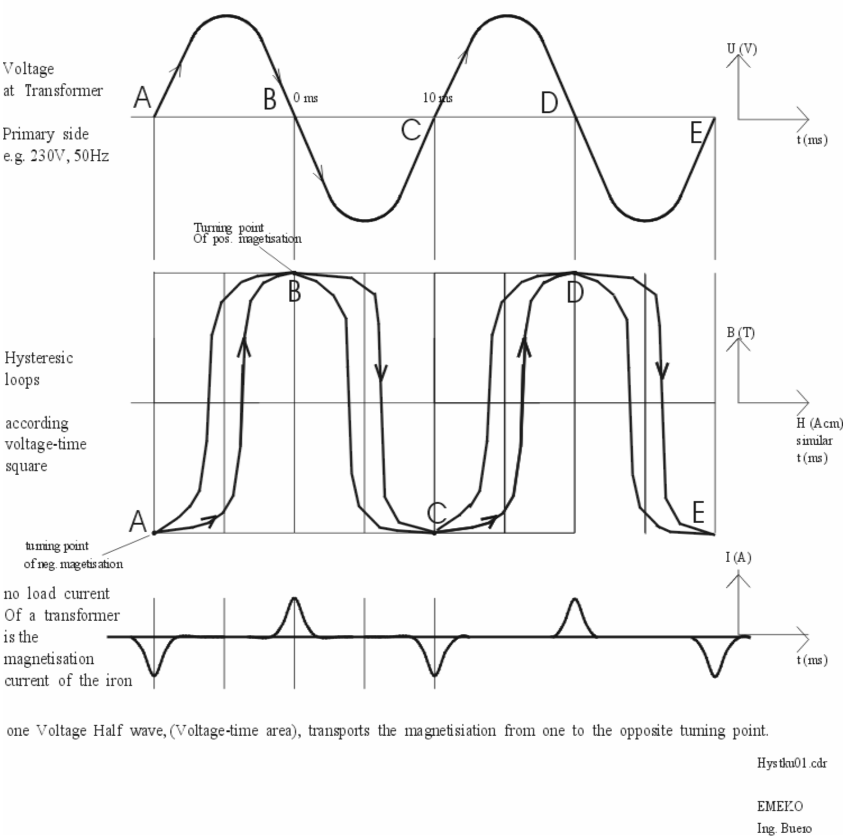
1.) Description of the electromagnetic physic into the iron core of transformers.
2.) Description of the Transformer soft start procedure from EMEKO.
3.) Description of the effect of voltage dips on the power line when feeding different types of single phase transformers.
4.) Consequences of voltage dip with a TSRL in front of a transformer.
5.) Measured voltage and current at a transformer, while feed with voltage dips accidentally generated by pulling and shaking the power line connector .

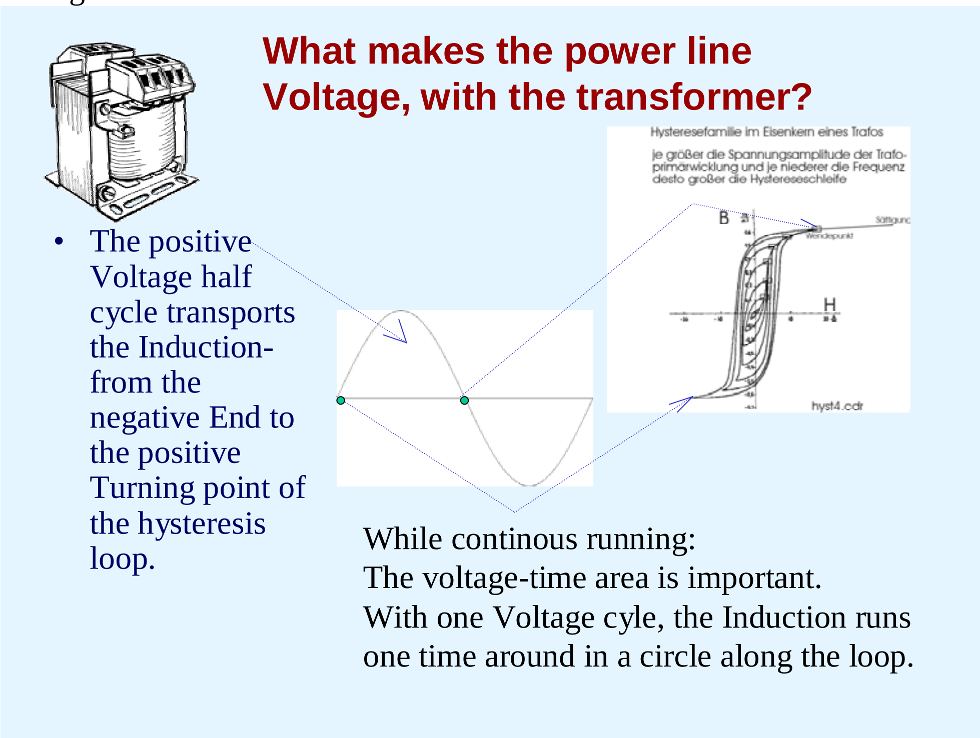
1.) **Description of the electromagnetic physic into the iron core of transformers.**
I**ntroduction:**
Notice: Not the input current, the Voltage time area makes it, that the magnetisation is running along the hysteresic loop, see curve in the middle of the graph image 1. One full wave of the power line voltage drives the induction 1 times around the hysteresic loop.
The current is the effect of the voltage-time area. He is the answer from the transformer to the effect of the voltage.

Image 1.
Continous Hysteresic loop in the iron of a 50Hz Transformer
in permanent no load situation



The voltage time area of the positive half wave, transports the magnetisation, -the induction, along the hysteresic loop from one end A, to the other end B.
The negative half wave brings it from the pos. turning point B of the hysteresic loop to the neg. turning point A at the end of the neg. half wave, and the positive half wave does it opposite.

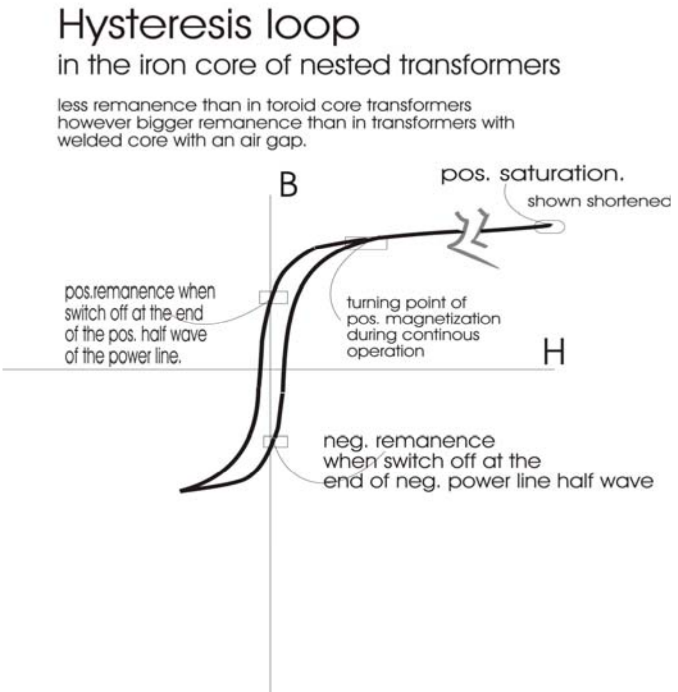
Image 2.



Hysteresic loop of a nested core transformer.

Image 3.

tshyst3e.cdr

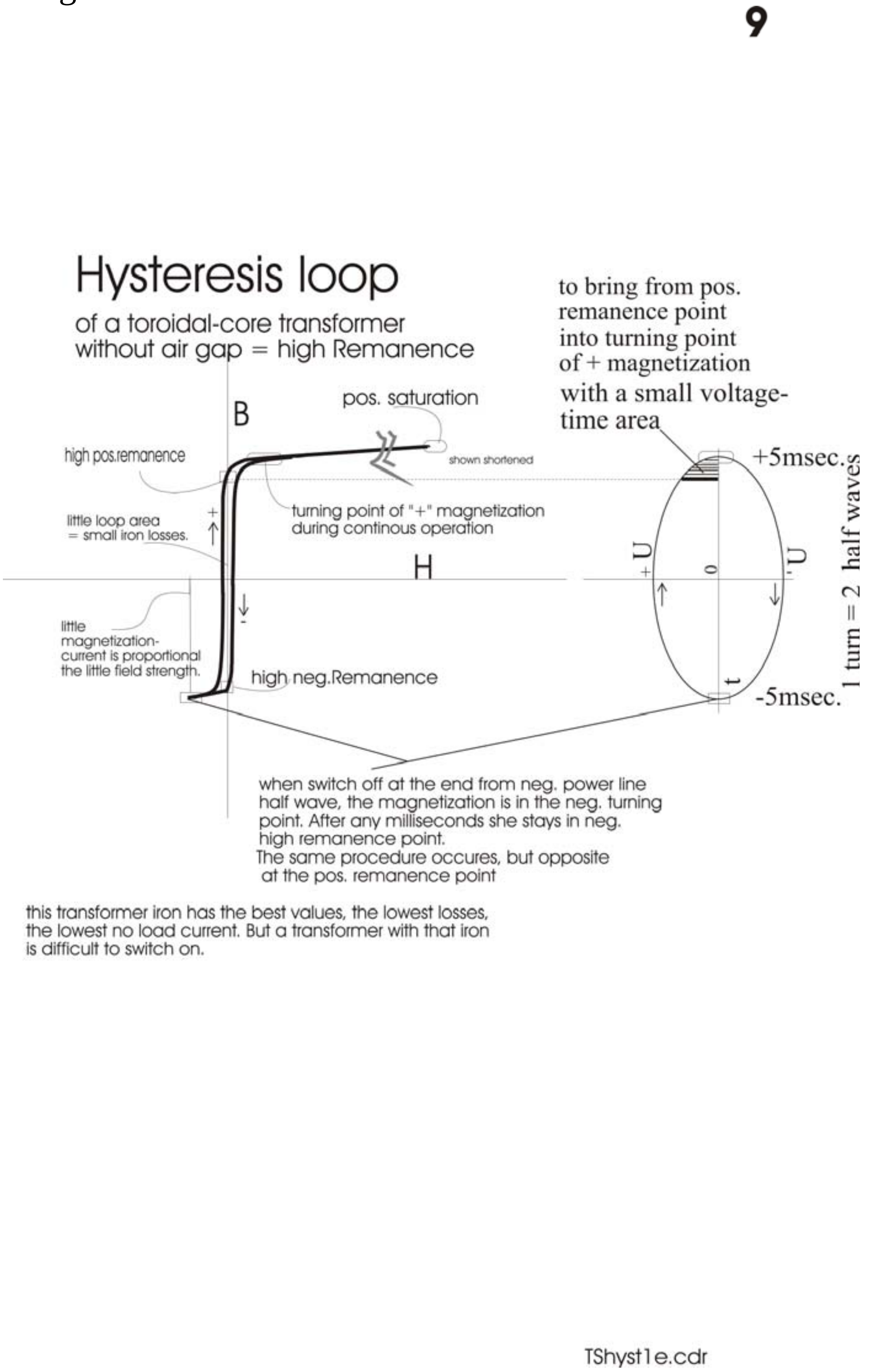


The induction at the stable magnetization, the remnance point at H = 0, is lower than the induction at the turning points. In succes of little air gaps in the iron core, the hysteresic loop is not vertical oriented.

He is inclined to right. A transformer with a Air gap of any 0,1 mm has a hysteresic loop who is inclined up to 45 degrees to right. Then the remnance is nearly to zero. Only for those transformers the peak switching solid state relays are suitable.

Against that, toroidal Transformers, see curve in picture 4, have no air gaps and have another hysteresic curve, than EI –core Transformers. The hysteresic loop is straight vertical oriented and have a very small hysteresic loop. The no load losses are 100 times smaller than with an EI core transformer. The losses are represented by the area inside the hysteresic loop.

Image 4.

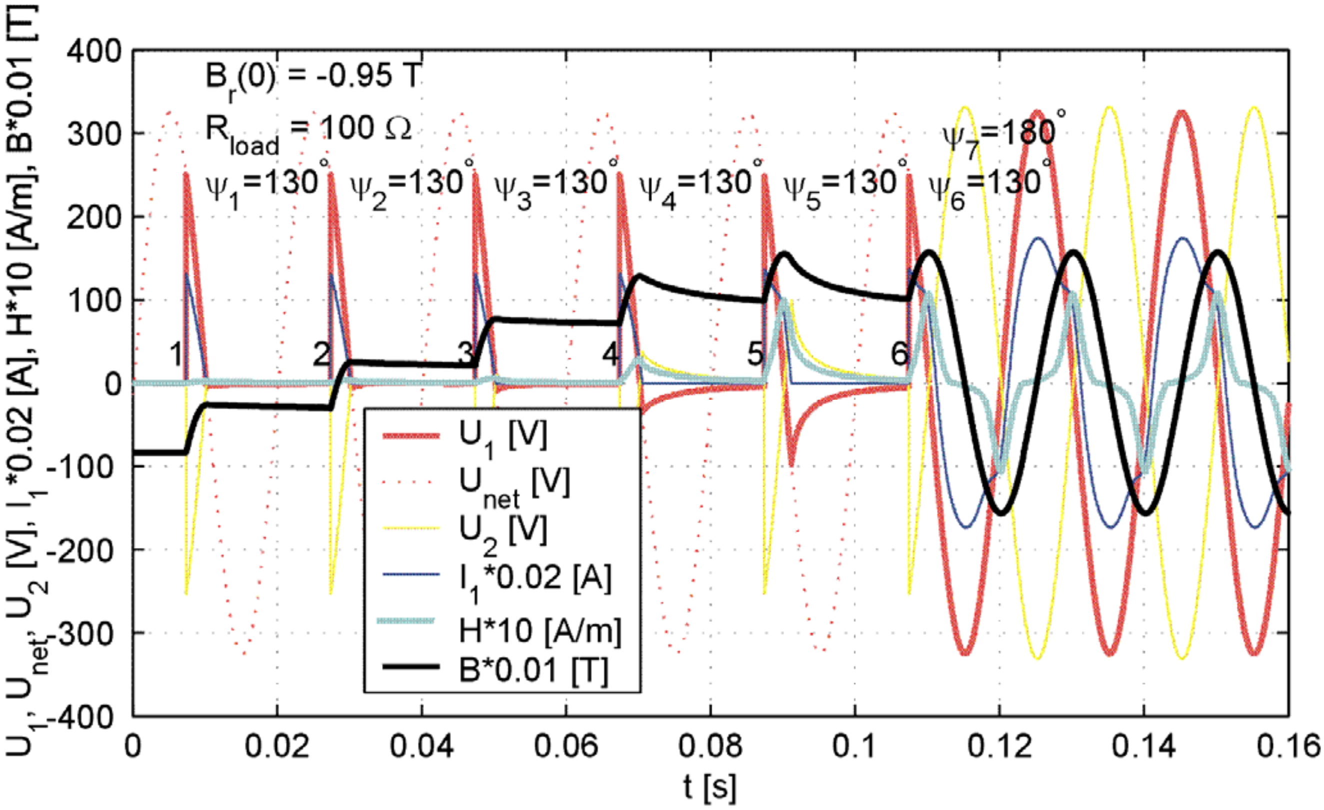


The induction in the remnance point is nearly so high like the induction at the turning points of the hysteresic loop, reached at every end of each half wave. The magnetisation in the remnance point stays on the same point as long until the transformer is switched on again. Remnance means residual magnetism.

2.) **Description of the Transformer soft start procedure from EMEKO.**

Image 5.)

Demonstrate with an nested core transformer with a primary 230V coil and a secondary 230V coil. The tested transformer has an hysteresic loop like shown in image 2.



Br(0) = -0,95 T in a nested core transformer, not a toroid, is the start point with neg. max. remnance before the start of the soft start procedure. Because the Transformer was switched off at the end of a negative half wave. The remnance stays for a long time on this value.
U net is the power line voltage curve. Away from Point 7, the U1 voltage is similar the U net.

Pulses Nr. 1-6 are unipolar phase cutting Voltage pulses U1-6 , who transports the Induction, -the black line-, in the direction of the pos. remnance. Only 4 pulses are needed from one to the opposite remnance point at this kind of EI Transformer with small air gaps in the core. The phase angle is 130 degrees when the pulse starts.

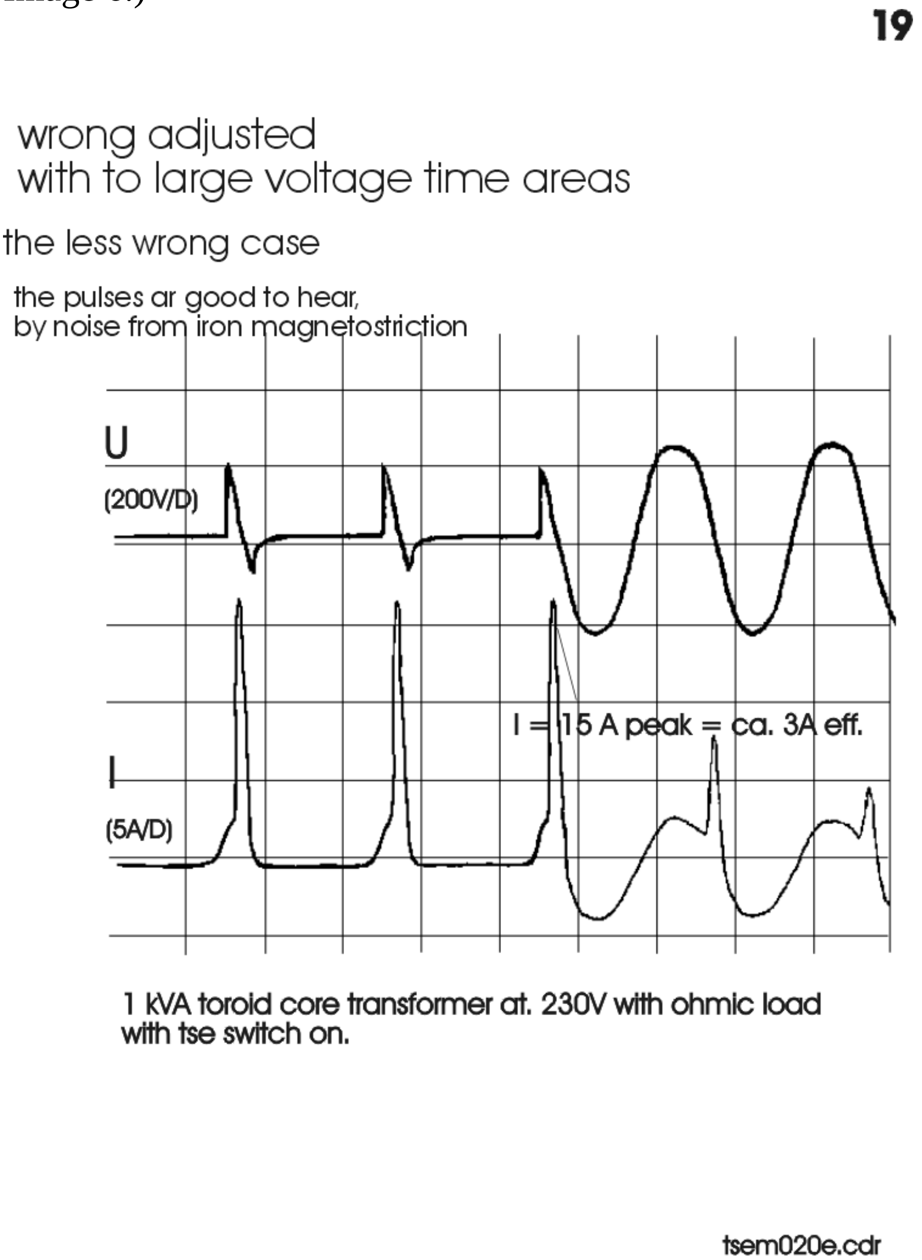
Directly at the end of Pulse 5, the max. positive remnance value is reached. Away from pulse 4, at the end of pulse 5 and 6, the reached induction is higher than the max. stable pos. remnance. It is the induction in the pos. turning point. This can be seen at the going down of the black line in the pause time between pulse 4 and 5 and 5 and 6, to the stable remnance point. -The black line is the induction.- The induction goes down onto the value of the induction at the begin of the pulse 5 and 6, representing the max. pos. remnance value. --Visible in the horizontal black line.--

After pulse 6, the magnetisation is coming in the positive turning point of the hysteresic loop, the voltage U1 is switched full on.

Notice: The input no load current I1 is corresponding to H, the magnetic field strength and additional to it is the load current. It is to see, that no over current occurs. The shape of the H = I no load current curve is typically for the no load input current of an EI transformer.
U2 is the voltage of the secondary side. He is opposite to U1 drawing for better seeing the “not“difference to U1 .

Here, in this graphic image 6, while the pre magnetizing, the TSRL voltage pulses are a little bit to width and the transformer core goes a little bit into saturation after each pulse. The no load current pulses rises to the end of the load current pulses.

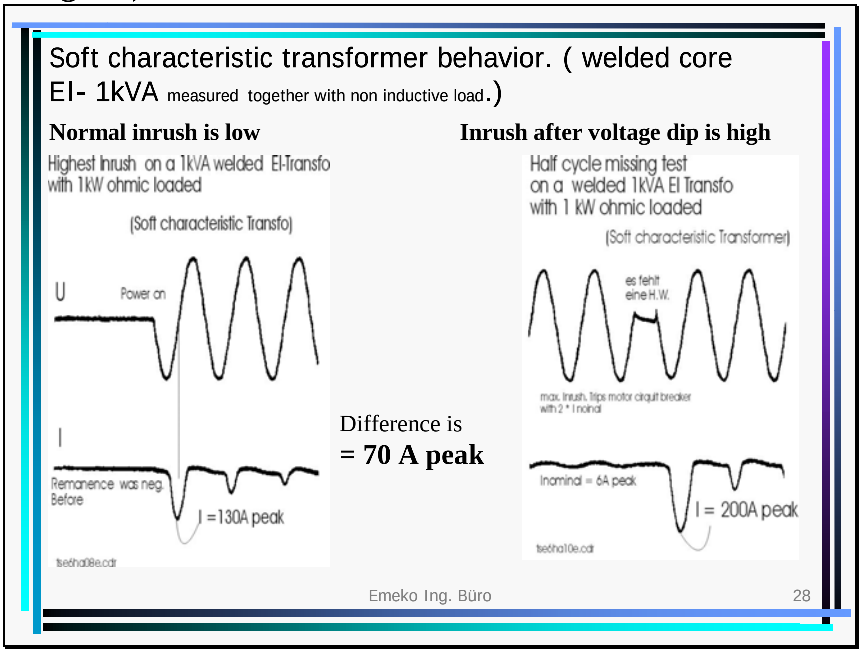
Image 6.)



This curve demonstrates very clear, the effect of the pre magnetisation into the iron core and the answer of the transformer with the input current pulses.
Here the pre magnetisation is a little bit to strong, but don’t blowing of fuses, like a big inrush does, because the current peaks are only 3 A eff. height.

3.) Description of the effect of voltage dips on the power line when feeding different types of single phase transformers. A soft and a hard type.

Measuring curves of the effect to transformers from voltage dips on the power line: Image 7.)

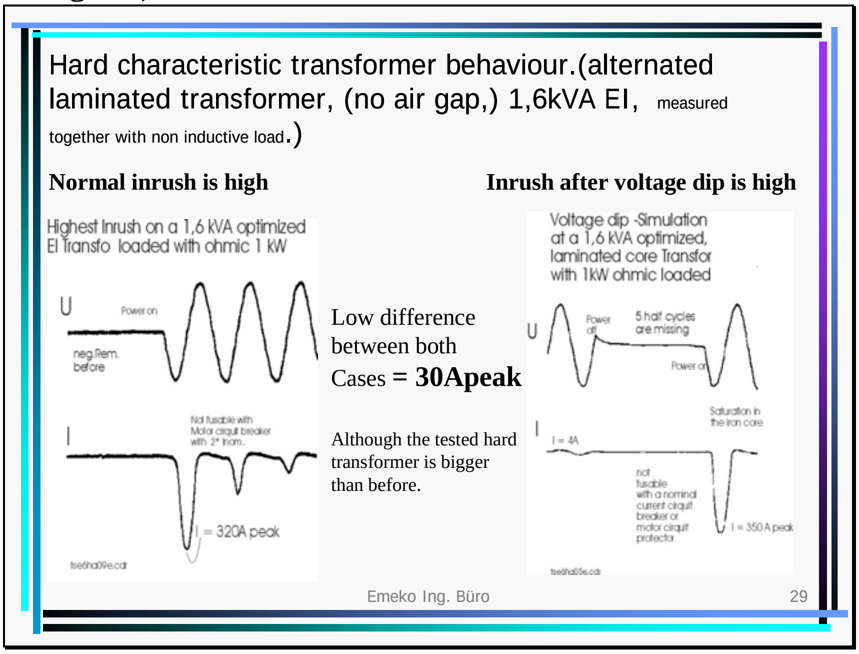


Before this Switching on at left side in image 7, the transformer was switched off at the end of the negative power line half wave. For that, the remnance was polarized negative at the max. point, before switching on at the begin of the neg. half wave. That brings the transformer iron core into full saturation. That’s the worst case for switching on after a long pause.

You see in the graphic on top at the right side in image 7: The inrush after a voltage dip is higher than with normally switch on in the worst case after a long pause.

Explanation: Because of not so widely running back of the magnetisation to the idle remnance point on the hysteresic loop at H = 0, in a short pause, (when missing a half wave), the inrush is higher than.

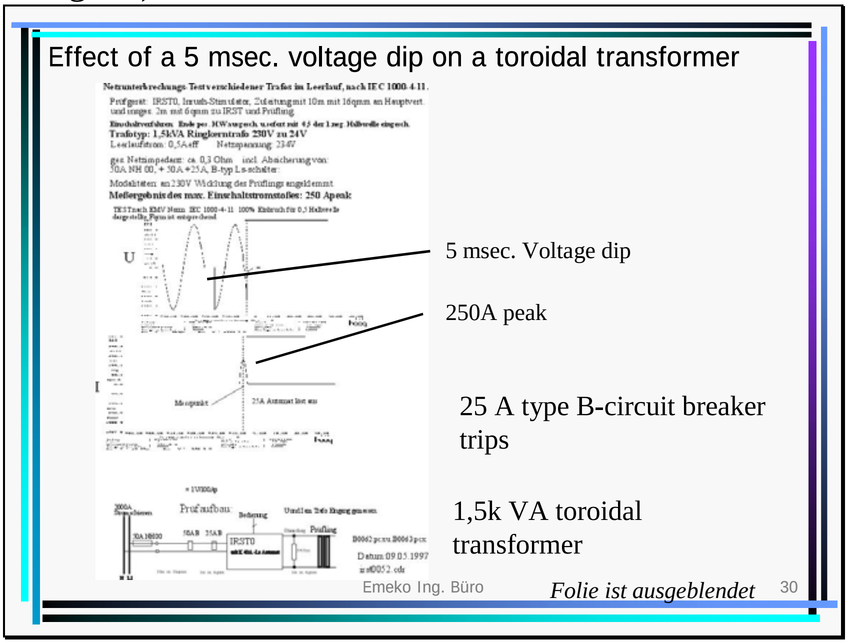
Measuring curves of the effect to transformers from voltage dips on the power line:
Image 8.)



In both cases, when normally switch on in worst case or when power line voltage comes back after a short dip, the remnance point has the nearly similar position on the hysteresic loop before switching on. See remnance at the toroid transformer, image 4, is higher than remnance at the nested core transformer.

Therefore the both inrushes, in worst case and after a dip are nearly similar but they are also higher than with transformers with air gaps in the core, because of the lower losses in the coil.

Measuring curves of the effect to transformers from voltage dips on the power line: Image 9.)



The effect with small voltage dips testing, smaller than 10 msec. seen in image 9, is similar the realistic sags on power lines.

Sometimes fuses trips accidentally and nobody knows why, when this happens.

The TSRL recognise this small voltage dip, switched off and starts either softly-here not shown- or calculated direct at the best point, -see image 11, and the fuse remains not affected, because no inrush occurs.

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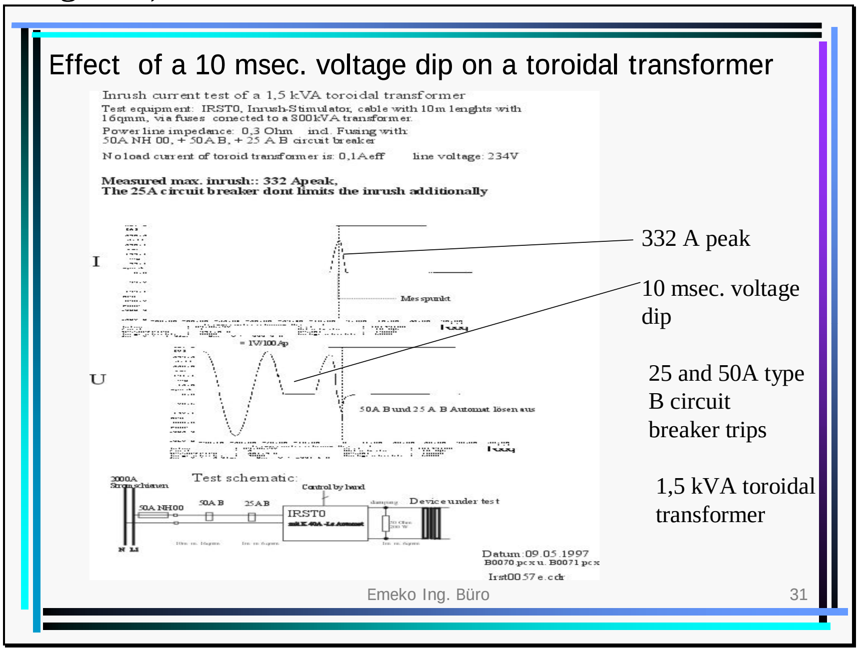
Measuring curves of the effect to transformers from voltage dips on the power line:
Image 10.)



Biggest inrush of a transformer, because one half wave was missing.

Inrush is bigger than with normal switch on in the worst case, after a long time pause,
While in the short time of this voltage dip the magnetisation can not run back to his stable remnance point in this short pause.

Therefore the core saturation is higher than with normally switch on in the worst case.

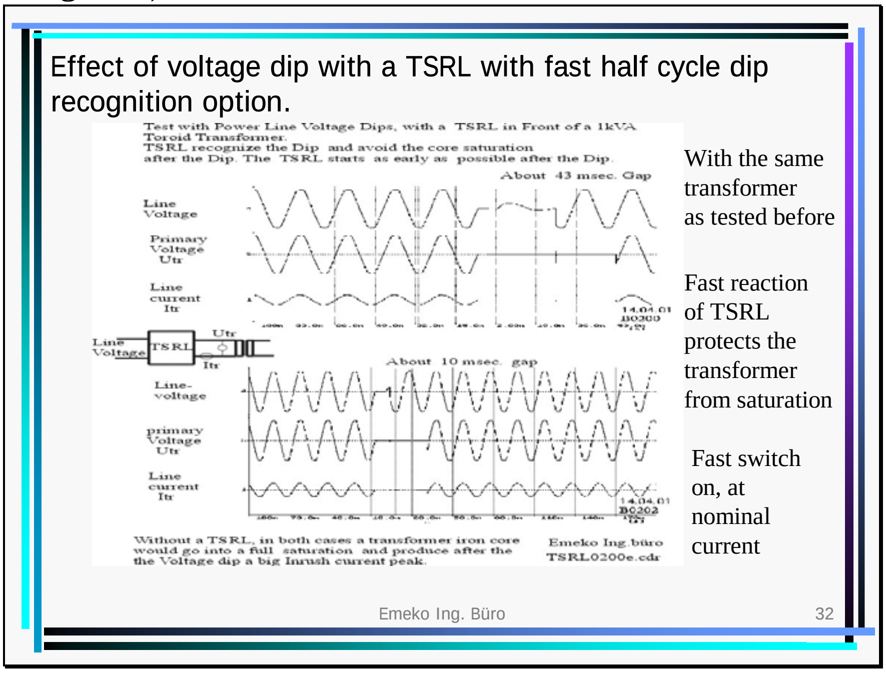
This occurs in a serious manner, when a 0,5 period voltage sag occurs on a transformer, when he is tested correspond:

EN 61000-4-11, 4. 3 **voltage dip** : (definition used for the purpose of this standard). For a single phase voltage of period T, there is a voltage dip if the rms value calculated with a time window (duration multiple of T/2) is lower than 90 percent of the declared voltage. It starts at the beginning of the first window and ends at the end of the last window which verifies the previous condition.

The worst case for an inrush is when missing one half wave, a 0,5 period.

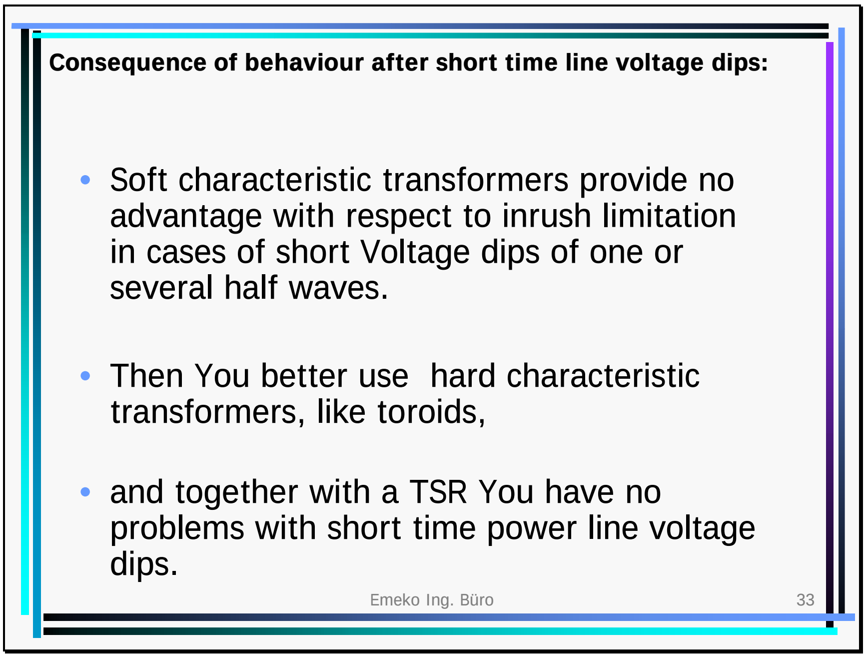
4.) Consequences of voltage dips with a TSRL in front of a transformer.

When the transformer has a soft starter TSRL in front, the voltage dips have no consequences in inrush current peaks.
Image 11.)



The effect of inrush after short time line voltage dips, can be avoided with a TSRL with the option: ----- „ schnelle Halbwellenausfall Erkennung.“= fast reacting on voltage dips. Fast switch off after a dip and a calculated fast switch on at the right time after voltage coming back, avoids inrushes.

The duration of the voltage gap at the transformer, after the TSRL, will be about 20 msec. longer than the power line gap, because the TSRL must wait on the right switch on point. He calculates it.



The consequence is hard for soft transformers.

They lead to use hard transformers together with a TSR.

The best hard characteristic transformer that I know is a toroidal transformer.

A toroidal transformer brings much advantages, like lowest iron losses, lowest no load current, lowest weight, low copper losses,(-can be implemented if inrush current is avoided by other means,) and a toroidal transformer brings also other advantages..... But it has also a big disadvantage.....
He has the highest inrush current peak. Up to 100 times the nominal current. But You have **no inrush** with a toroidal transformer when he is used together with a TSRL.

When inrush current peaks can be avoided with a Transformer-Switching-Relay, then the toroidal transformer can be the best choice. Its no load current and losses are more than 50 times lower than with welded EI core transformers.

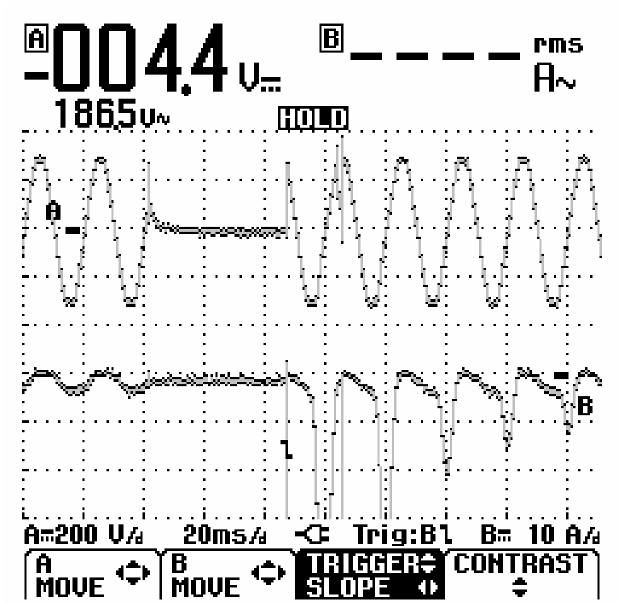
Emeko Ing. Büro 34

The most prejudice against toroidal transformers refer to high inrushes and to loose wires into the windings. Subsequent from inrushes when the coils are not impregnated with resin.

(The inrush produce high forces inside of windings and leads to loose wires. Loose wires in combination with high forces leads to damaged resin onto the wire. And leads therefore to shorted turns in the transformer windings, because of wire movement while inrush. Then the transformer is defect.)

All that negative points are eliminated with a TSR.

5.) Measuring curves on a transformer, while feed with voltage dips, per accident, by pulling and shaking the power line connector . No TSRL was connected in front of the transformer under test.
Image 12.)

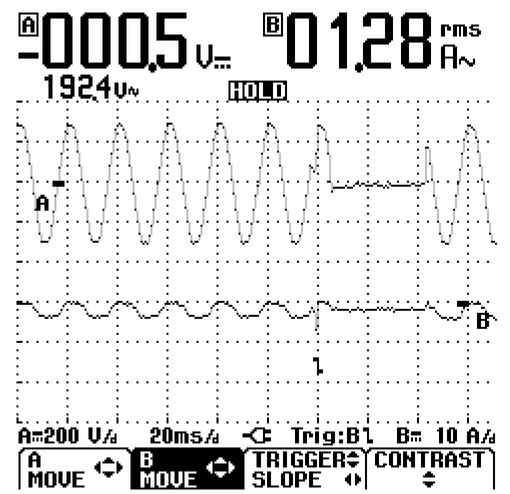


shwat001.fvf, schneller Halbwellenausfalltest, gemessen v. EMEKO Ing. Büro. an 0,8kVA EI Trafo mit Ohmscher Last, indem Netzsteckerwackler erzeugt wurde.A = U an Trafo prim, B= I in Trafo prim. getriggert auf I peak

Demonstration of the effect on transformers when a voltage dip occur per accident in the worst case.
Here the transformer gets two times after the other the same polarity of a voltage time area, before and after the dip. He goes full into saturation and draws a big inrush current peak.

Measuring curves on a transformer, while feed with voltage dips, per accident.

Image 13.)



shwat003.fvf, schneller Halbwellenausfalltest, gemessen v. EMEKO Ing. Büro. an 0,8kVA EI Trafo mit Ohmscher Last, indem Netzsteckerwackler erzeugt wurde.A = U an Trafo prim, B= I in Trafo prim. getriggert auf I peak

Demonstration of the voltage dip effect on transformers in a good case, image 13.
Here the transformer gets no inrush problems, because the voltage time areas after the dip brings no dc offset . The core goes not into saturation.
During the voltage gap, the remnance is running to the lower than pos. max. point, because it was not a full half wave, and after coming back of the voltage with the small pos. pulse, the magnetisation goes to the pos. turning point of the hysteresic loop, like in normal operation.
But this good case shape of a voltage dip with a nearly full cycle dip is not applicated in the test procedure.

Transformers in medical equipments, must be tested correspond EN 61000-4-11, with voltage dips like 0,5 cycles. See Image 10 and 12. Then two similar polarisated half waves from the power line voltage brings the core into full saturation. The fuse in front of the transformer trips and in some medical applications the test fails. A TSRL can avoid this.

For that reason, more and more manufacturers of medical equipments are getting the TSRL and can pass the Test with voltage dips correspond EN 61000-4-11.