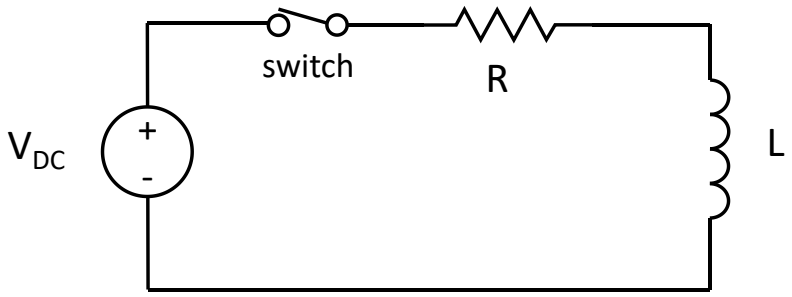
by V. M. García-Chocano

INTRODUCTION:

The switching of inductive loads deserves special attention because this operation may lead to high-voltage transients that can damage the involved equipment. Inductive loads are those components capable of generating a magnetic field and typically consist of solenoids, motors, relays, transformers, Helmholtz coils or induction coils. This document introduces the cause of the problems associated with the switching of inductive loads and explains several techniques employed to deal with such an operation.

WHAT IS THE PROBLEM?

Take the example of the circuit in the figure below. It comprises a resistor (R) and an inductor (L) connected to a voltage generator (V_{DC}) through a switch. Suppose that the switch is initially connected, and a given current I_{DC} flows through the resistor and the inductor.

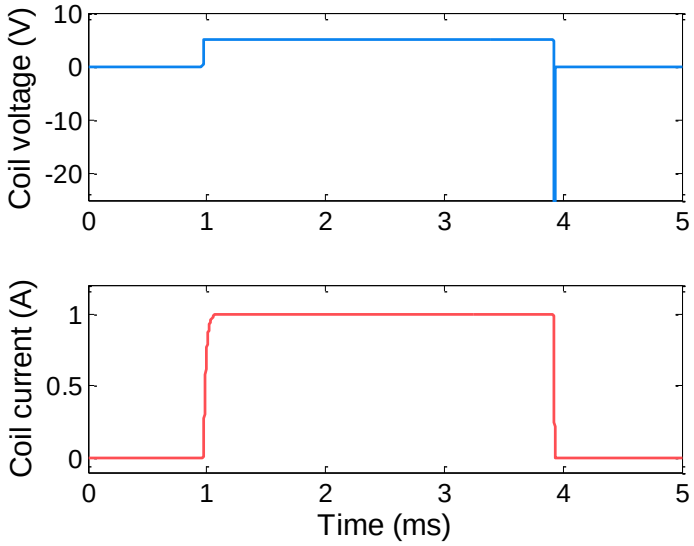


The equation that relates voltage and current in an inductor is

$$v_L(t) = L\frac{di}{dt}$$

If the switch is suddenly opened, the current goes to zero in a very short time. Its time derivative dramatically increases resulting in a short but high-level voltage pulse. The physical reason of this phenomenon is that the energy stored by the inductor (in the form of a magnetic field) must be abruptly released when its current vanishes.

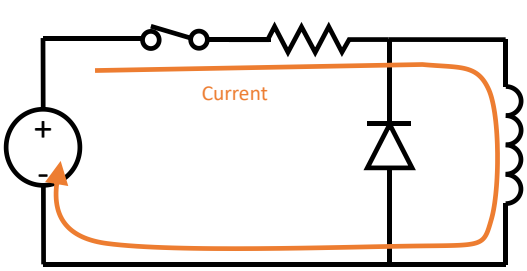
The next figure shows a simulation of the above circuit with V_{DC}=5V, R=5Ω, L=100µH and a switching time of 100µs. At 1ms the switch is connected, charging the inductor with a current of 1A. Then, at 4ms, the switch opens the circuit. A negative pulse with an amplitude of -38V is generated, even though the circuit operates with a source of 5V. Note that higher pulses can appear as the inductance increases or the switching time decreases.



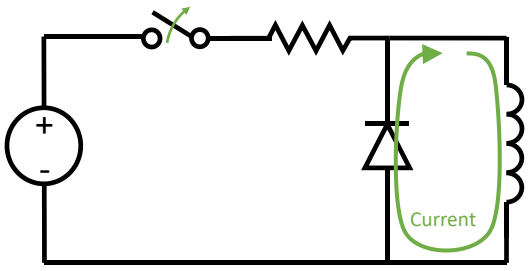
In practice this phenomenon produces an electric arc that damage the contacts of electromechanical switches. When working with solid-state switches, the pulse can exceed their voltage ratings and break them. The fast operation of this type of switches make them especially prone to this type of failure if no measures are taken.

HOW TO FIX IT:

Although dangerous, the switching of inductive loads is a well-known issue and standard solutions are available. For circuits operating with a DC voltage, the classical design includes a single diode (known as freewheeling diode) in parallel with the coil, as illustrated below. When the switch is closed, the diode is reverse-biased and therefore it does not impact in the circuit. When the switch opens the circuit, the negative pulse of the coil forward-biases the diode. Thus, the diode limits the voltage and dissipates the energy of the coil.

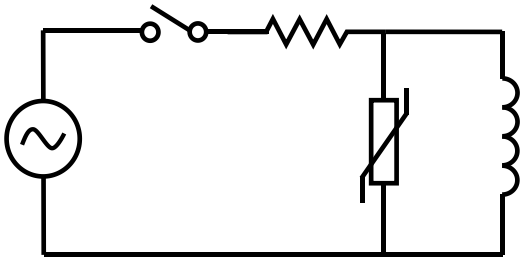


Switch closed

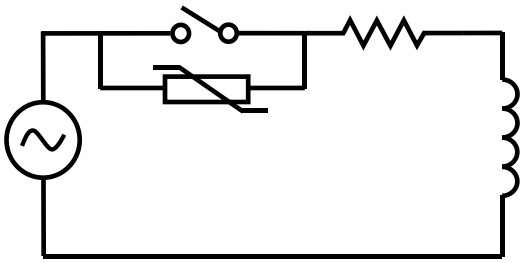


Switch opening

The presented approach does not work with AC voltages because the diode would drive current during the negative half periods. In this case the solution is based on the use of components that limit the voltage at levels higher than the input voltage but lower that the safe limits of the circuit. Varistors are typically employed for this purpose (see figure below). A damping network consisting on a resistor in series with a capacitor (known as Snubber network) can be also employed instead of varistors. In addition, these networks can be placed either in parallel to the inductor or the switch. The usage of any type of network will depend on the specific characteristics of the circuit.



Varistor in parallel with inductor



Varistor in parallel with switch

Of course, note that the management of discharged inductors does not involve any risk. In those systems where the inductors are excited with an arbitrary signal, a decaying waveform can be applied before open the switch. Even in this case a protection network is recommended, although its requirements are highly relaxed since it will only work in the case of a failure of the system (instead of every commutation).

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Ciprian SARL
65 Chemin de Ribotière
38330 Saint Ismier
France
www.ciprian.com
contact@ciprian.com
tel. +33 476 77 17 77
fax. +33 458 00 13 10