, electromagnetic transients are inevitable when switching inductive loads such as free-running transformers, induction motors or power compensation coils. The potential occurrence of switching oscillatory overvoltages defines the insulation co-ordination of cable-networks. Harm can be caused to this insulations by either the amplitude or rise time of transients. In this work, the basic phenomena of switching transients are defined and shown with simple power system models. This work also outlines several mitigating methods.

Introduction

When an inductive load is switched into or out of a system, the transient voltage at the terminals of the load may contain several high frequency oscillatory components. When this oscillatory terminal voltage has a frequency component near one of the natural frequency of the inductive load (e.g. a transformer) and is of sufficient magnitude and duration, permanent damage to the insulation structure of devices in the power system may occur [1]. The basic phenomena for transients during inductive load switching includes [2];

- **Pre-Ignition:** Gap breakdown when closing circuit breaker (CB)
- **Normal Current Chopping:** Occurs when opening a switch or CB.
- **Multiple Restrikes:** Series of ignitions between switch contacts during opening operation.
- **Virtual Current Chopping:** 3-phase re-ignition due to high frequency equalizing currents.

Modelling of Switching Transients

EMTP-ATP-Draw software is used in the modelling of switching transients from inductive loads. Pre-ignition and normal current chopping is demonstrated using the single-phase power system model in Fig.1. When the CB is initially opened and closes at a time $t = 5\text{ms}$, pre-ignition surge is observed at time, $t = 5\text{ms}$, followed by a series of high frequency voltage as shown in Fig.3. When the initially closed CB is opened at 5ms , the transient voltage resulting from the normal current chopping is observed as shown in Fig.4. The 3-phase power system model is used to present the phenomena of multiple restrike. When the initially opened CB is closed at time $t = 9\text{secs}$, the transient overvoltages across the transformer and CB are shown in Figs. 5 and 6 respectively.

Power System Models:

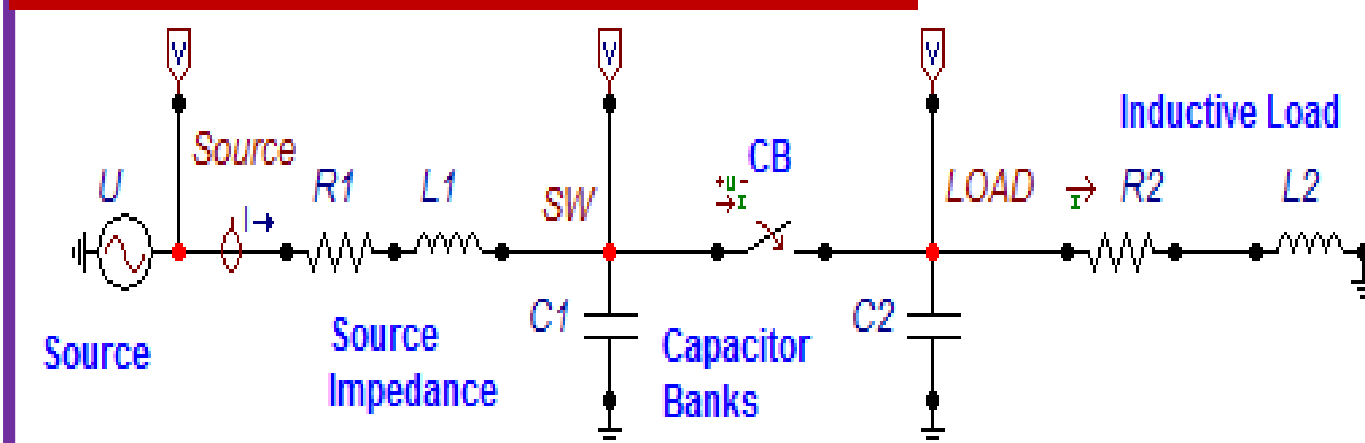


Fig.1: Schematic of a single-phase system with inductive load

Single Phase System
Voltage Source: 33kV
Source Impedance: $0.033 + j0.792 \Omega$
Load: $0.47 + j11.3 \Omega$

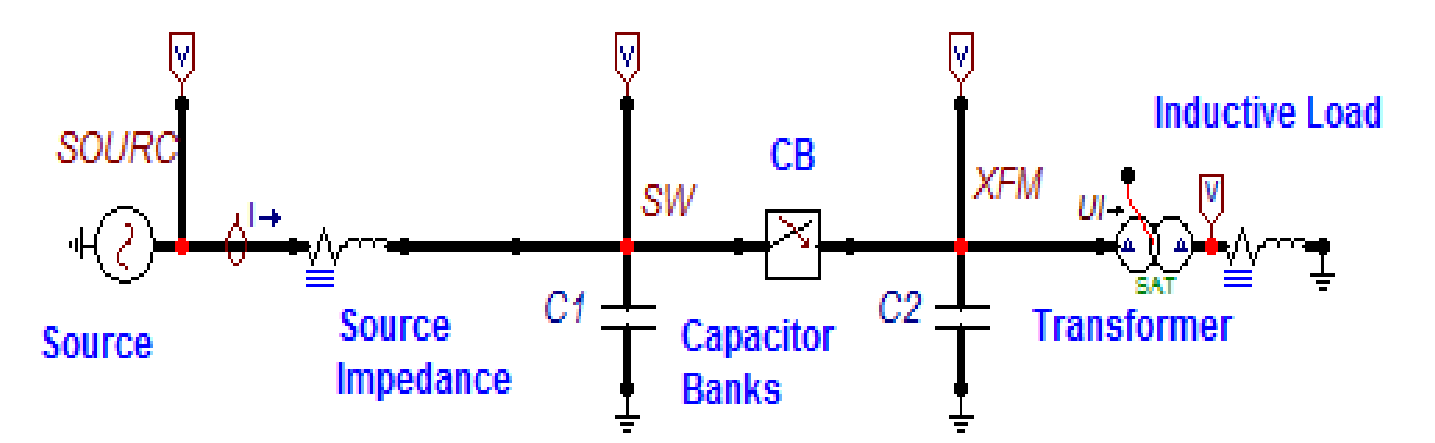


Fig.2: Schematic of a three-phase system with inductive loads

Three Phase System
Voltage Source: 33kV Line-to-Ground
Source Impedance: $0.033 + 0.792 \Omega/\text{ph}$
Load: $0.47 + j11.3 \Omega/\text{ph}$
Transformer: 33kV/12kV Delta/Delta

Modelling Results

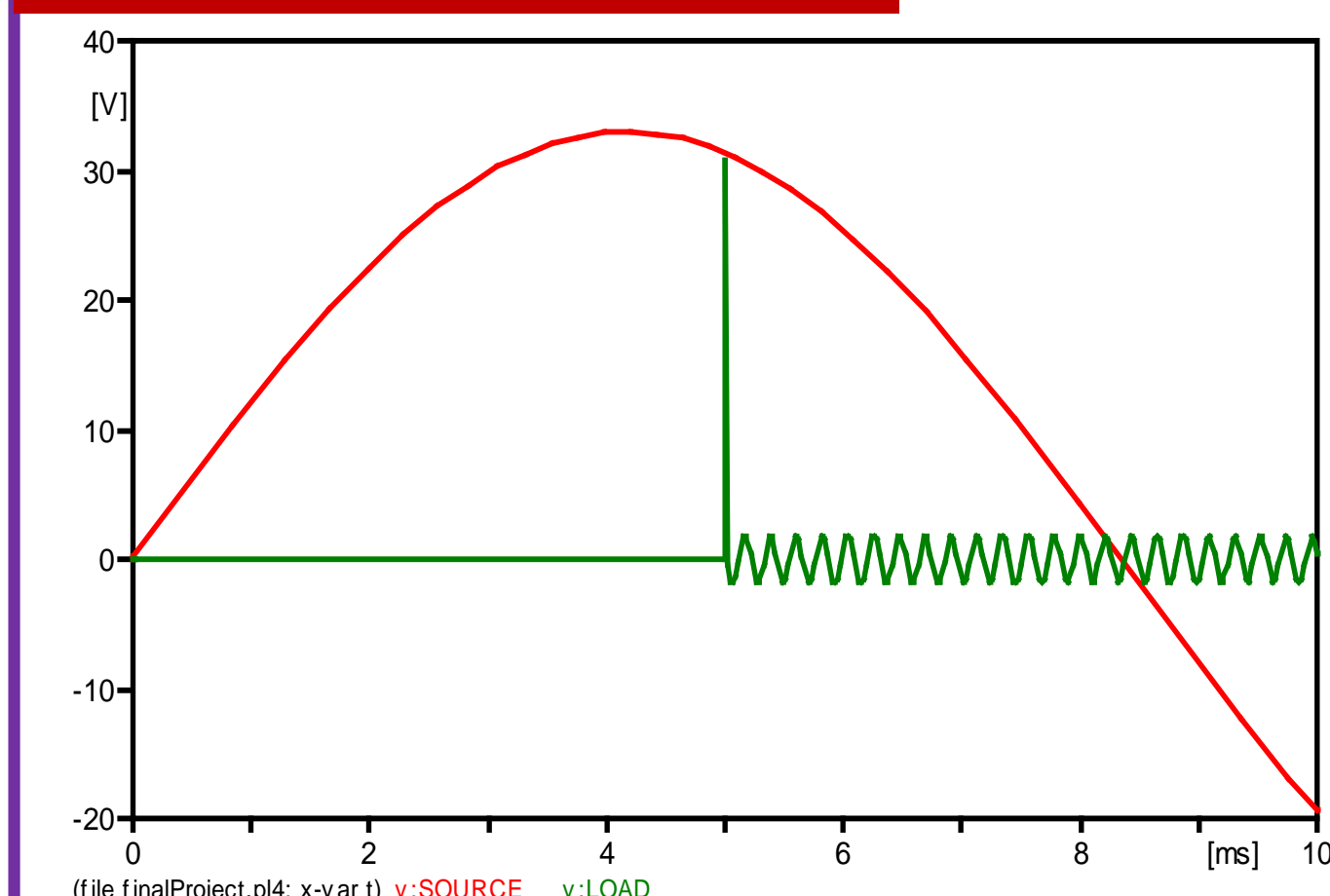


Fig.3: Pre-ignition when CB is closed at time $t=5\text{sec}$

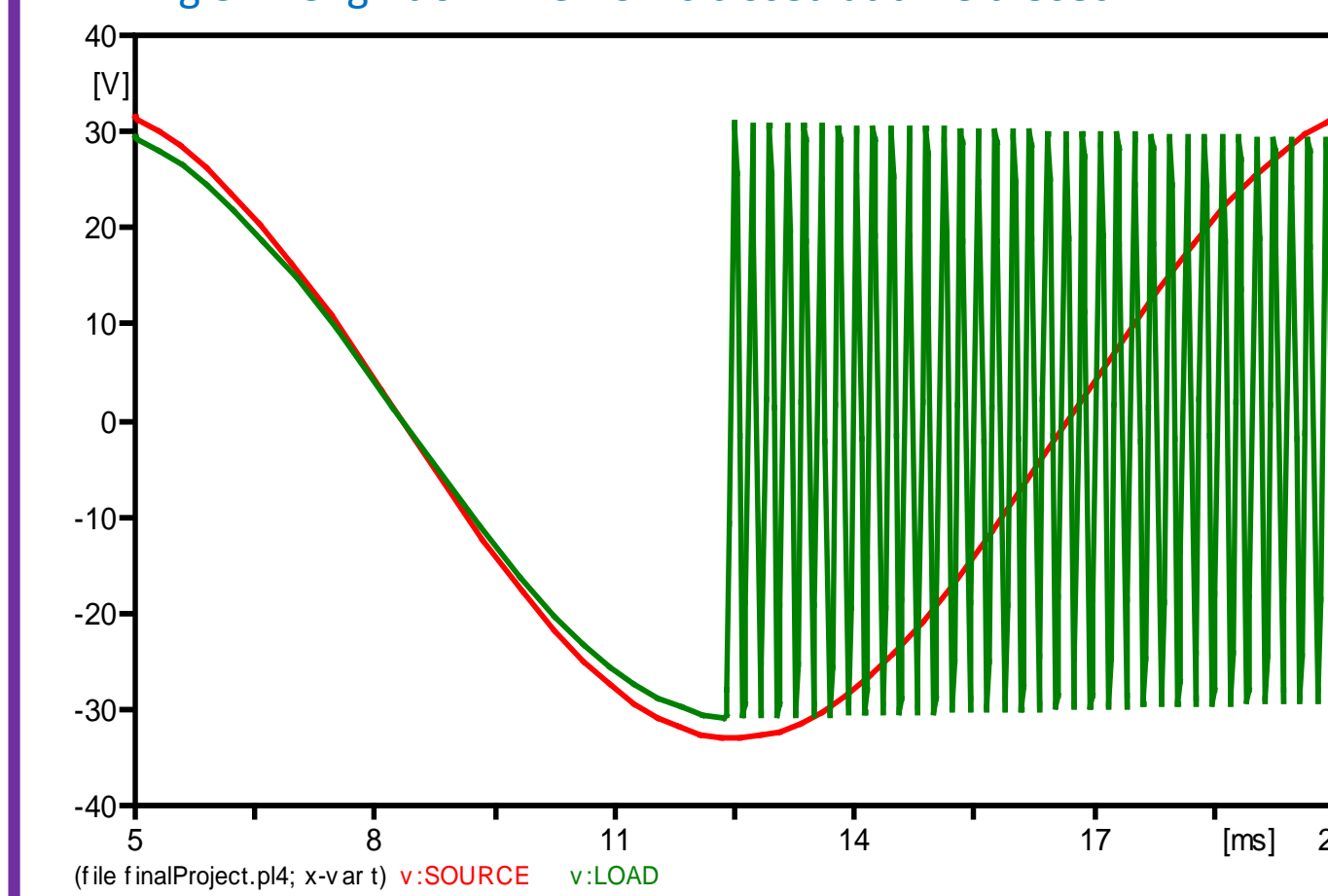


Fig.4: Normal Current Chopping when CB is opened at time $t=5\text{sec}$

Multiple Restrike

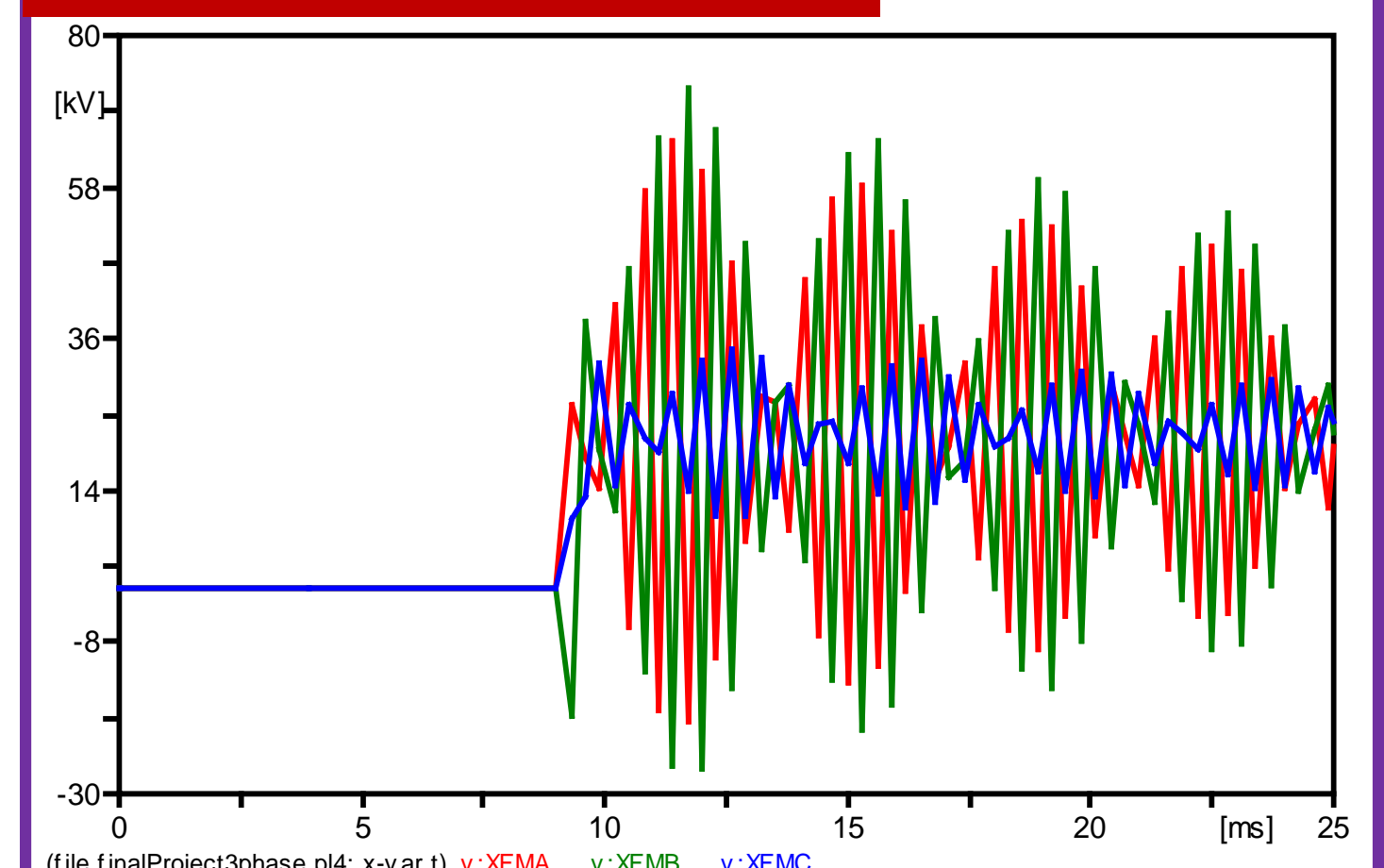


Fig.5: Transient Overvoltage across transformer terminal when CB is closed at time $t=9\text{sec}$

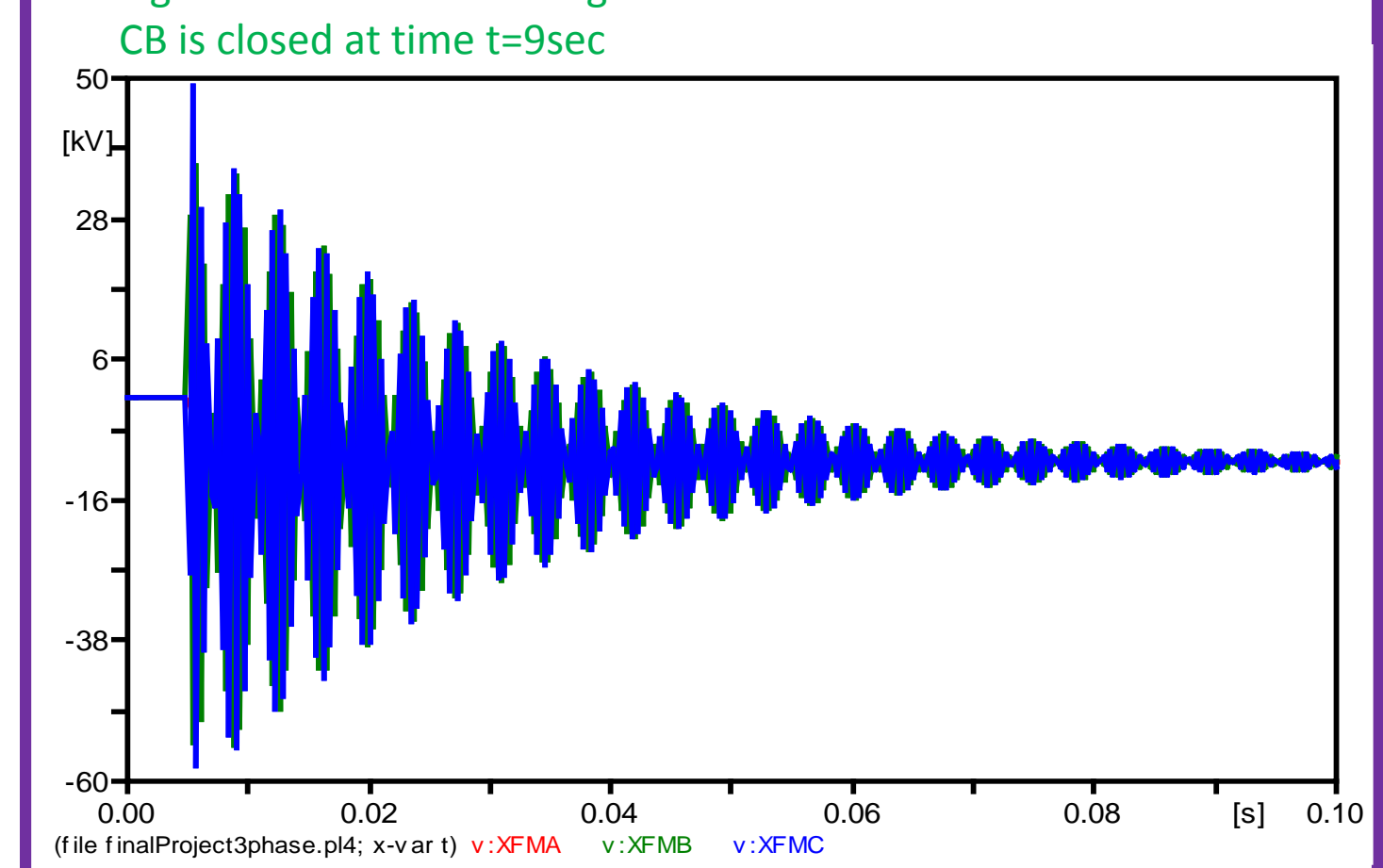


Fig.6: Multiple Restrike on CB terminal when CB is closed at time $t=9\text{secs}$

Mitigation Methods

By connecting a high resistive ballast (RB) across the CB, the effect of switching transients can be minimized. In this work, the 3-phase model of Fig. 7 and simulation result of Fig. 8 are used to present this mitigation method. $RB = 20\text{k}\Omega$

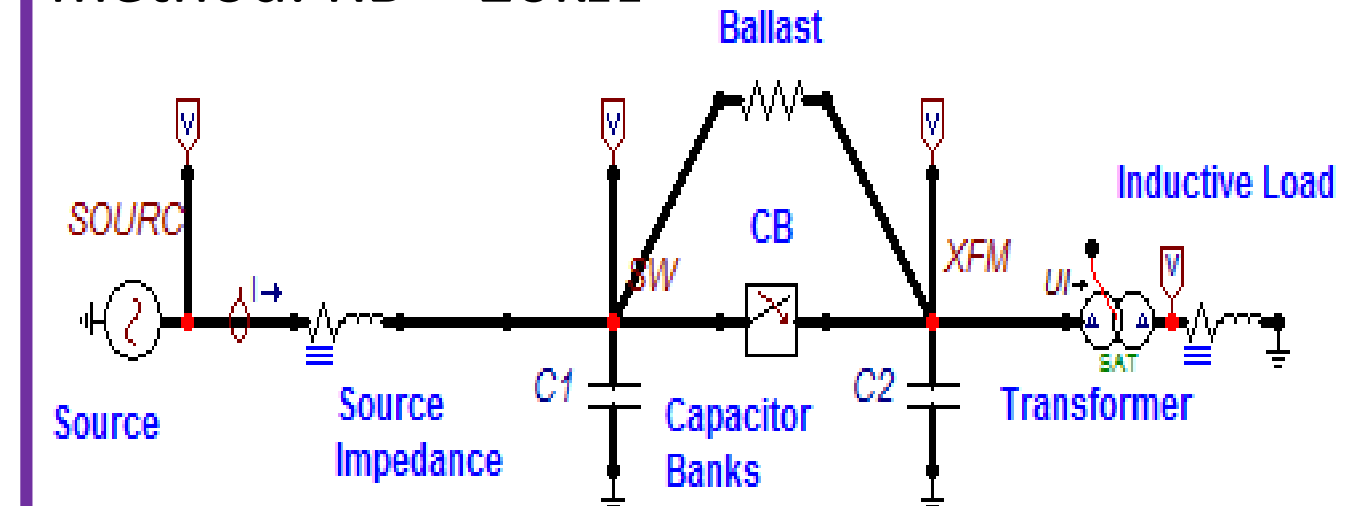


Fig.7: 3-phase model with a resistive ballast connected across the CB

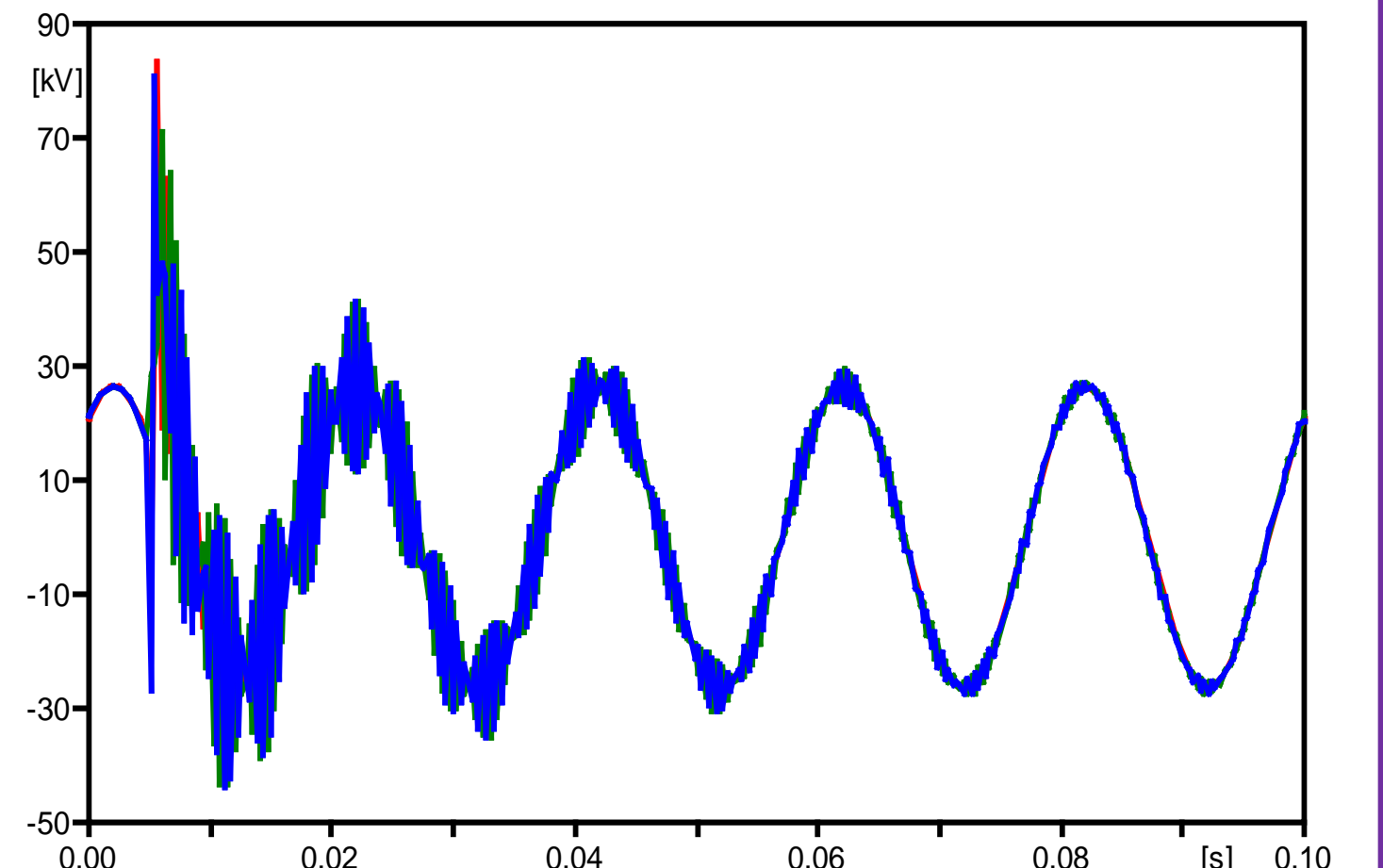


Fig.8: Voltage across the CB when a resistive ballast is connected across the CB

Conclusion

Irrespective of the quenching medium, high frequencies of overvoltages and steep fronted surges arises when breaking inductive loads. In practice, this causes a heavy burden on inductive loads and insulation co-ordination. Mitigation can be achieved by connecting a resistive ballast across the circuit breaker or by using a RC snubber.

References

- [1] IEEE Std C57.142th-2010 "IEEE Guide to describe the occurrence and mitigation of switching transients induced by transformers, switching device, and system interaction", IEEE Power & Energy Society, April 2011.
- [2] G. Schoonenberg and R. Smeets, "Control of inductive load switching transients", 22nd International Conference on Electricity Distribution, Stockholm, June, 2013.