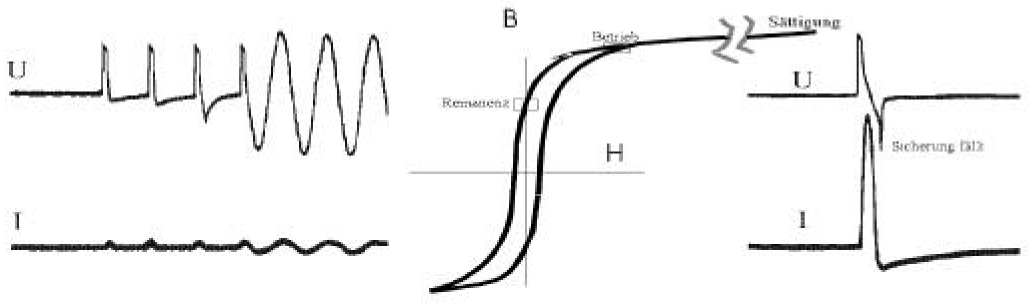
Can inrush currents in transformers be avoided?

Curves below show various transformer switching on behaviour:

New: Switching on without inrush current:

Hysteresis loop in the iron

Standard: With inrush current, directly switched on



With Transformer Switch Relay, premagnetised and switched on opposite to the direction of premagnetized remnance polarity without inrush current at the nominal or open circuit current.

Directly switched on with a contactor in the direction of the remnance polarity results in a 200A peak inrush from a 1,2 kVA Transformer

Disadvantages caused by inrush current peak.

a) Because of the troublesome inrush current peak, transformers must be constructed is such a way that this effect is minimized.

b) Fuses used with a transformer on the primary side cannot be fast acting because of inrush current. Additional fuses on the secondary side are needed. If an error occurs due to either slow acting or overrated fuses, transformer damage cannot be completely eliminated.

c) If the power line impedance is higher when the power line is a long distance from the input, then the voltage drops during the inrush pulse, and other participants at the power line are influenced .in a negative manner.

How does the inrush current peak occur on a single phase transformer?

1.) **Dependence on the moment of switching on**: Remnance, the magnetic memory or induction, B, of the iron core, remains for a long time after switching off, see figure of the hysteresis loop, center picture on top. The polarity of the remnance depends of the polarity of the last voltage half-wave before switching off. On re-switching on of the transformer, if the power line half- wave has the same polarity as the remnance, then an inrush current peak occurs because of the saturation of the iron core. The iron cannot be magnetized beyond its saturation limit, if the magnetization is in the same direction as previous. The transformer thus looses its inductive resistance caused only by reverse magnetisation of the iron core. This is illustrated in the hysteresis curve above. The strength of magnetization in the iron core is driven between the limits of the hysteresis curve, from the product of voltage and time squared ,within one half-wave of the power line in 100 Hz cycle. A positive half wave brings the magnetization from neg. state to the positive state and visa versa. The turning points of the hysteresis loop correspond to the no load current peaks, plus and minus. The field strength H is proportional to the current flowing in the transformer.

2.) **Only the resistance of the copper wire from the primary windings, plus the power line impedance limits the inrush current peak**, in case of the iron saturation. The copper resistance of the primary coils is very low in the case of low-loss transformers. This results in increased inrush current peaks. (Up until now, this was a hindrance in building extra-low loss transformers) Transformers with small air-gaps and therefore with low iron losses have an exceptionally high value of remnance in the iron core. (e.g the loss of air gap in toroidal transformers meets this requirement.) .

3.) **The influence of the transformer type becomes evident:** The higher the induction of the transformer core, the smaller the air gap and the lower the copper losses - all three factors used to indicate transformer quality - the higher is the resulting inrush current peak. This can approach up to 50 times the nominal current value in the first half wave after switching on, see figure on top right. This case approaches a short circuit current and cannot be controlled alone with slow blowing fuses.

4.) **What is today's status and what can be improved in the future?** The current most popular transformer type for electrical equipment with bonded E-I-shaped iron cores have larger air gaps than core transformers with alternating laminates or distributed air gaps, or toroidal core transformers. These bonded transformers must be physically larger to fulfill similar power requirements, however, the efficiency is lower compared to alternating laminates or toroidal type transformers. However switching-on currents of bonded core transformers is less but still can be as much as 15 times the rated current, a value which can just be accommodated by slow acting fuses.

Elimination of inrush current would allow the manufacture of small low-loss transformers without any drawbacks but with economical advantages**.**

Such **transformers are available** either with toroidal cores or laminate cores with distributed air gaps. The **total weight can be up to 40% less** compared to transformers with bonded E-I shaped cores. Toroidal core transformers can have disadvantages regarding the winding. Transformers with either laminates or distributed air gap cores can be as easily wound as bonded transformers.

The enamel of the copper wire has the highest temperature class, and the diameter of the copper wire is kept as small as possible to reduce copper costs. This transformer needs more windings because of the air gap and has more windings due to the larger iron package. These transformers are larger and heavier than transformers with modern cores such as the Unicore from ”Telmag- GB” compared to similar rated standard toroidal transformers. Transformers with modern cores has lower losses and run at lower temperatures. However transformers with bonded E-I shaped iron cores have lower inrush current peaks, because of lower remanence and higher copper resistance. Inrush currents peaks are about 15 – 18 times nominal current values, too high for fast blowing fuses but low enough to be handled with slow blowing fuses or electromechanical motor protection relays. However these relays are expensive, require 3 poles instead of 2, and the transformers are more expensive than smaller transformers with a modern iron cores. **Improvements which consistently eliminate inrush current peaks** can only lead to improved transformers.

Using a Transformer Switching Relay, TSR, whereby inrush is always avoided, the primary-side fuse can be a fast-blowing nominal current value fuse, and the transformer can be low-loss and be physically smaller. In this case the secondary voltage does not drop in value on loading. In addition a secondary fuse is no longer necessary due to correct primary side fusing. The costs are therefore lower then before.

Transformers which are frequently switched, e.g. transformers for low voltage heating, using the TSR means that the electromechanical contactor on the primary side is no longer necessary, as the TSR itself acts as a switch. This leads to further cost reductions.

Transformer switching without inrush peaks sometimes happens by chance, but is much more reliable when using a TSR. After a short premagnetizing time of ca. 0.1 sec., the TSR switches on the transformer without inrush current, according to a patented procedure, depending on the transformer type (see figure on top left). The effect can be seen by the current curve. TSR components are semiconductor relays which are switched using robust thyristors which are subsequently bridged by the relays . **TSR have been available for the past 5 years and are produced in Germany.**

Advantages while switching a transformer with a TSR.

1) Avoiding inrush current is better than limiting it. *Inrush current limiters are somewhat cheaper than TSRs but they have some disadvantages such as the pause required between switching, are not short circuit current proof, and the need for an additional contactor for switching.*
2) Primary fusing can be made with fast acting line protectors such as Type R-, Z-, B or with fuses such as Type g/R .
3) TSR can be controlled as a relay using a control input.
4) No heating up, because of the hybrid character of thyristor and relay.
5) TSR can be switched without pause between switchings.
6) TSR with relay bridging has a working life of greater than 5 Mio. switchings, TSR without relay bridging has an unlimited working life.
7) TSR are short circuit proof when correct fusing is applied.
8) Also available with optional power line half wave defect recognition: no inrush after a lack of one power line half wave.
9) Available for currents up to a few hundred amps and power line voltage range 100 to 500V. Also available for 3-phase transformers.
10) The TSR can be installed in many customer specific electronics applications.
11) The TSR start procedure is independent of the load state.
12) In addition transformers with a toroidal cores can be switched on without inrush currents, independent of loading.

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