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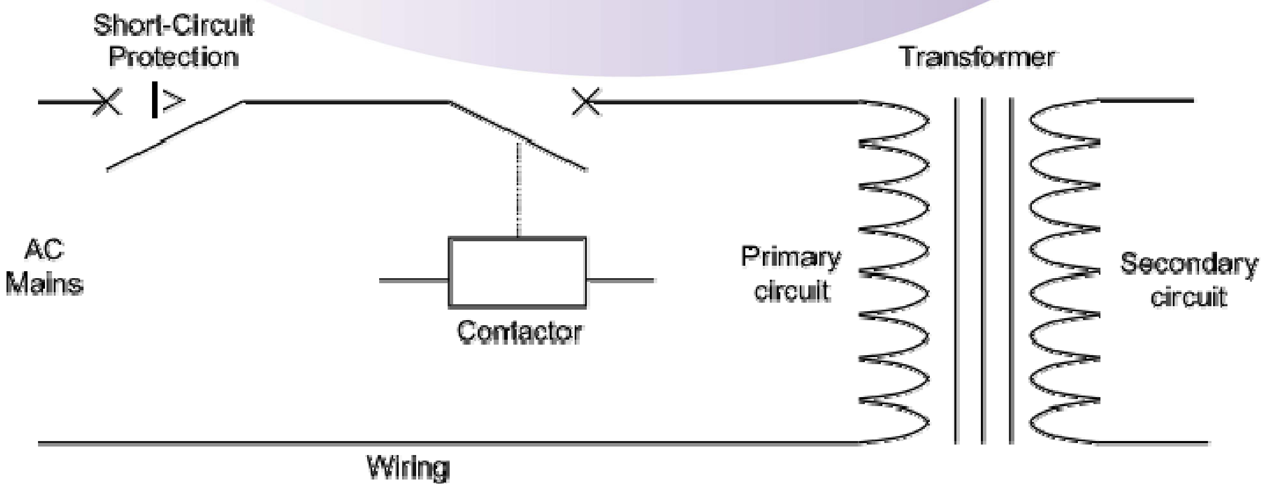
Solid State Relays (SSR)

TRANSFORMER CONTROL (AC-56a)
celduc® relais solutions

Tips and tricks to make good control of transformer primary using **celduc® relais** solutions

TECHNICAL INFORMATION

Switching ON the primary of an AC transformer can often generate high inrush currents.



Frequent switching of the primary without adapted solution can lead to damages in the transformer primary circuit:

- The inrush current can cause the tripping of the circuit protection and the user may have to increase its current rating to allow a correct operation, leading to safety hazards with a bad coordination of the short circuit protection.
- The inrush current can damage the contacts of the mechanical contactors (arcing, welding because of the bounces at closing).
- The inrush current can also damage the primary winding of the transformer especially if the switching frequency is important
- The inrush current can make mechanical stress in the wires and connections because of the magneto-mechanical effect

Using celduc® relais SSR instead of contactor can improve considerably the switching operation provided the user choose the right SSR switching mode. celduc® relais can help for the choice and this document gives information to understand our advices.

1) Non-saturable induction coils

This is typically air coils or transformers with an air gap.
The figures below show that the current value depends on the instant of switching. Whereas the zero voltage cross switching creates an inrush current of the double from the nominal, the peak voltage switching removes any problem of inrush current.

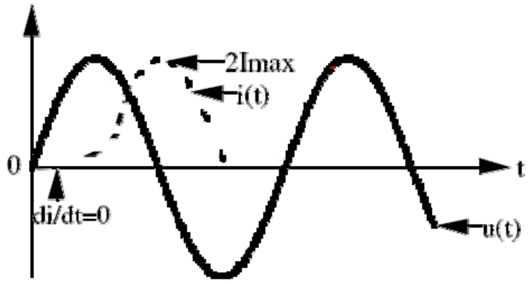


Fig. 1: zero cross starting current surge = 2Imax

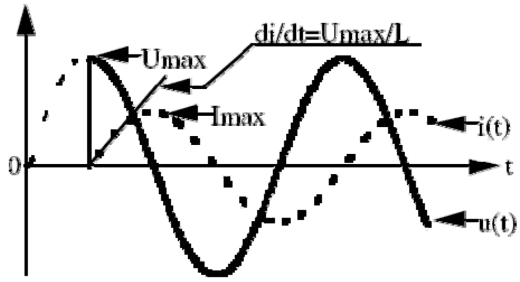


Fig. 2: peak starting, no current surge

2) Saturable induction coils

These are coils around a ferromagnetic metal (e.g. iron) without air gap like standard transformers.
Saturation occurs when the metal core cannot store induction anymore: the coil then tends to become an air coil again.

Reminders:

➔ Conversion from voltage to **magnetic flux** (in Weber, Wb): $\Phi = \frac{1}{N}\int_0^t u.dt$ with u = voltage applied to the coil and N = number of turns in the winding

➔ Value of the **induction** (in Tesla, T): $B = \frac{\Phi}{A}$ with A=cross section of the iron core (in m²)

And also: $B = \mu.H$ with μ, permeability (=μ0.μi) depends on the core material with μ0=4∏.10^{-7}

➔ Value of the **magnetic field** (in Ampere Turns, AT): $H = \frac{N.I}{L}$ with N = number of turns in the winding, I = current, L is the length of the magnetic circuit.

With $B = \frac{\Phi}{A}$ and $\Phi = \frac{1}{N}\int_0^t u.dt$, B is linked to the voltage u (the quantity applied for a given duration).

With $H = \frac{N.I}{L}$ and $H = \frac{B}{\mu}$, H is proportional to the current and depends on the voltage as well as the material of the core.

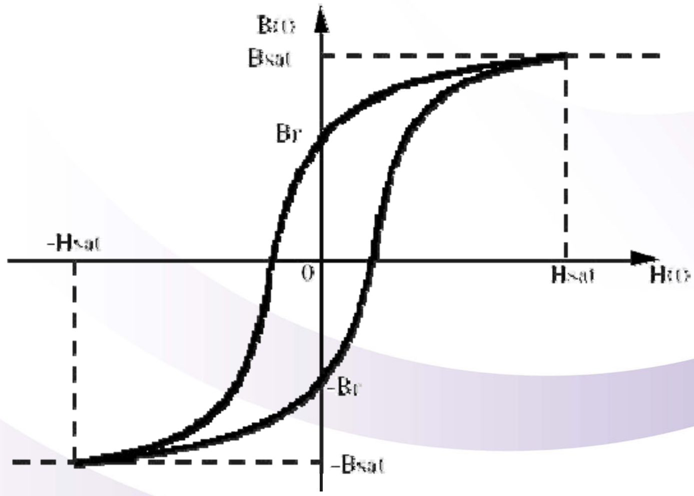


Fig. 3: Magnetic hysteresis cycle

<u>Description of the phenomena:</u>

In ac steady state supply, the magnetic field H (and therefore the current in the coil) varies according to the induction B and as described with the hysteresis cycle shown fig. 3.
At zero current (typical stop of ac SSR), a residual induction remains (like a magnet) in the magnetic circuit (+Br -Br).
Without any connection to the mains, the remaining induction in the transformer can last for years like a permanent magnet.
If the induction (linked to the voltage applied) comes in addition to the remanent induction Br (B>Bsat with Bsat depending on the core material), the magnetic circuit goes to saturation (the magnetic circuit cannot store anymore magnetic energy) and the current (proportional to H) increases dangerously. The current is then only limited by the resistance of the coil windings and that of the line (and sometimes the short circuit protection devices).

SWITCHING WITH STANDARD SOLID-STATE RELAYS

a) Zero cross switching: (e.g. control by zero cross SSR)

Two cases can occur:

Case Nr1: the starting is performed on the same half cycle polarity vs the previous current stop

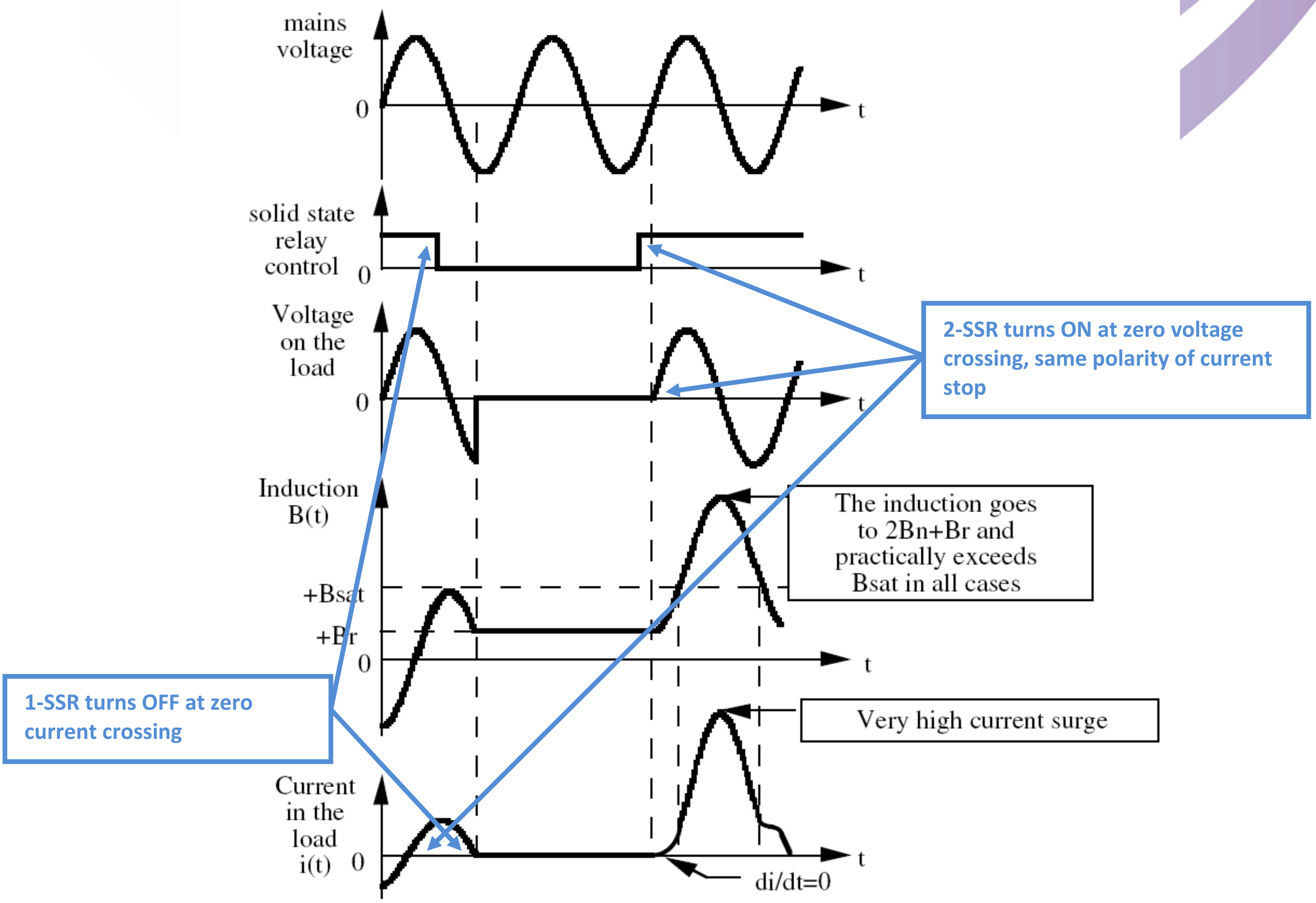


Fig. 4: zero cross switching,
stop and start with same polarities

In most of cases, the Bsat saturation induction is exceeded. The amplitude of the current (proportional to H), becomes very high.

⇨ **In this sequence of switching, zero-cross control produces the most surges : this is the worst case for a transformer and must be avoided**

Case Nr2: In order to decrease this current surge, it is preferable to have full cycles in time (avoid adding induction to the remaining induction). Therefore, zero-cross turn-on takes place on the half cycle opposite that of the previous current stop.

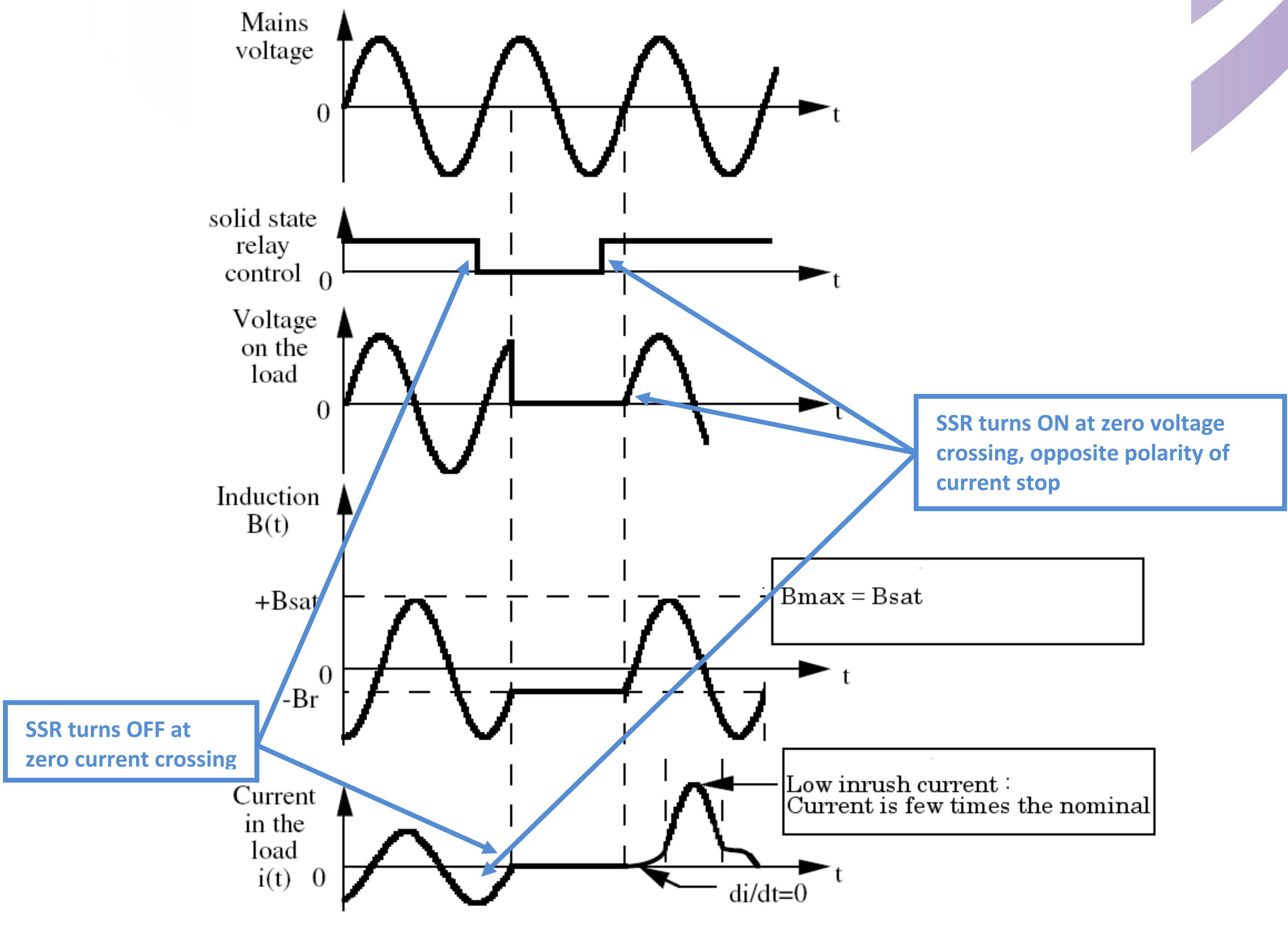


Fig. 5: zero cross switching, opposite polarities

This case is the ideal but requires working with the memory of the previous stop as otherwise the case Nr1, the worst case, can occur especially if the main disappears (disconnection, missing cycles).

⇨ **With a use of a zero cross solid state relay, the cycle polarities at turn OFF and at turn ON must therefore be known to send the control. This is not standard zero cross relays.**
⇨ **It results that zero cross starting must be avoided on this type of load.**

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b) Random switching: (e.g. control by a random SSR)

The switching occurs at any point of the sine wave and the probability of zero cross switching is lower. With an external synchronization circuit, it is possible to fix the switching point to the best moment: peak of the voltage sinewave.
This type of relay is anyway preferable to a zero cross relays but, as zero cross can occur, the relay inrush current rating must be chosen correctly.

With standard SSRs, it is preferable to use random relays, but in all cases, the rating of the SSR should be oversized.

The choice of the relay current rating must therefore be checked with the repetitive curve of Itsm = f(t).

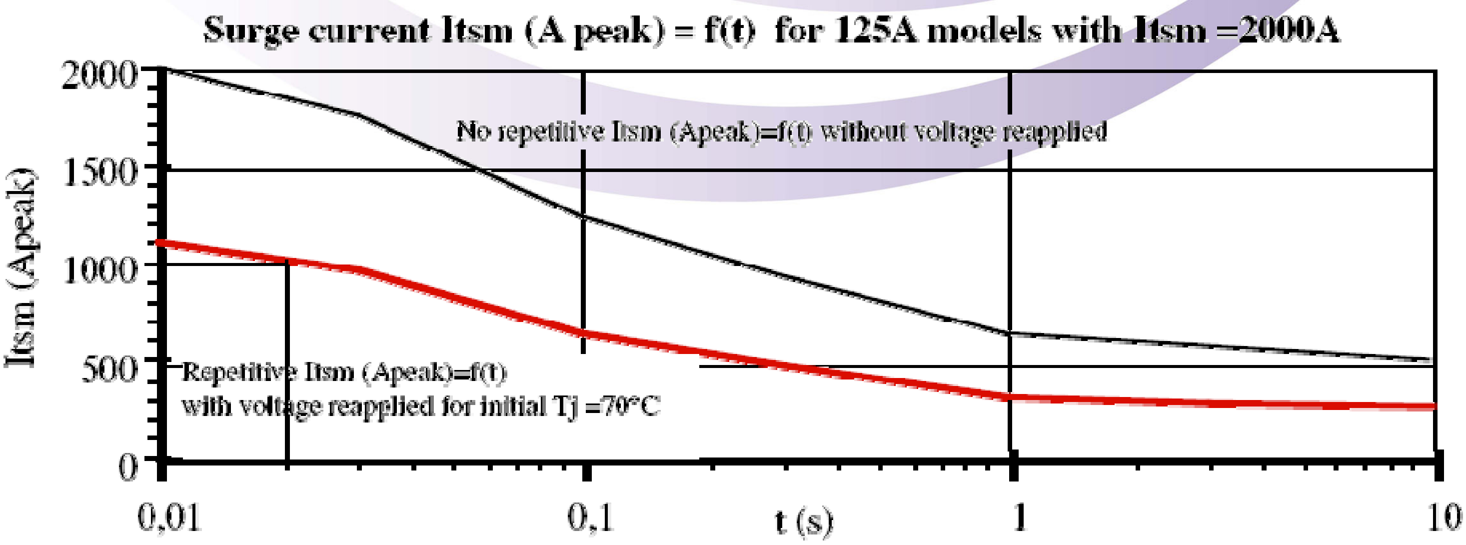


Fig. 6: 125 Solid-state relay ITSM curve

Extreme example with a relay of 125 A: With a surge of 10ms, the relay can withstand approximately 1100A about.
As the transformer inrush current can be as high as 100 times its nominal, the relay above can drive a transformer with a nominal current of around 11Arms taking 100In at starting, the max transformer current with this relay would be 11A i.e. 7.5kVA at 400VAC. As the line and the protections can also limit the current, a transformer of 10kVA can roughly be controlled with a 125A relay.

Note 1: With small transformers, the winding resistance reduces significantly inrush current.

Note 2: When the current inrush occurs, high current pulses are repeated every 20ms @50Hz with a small decrease in time: For this reason, the initial saturation current should be avoided.

PEAK SWITCHING SOLID-STATE RELAY

This consists in switching ON the SSR at the peak of the voltage sinewave.

Two cases can occur:

Case Nr1: The starting takes place at the peak but on the same half cycle as that of the previous stop.

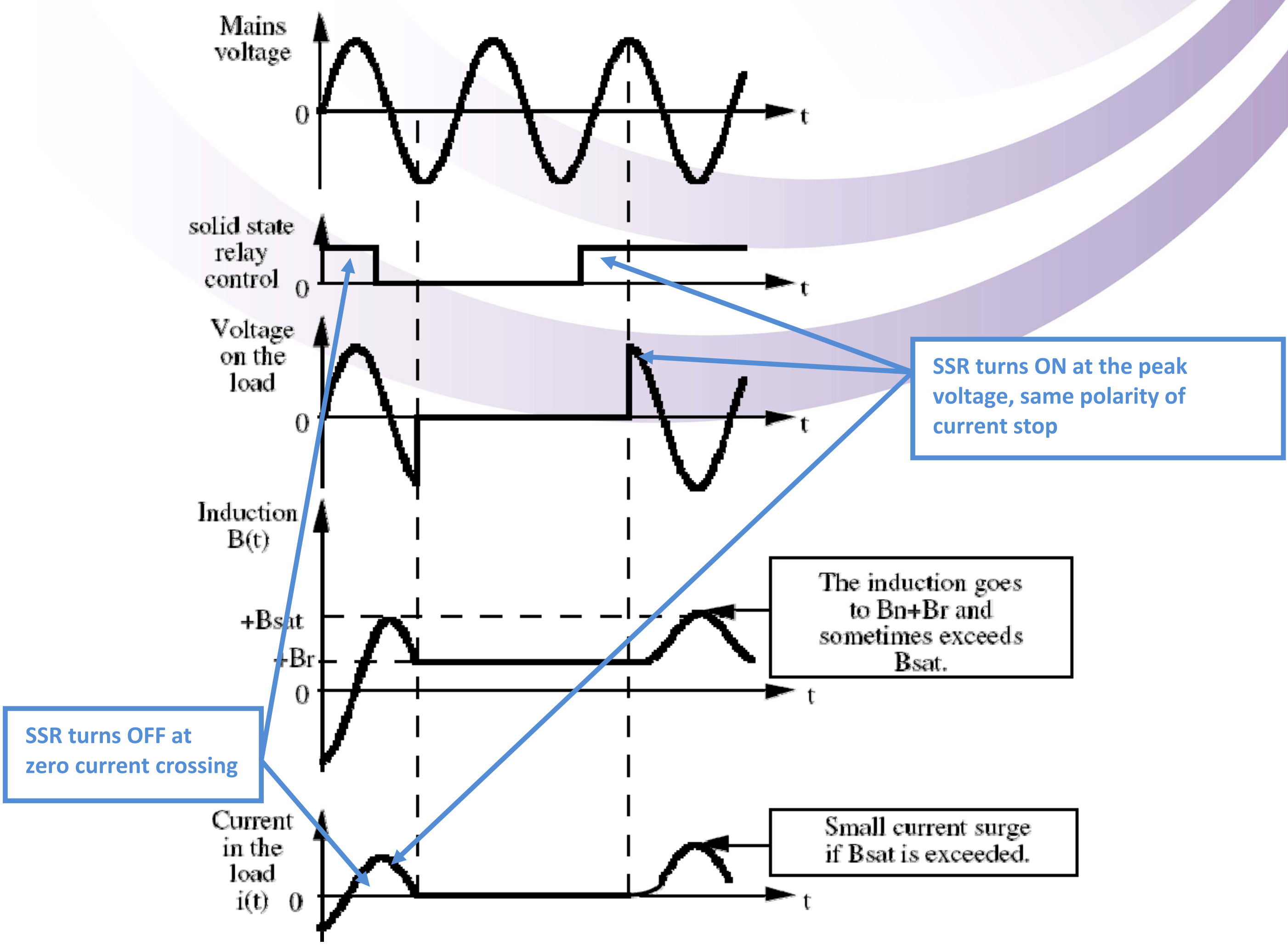


Fig. 7: Peak switching, same polarities

This type of control is still not the optimum as at start more induction is added to the remaining Br and could lead to an inrush current, but anyway much less than zero cross switching

This type of control is proposed by the SOP69070

100-510VAC
32A-AC56a (with heatsink)
125A-AC51 (with heatsink)
Control: 5-30VDC

Case Nr2 : The starting takes place at the peak but on the opposite half cycle of that of the stop.

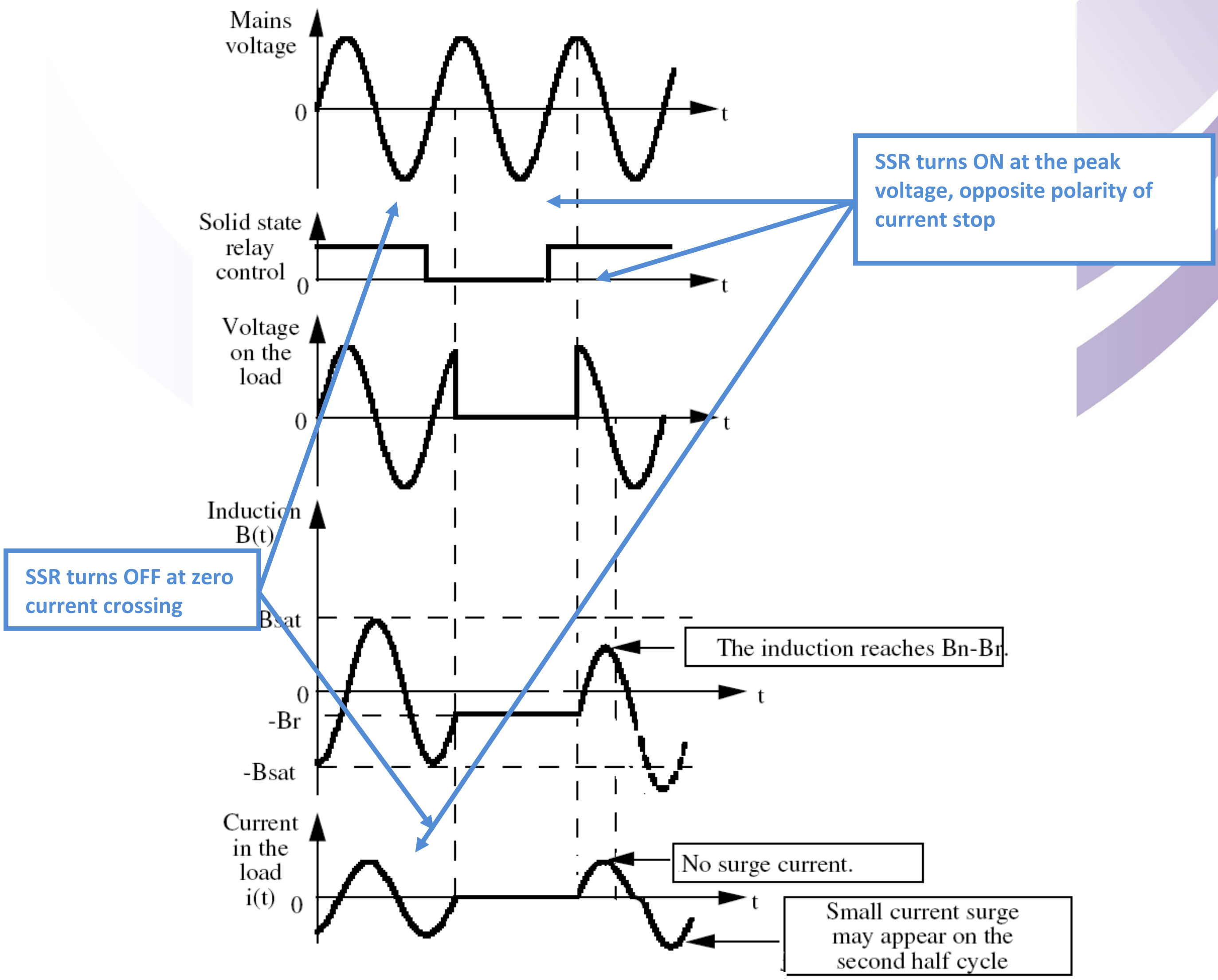


Fig. 8: Peak switching, opposite polarities

Note: If a transformer is very near Bsat at In, a small current surge may take place on the second half cycle.

⇨ **Conclusion: peak switching with or without full cycle sequence is a good transformer inrush current solution.**

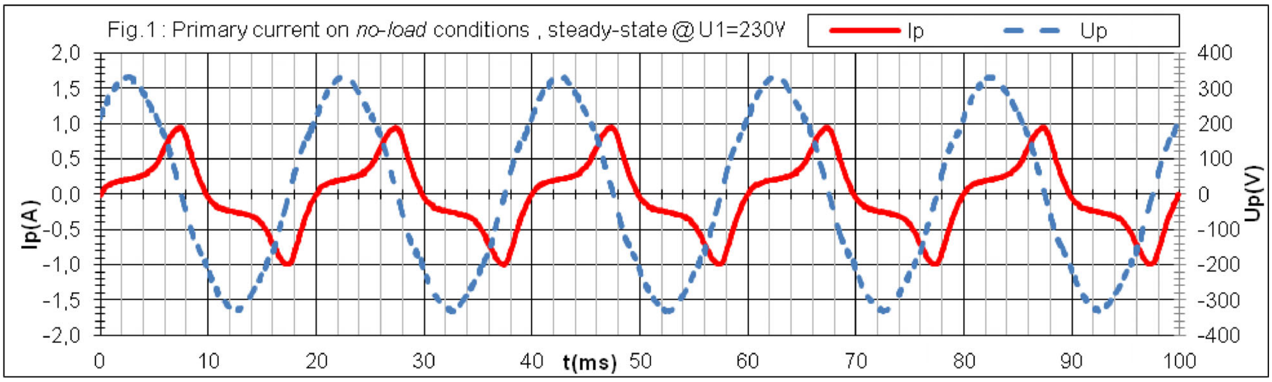
SOP69070
100-510VAC
32A-AC56a (With heatsink)
125A-AC51 (With heatsink)
Control: 5-30VDC

CASE STUDY: COMPARISON OF SWITCHING TECHNOLOGIES

Transformer used for this case study: 3kVA 230V-13A /12V- 250A
Primary current on *no-load* conditions: 0.5Arms

Diagram	1	2	3	4	5
Case	Steady-state	Turn ON at zero-cross	Turn ON at zero-cross	Peak starting	Peak starting
celduc's range		SO8	SO8	SOP	SOP
Conditions		Starting half cycles = Stop half cycles	Starting half cycles ≠ Stop half cycles (opposite)	Starting half cycles = Stop half cycles	Starting half cycles ≠ Stop half cycles (opposite)
Peak current (no-load condition)	1A	280A	5A	~30A	~30A

1



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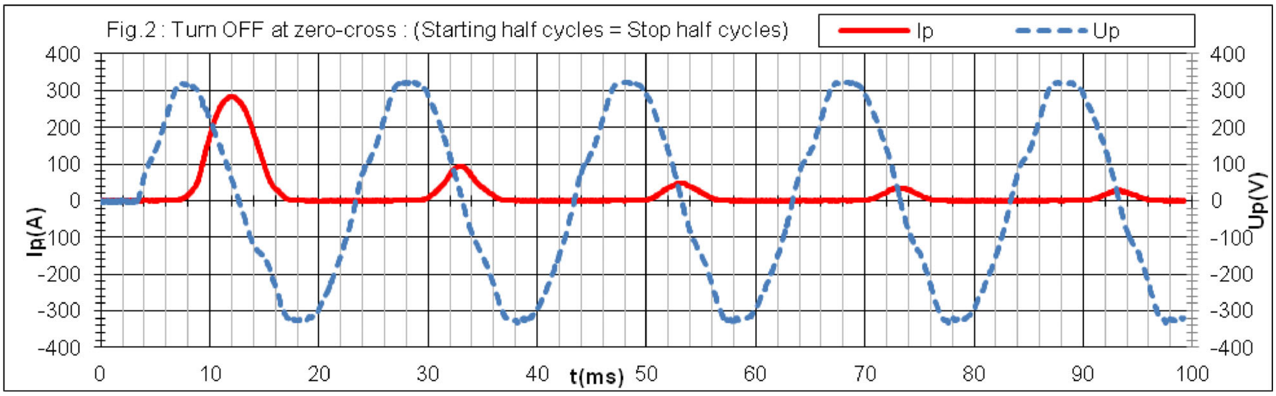


❸

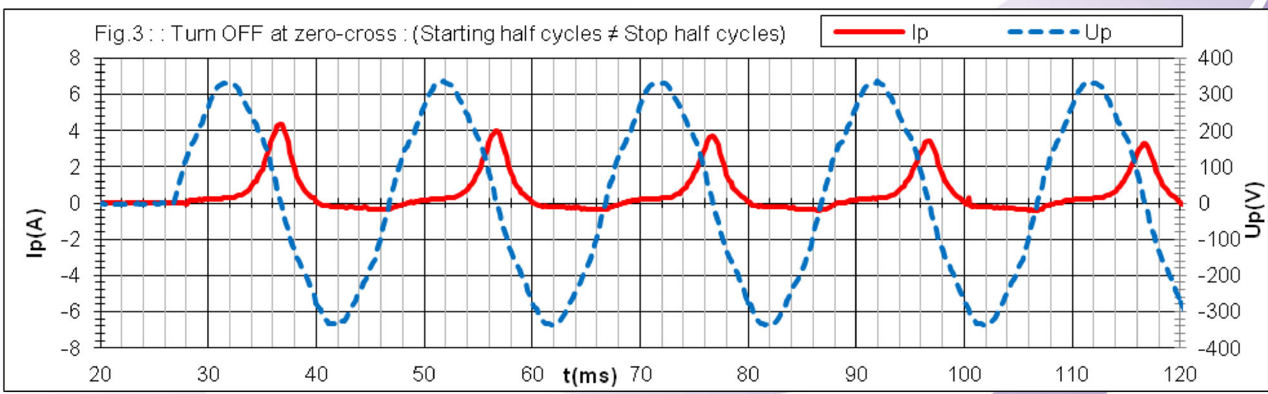


Fig.3 : : Turn OFF at zero-cross : (Starting half cycles ≠ Stop half cycles)
Ip
Up
Ip(A)
Up(V)
t(ms)

❹

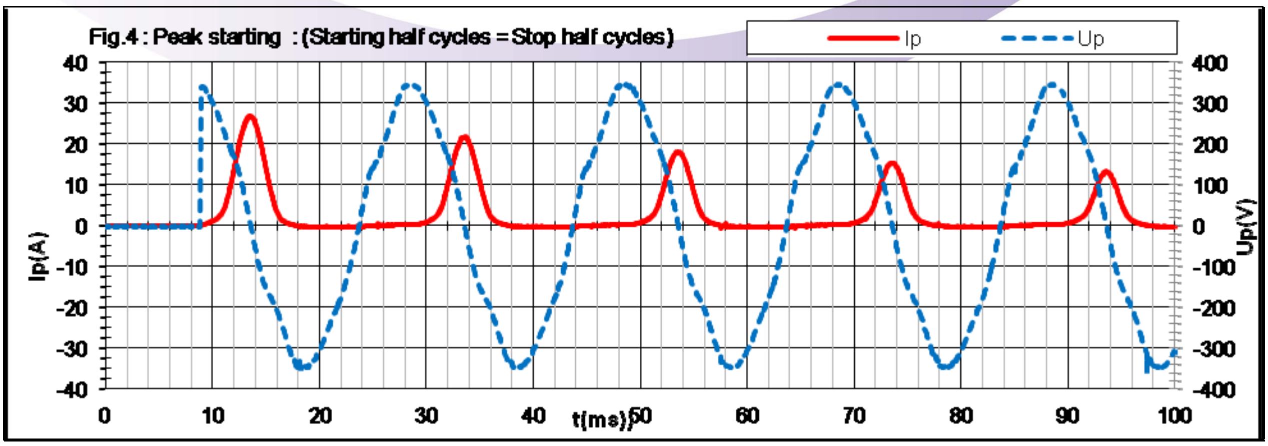


Fig.4 : Peak starting : (Starting half cycles = Stop half cycles)
Ip
Up
Ip(A)
Up(V)
t(ms)

❺

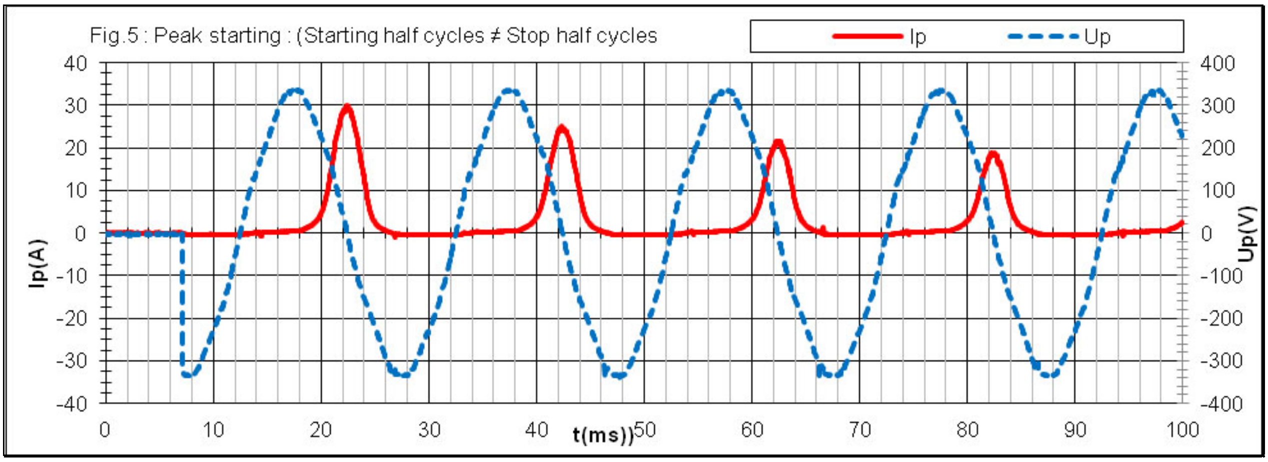
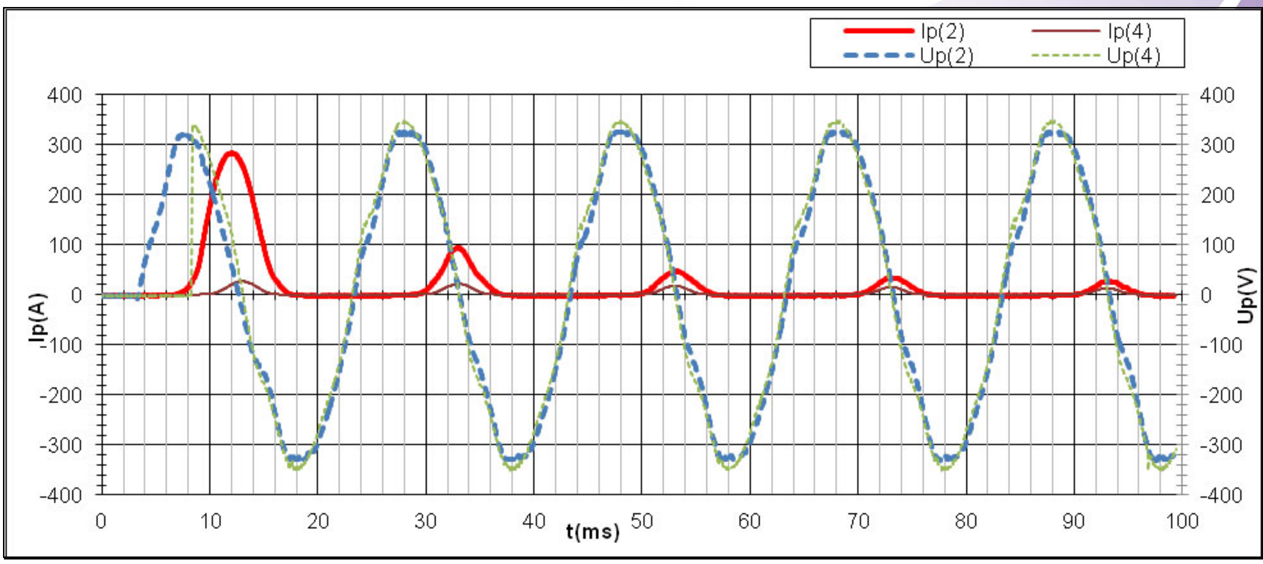


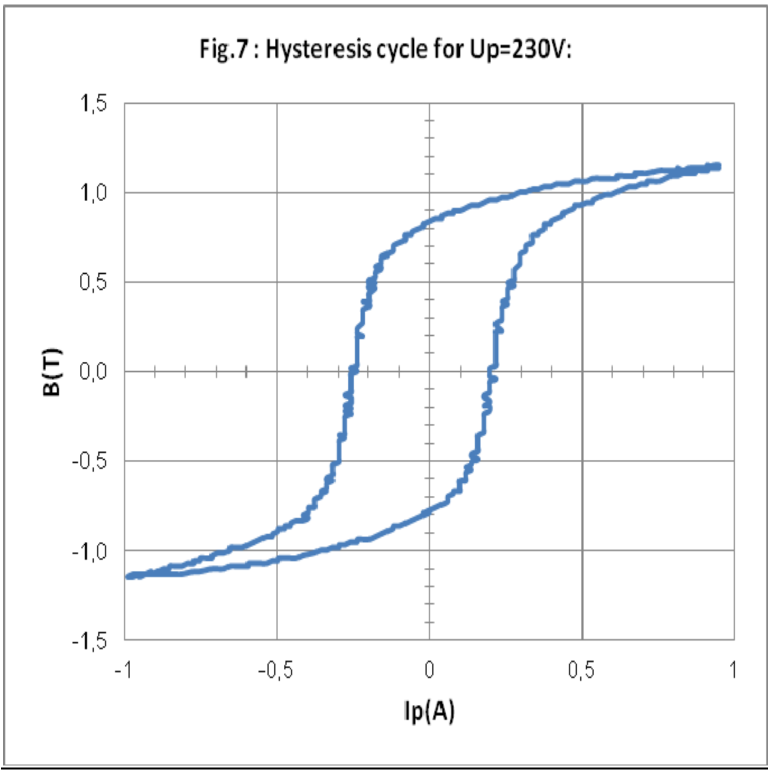
Fig.5 : Peak starting : (Starting half cycles ≠ Stop half cycles
Ip
Up
Ip(A)
Up(V)
t(ms))

❻

Comparison of switching between zero-cross SO8 (❸ ——) and peak SOP (❹ ——)



Hysteresis cycle measured for this transformer



OTHER SOLUTION: SOFTSTARTERS

The goal is to apply progressively the voltage to the primary of the transformer. This is one solution for application that stays ON for a long time.

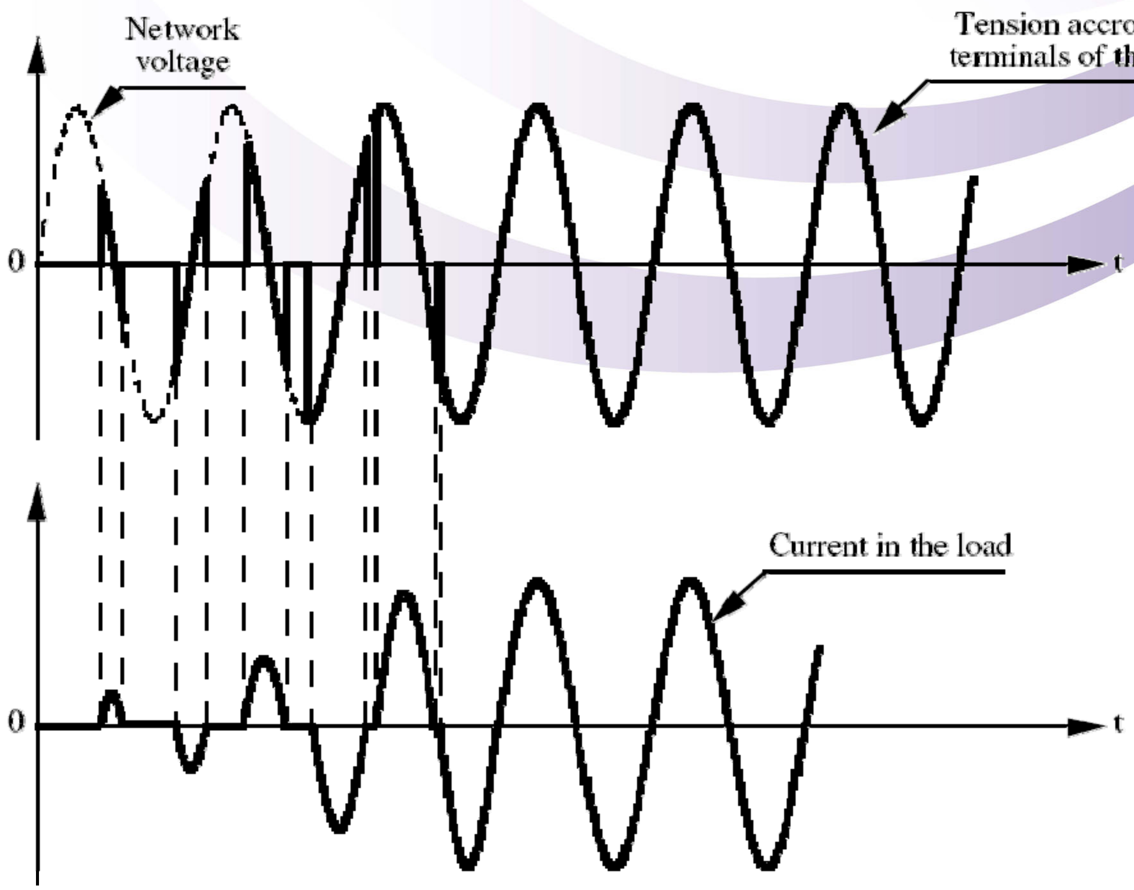
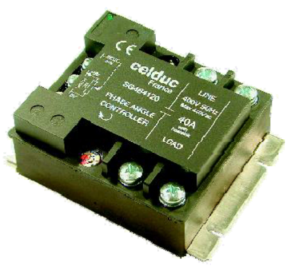


Fig. 9: Soft-start

➔ **For single phase transformers, this softstart function can be built based on an analog proportional controller (e.g. SG4 series)**



➔ **For 3 phase transformers, the softstart function can be done by SMCV or SMCW series provided the secondary of the transformer is connected to a minimum load (See the special application note SMCW on transformers). A bypass contactor can be used to reduce the control system size.**

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CONCLUSION

Applying electric power to the primary of a transformer can lead to more or less big troubles, especially if this operation is intended to be very frequent.

Replacing a contactor with a standard solid-state relay requires to use at least a random switching version and to use it at around 10% of its nominal current rating.

celduc® relais has launched a new solid-state relay **SOP69070** featuring a peak control mode to drive up to 32A transformers. The SOP69070 is a very efficient control solution for small to medium transformers.