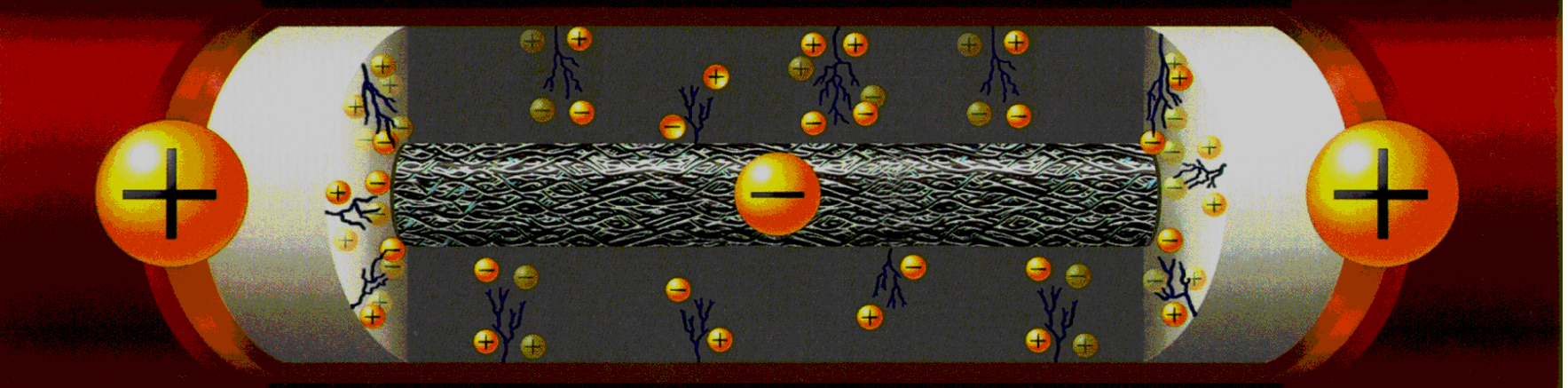
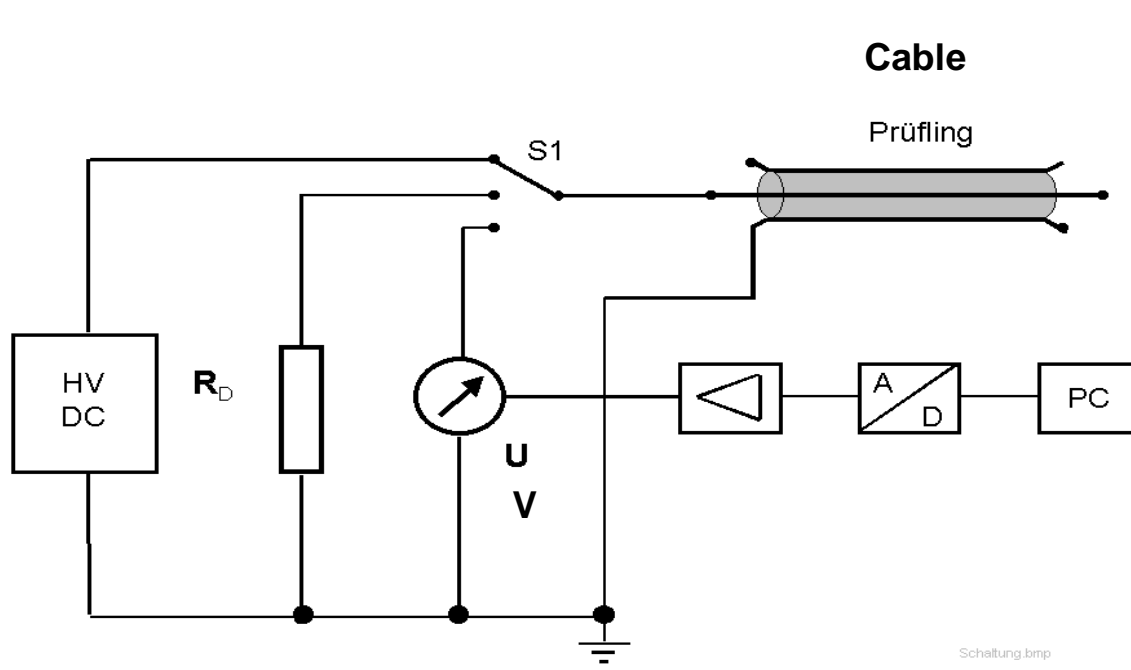


CABLE DIAGNOSTICS



The Return Voltage Method
A Non –Destructive Global Assessment
Method for PLC Cables / Transformers



BLOCK DIAGRAM RETURN VOLTAGE METHOD

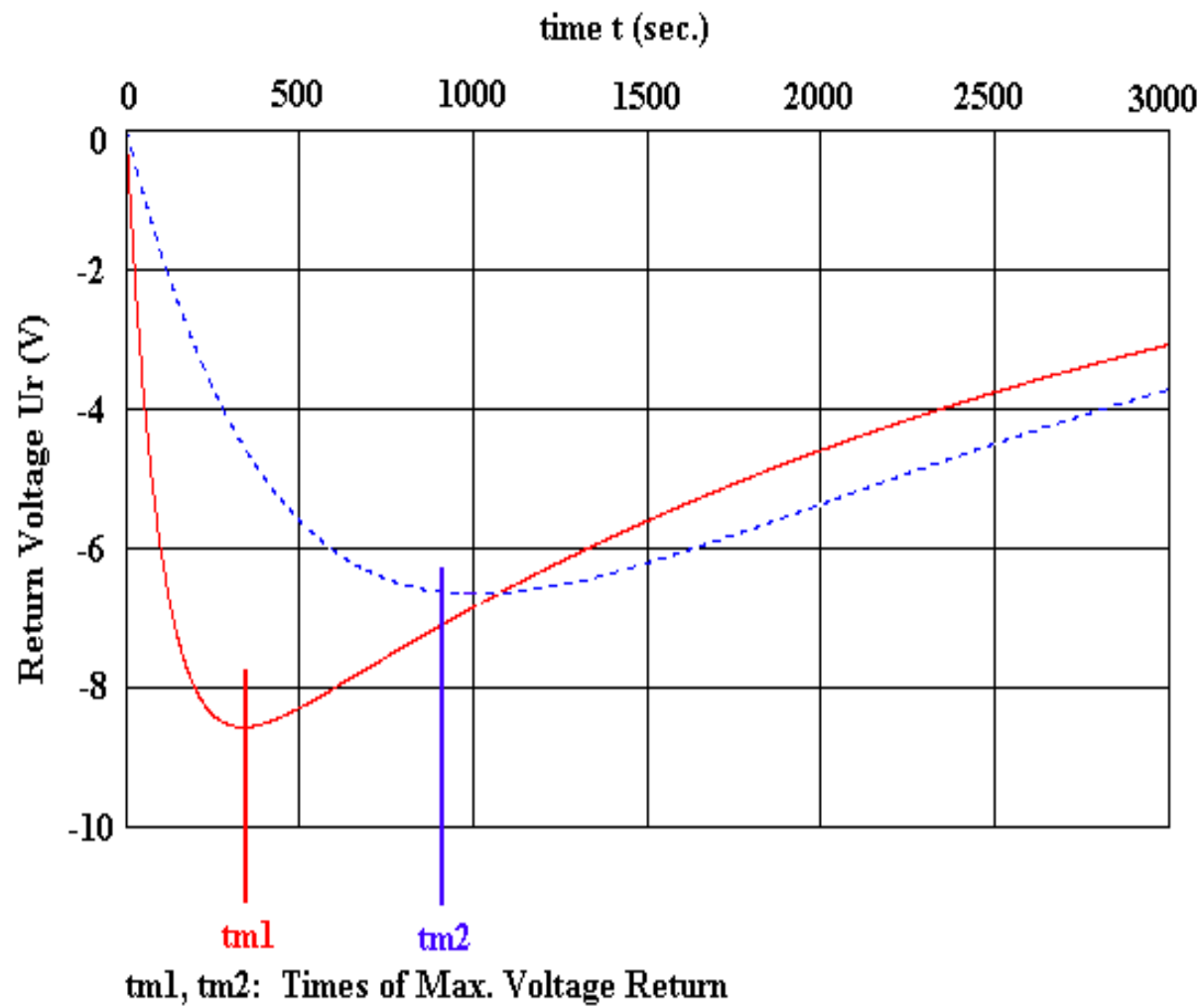
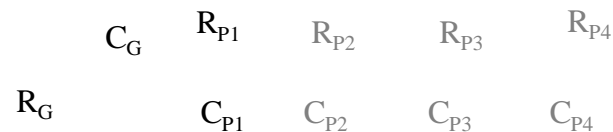
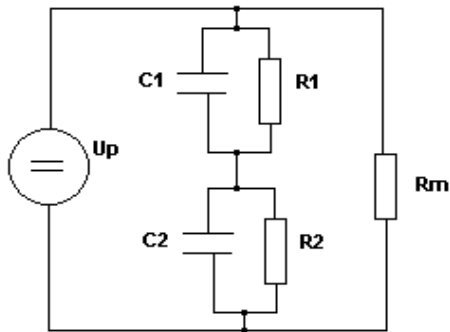


Fig. 2: Two Typical Return Voltage Curves

Diagnostic (Predictive) Method to Assess Global Condition of PILC Cable Insulation, Return Voltage Method (RVM)



$$V_R(t=0) \approx 0$$

$$I_R(t=0) \approx \frac{V_C}{R_{p1}}$$

$$C_{p1} \ll C_G$$

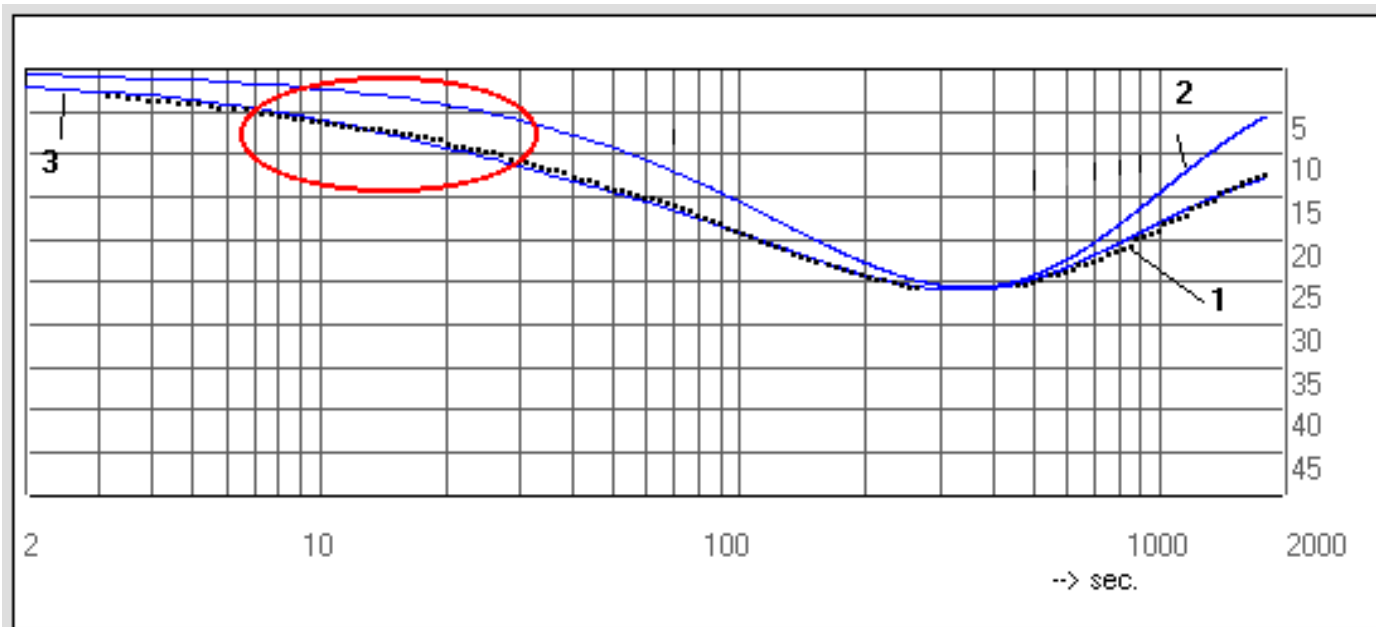
$$V_R(t) = V_S \left(e^{-\frac{t}{\tau_2}} - e^{-\frac{t}{\tau_1}} \right)$$

“Physics” Maxwell Equation

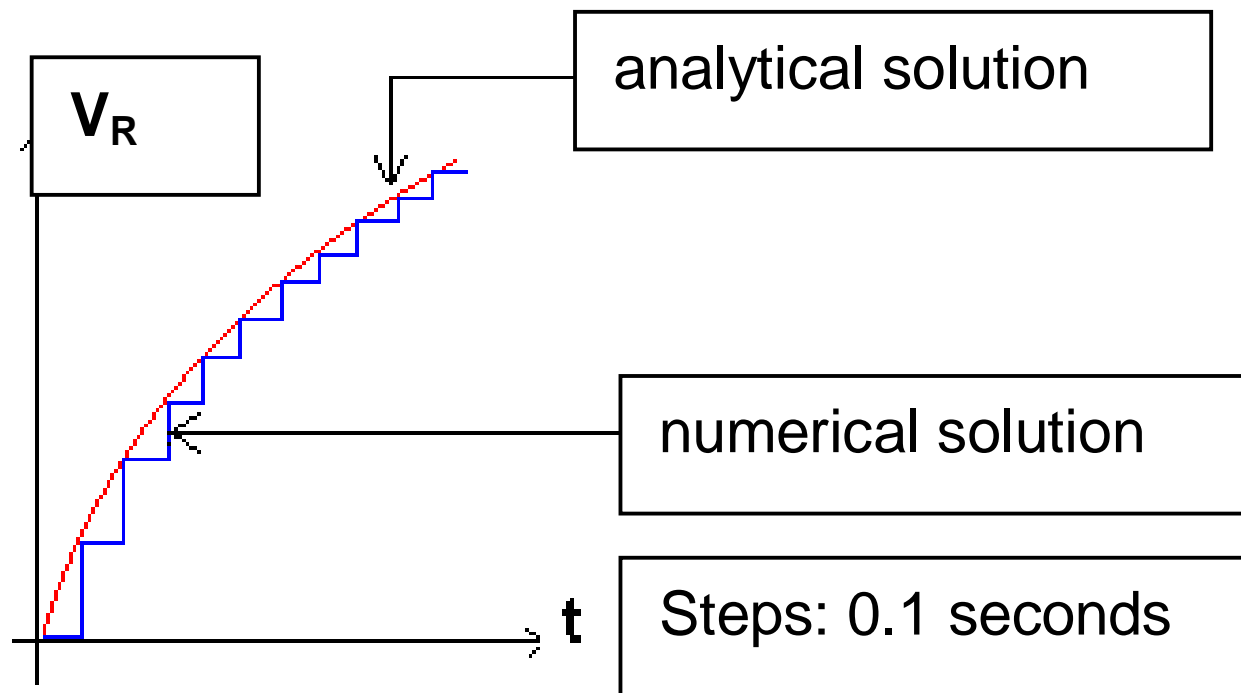
$$V_R(t) = V_C \frac{1}{1 - \frac{\tau_p}{\tau_G}} \left(e^{-\frac{t}{\tau_p}} - e^{-\frac{t}{\tau_G}} \right)$$

“Engineering” Equation

2 Equivalent Circuit Diagrams to represent Laminated (PILC) Insulation

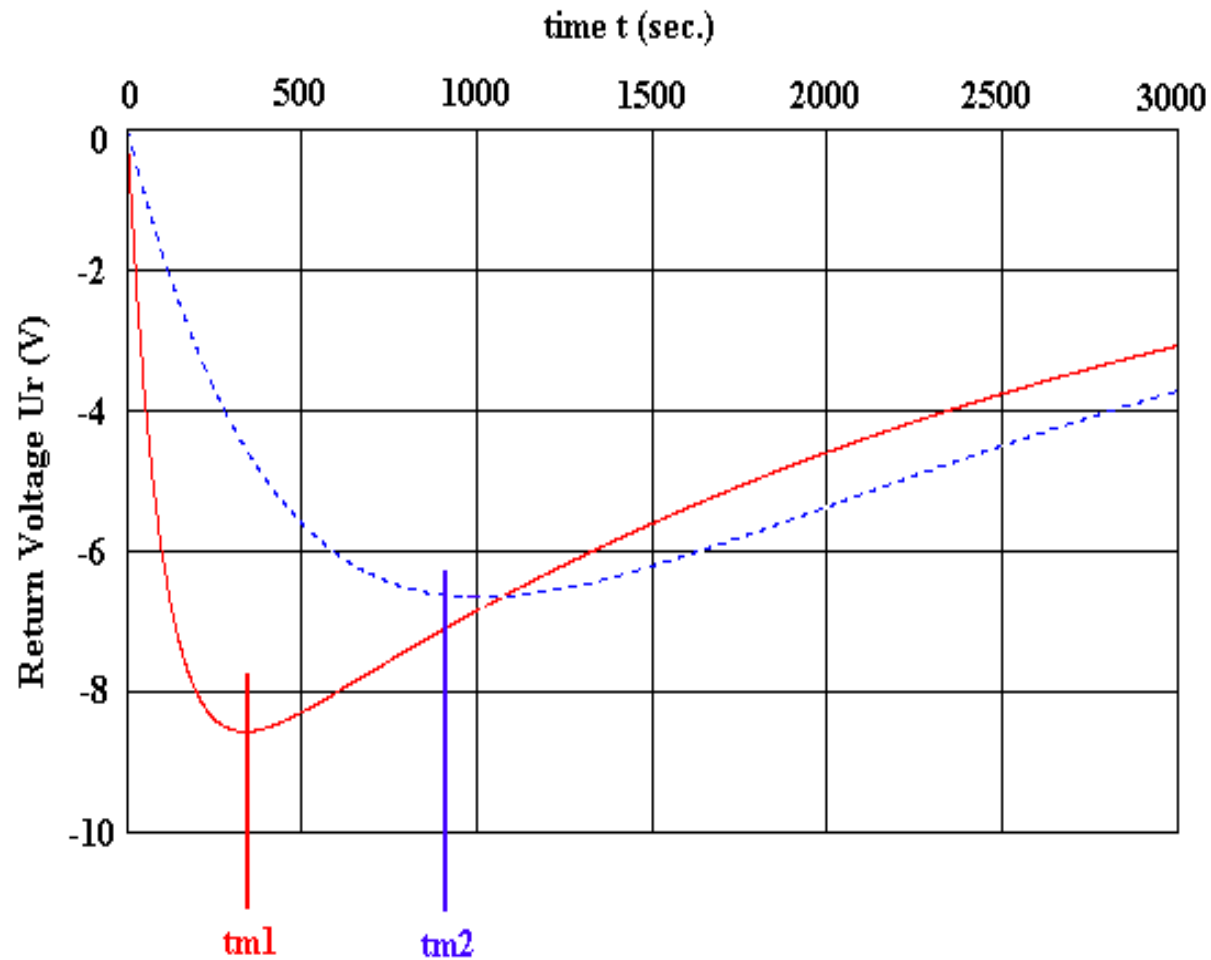


- (1) measured (recorded) curve
- (2) equation 2 with one time constant
- (3) equation 2 with three time constants



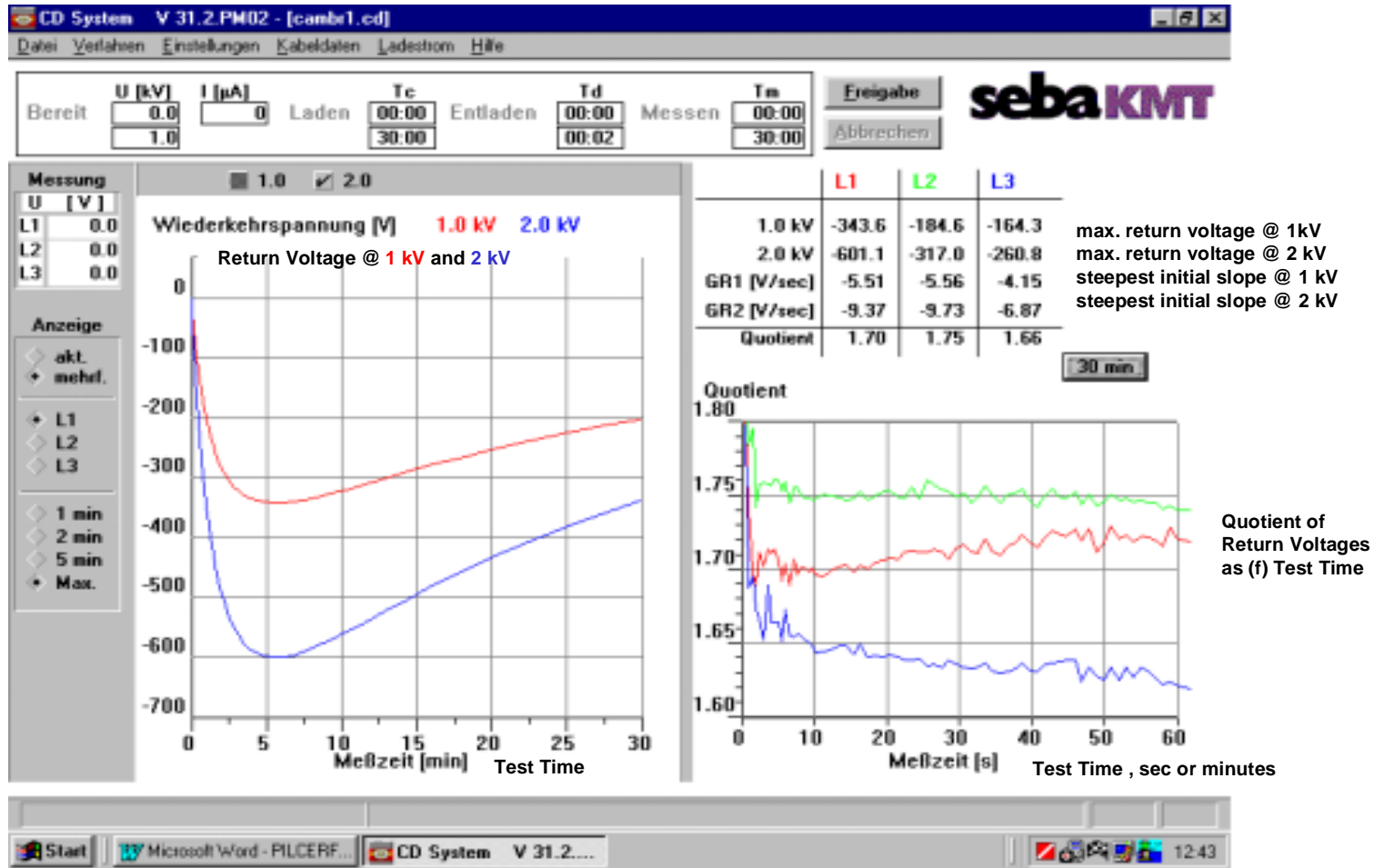
Three Polar Components $C_{p_{1-3}}$ result in Diff.Equation of 4th order!

Must be solved iteratively and numerically



$tm1, tm2$: Times of Max. Voltage Return

**Fig. 2: Two Typical Return Voltage Curves;
Moisture effects Magnitude and
Time to Maximum of Return Voltage**

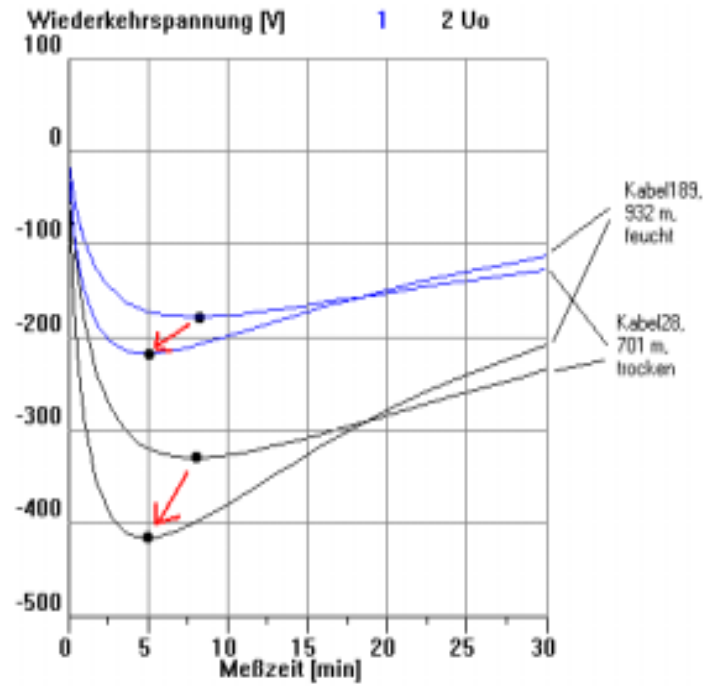


Q_{IS} Dry: 2.00....1.87
 Q_{IS} Moist: 1.86... 1.65
 Q_{IS} Wet: < 1.65

Q_{IS} : Quotient of Initial Slopes

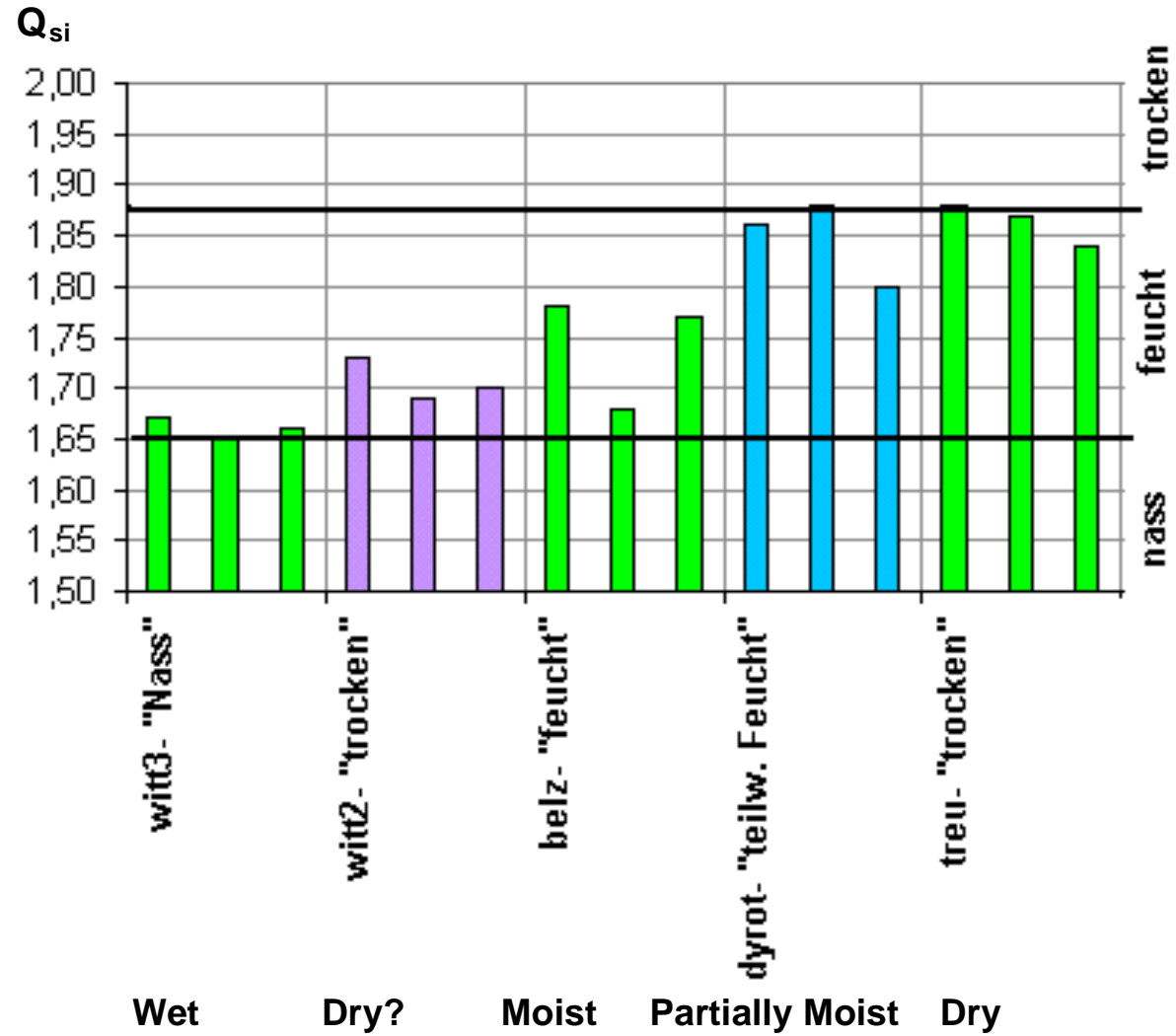
Q_{RV} : Quotient of Return Voltages

Return Voltage @ 1 kV @ 2 kV

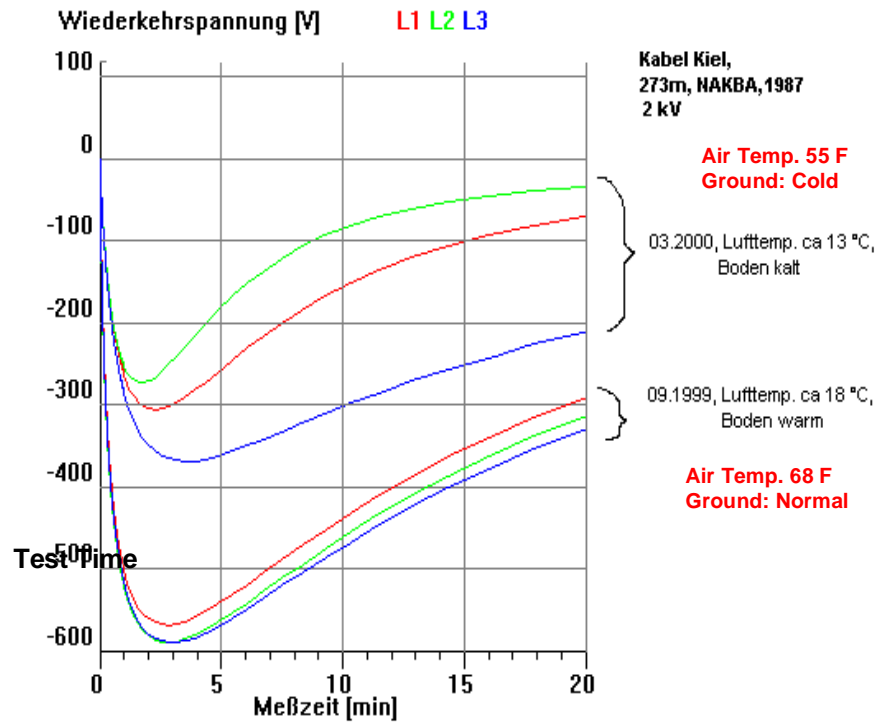


Effects of Moisture on Initial Slope & Time of Maximum Return Voltage

Cables A'burg



Return Voltage measured @ one voltage & two temperatures



Temp.° C	1 kV V/s	2 kV V/s	Quotien t
5	1,230	2,385	1,939
20	1,495	2,920	1,953
35	2,030	3,985	1,963

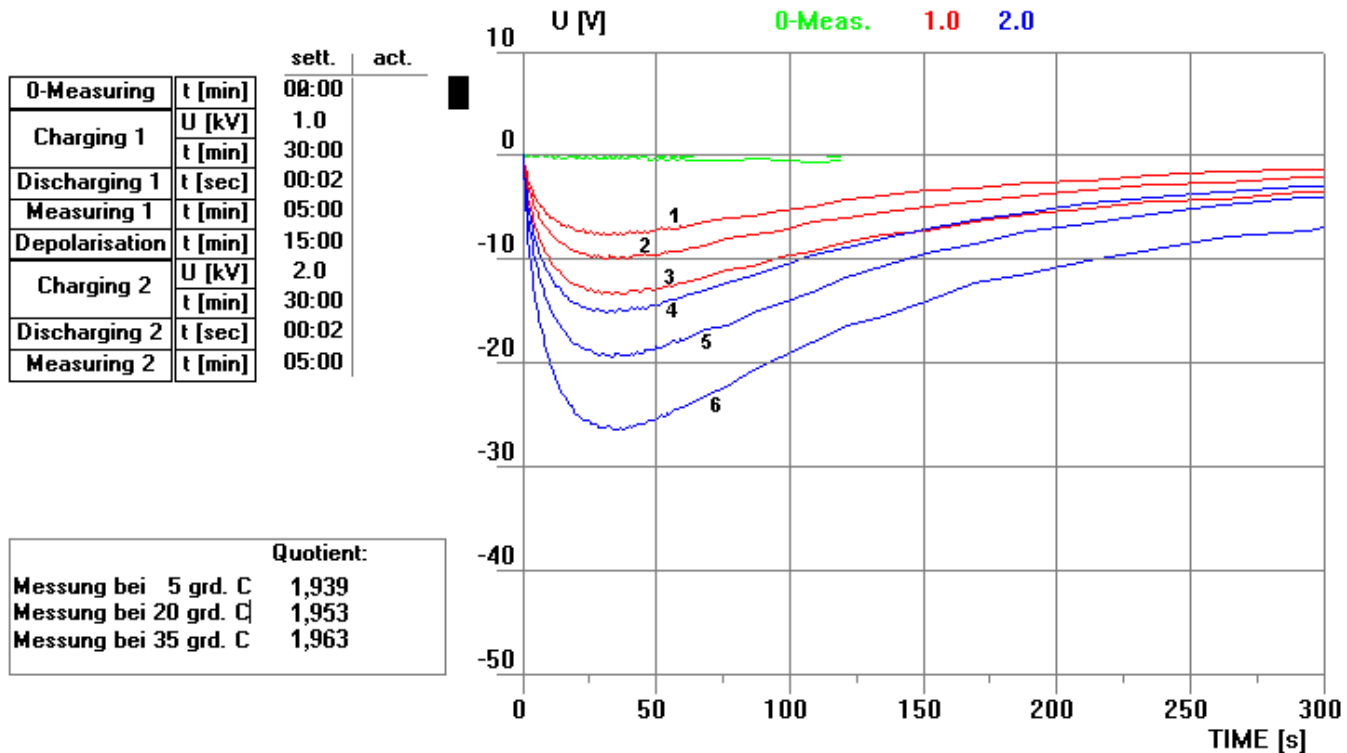
Table 1: Temperature Effects, Tests run on same cable reel after soaking @ 3 temperatures

Important:

Even the Return Voltage is Temperature dependent,
the **Quotient** of the **Initial Slope** of 2 Tests @ different Voltages is not!

<<Eliminates Temperature Effect >>

START CANCEL

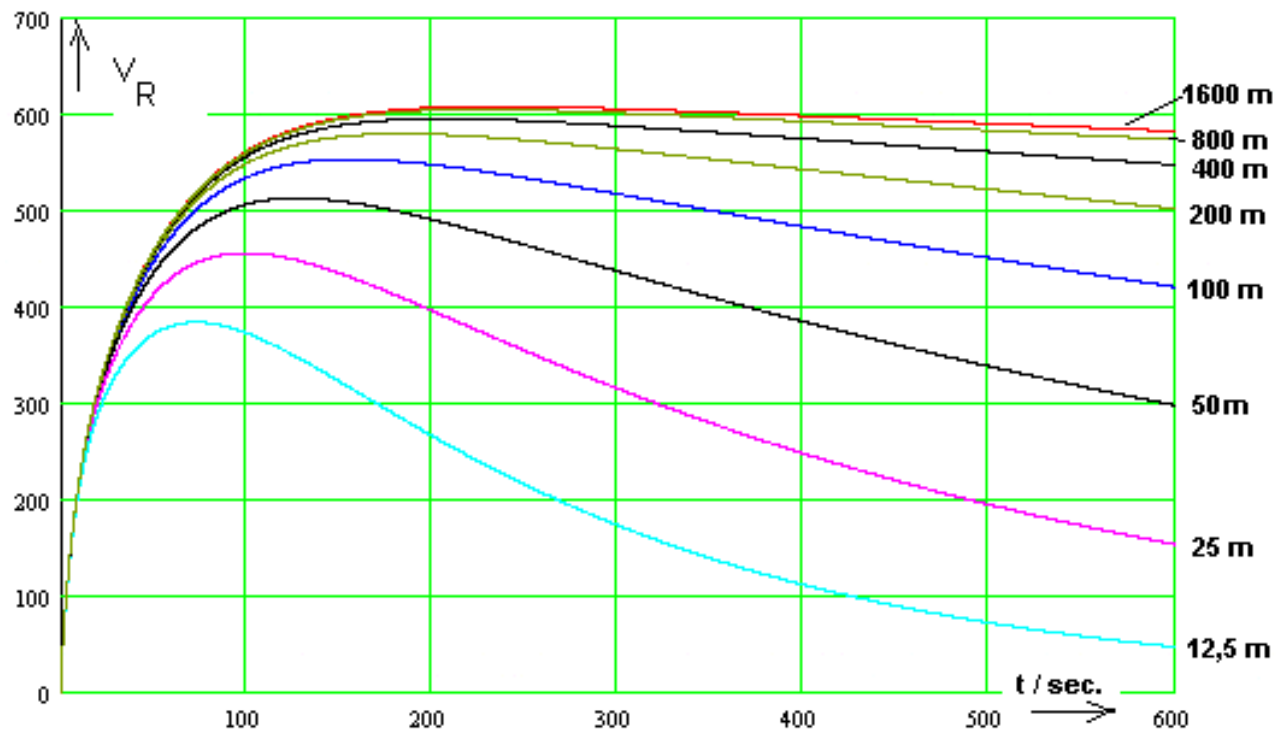


Kurve 1 : Ladung mit 1 kV, 5 grd.C
 Kurve 2 : Ladung mit 1 kV, 20 grd.C
 Kurve 3 : Ladung mit 1 kV, 35 grd.C

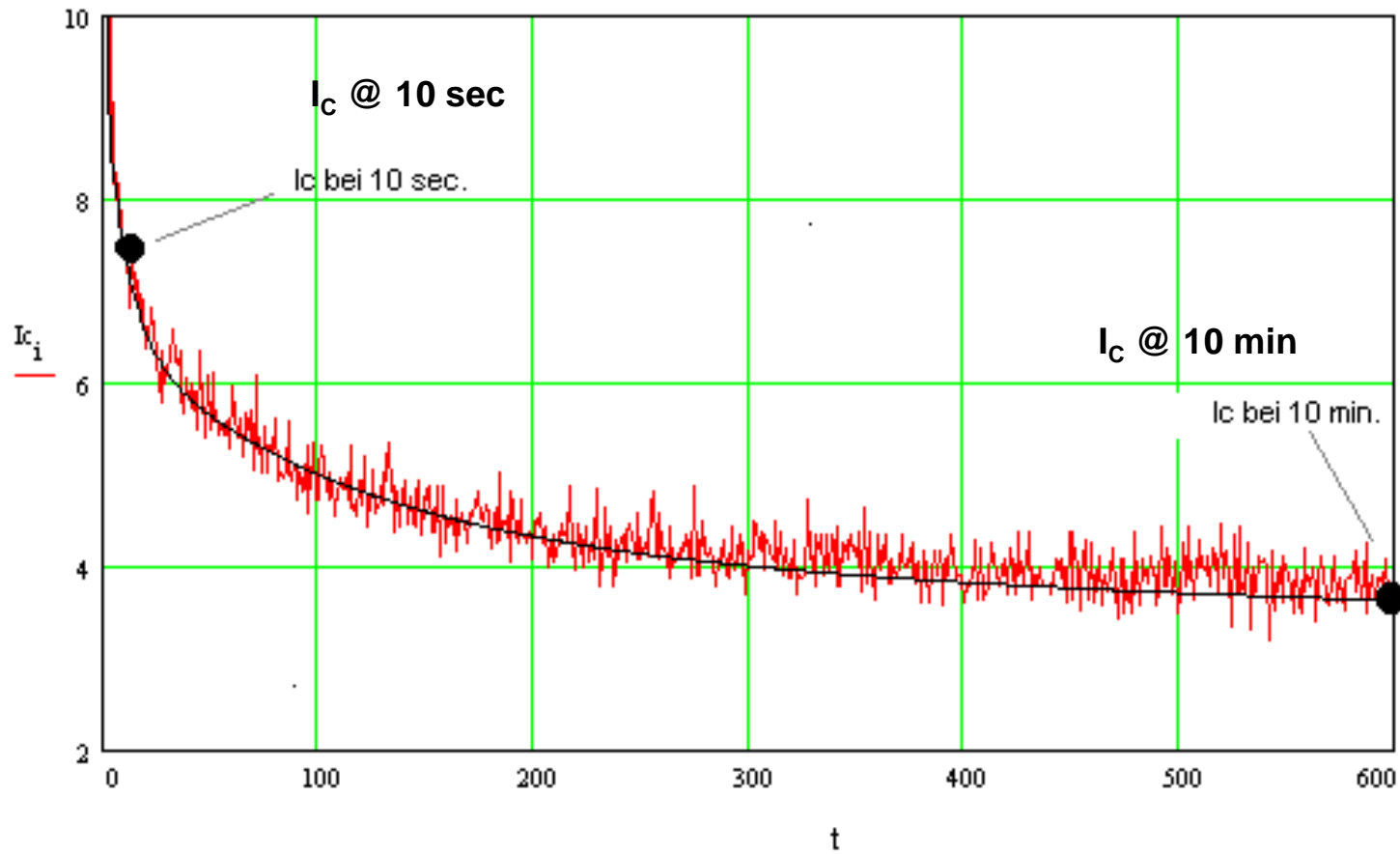
Kurve 4 : Ladung mit 2 kV, 5 grd.C
 Kurve 5 : Ladung mit 2 kV, 20 grd.C
 Kurve 6 : Ladung mit 2 kV, 35 grd.C

NUM

Cable tested @ 3 Temperatures and 2 Voltages

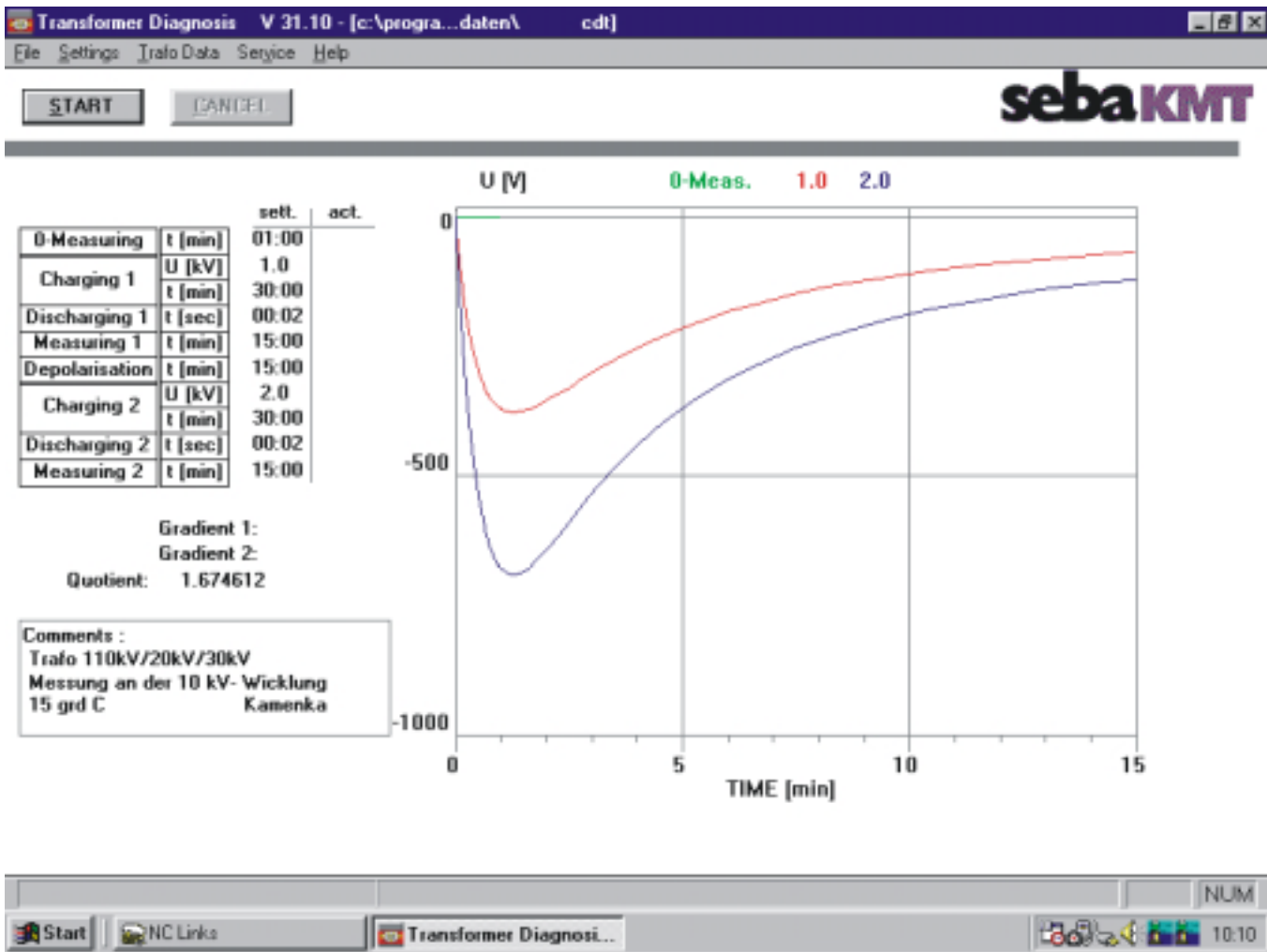


Effect of Cable Length on Return Voltage (>2000 ft negligible)



Ladestrom.bmp

Leakage Current over time (large ratio ~ 1.5 indicates wet cable, ~ 1.2 indicates dry cable)



Transformer tested @ 1 & 2 kV