Dielectric Loss Considerations

General

In 2004 Kerite celebrated our 150th year in business. We have been manufacturing medium voltage power cable since well before 1900, and our earliest URD applications were in 1926. The "Kerite" ingredient in our cable dates back to our first power cable, although the base rubber resin has evolved from natural rubber to EPDM synthetic resin adopted in 1963. In the past we have used two different insulation formulations, High Temperature Kerite (HTK) and High Voltage Kerite (HVK). HTK was our traditional insulation. HVK was introduced in the early 1970's for application on voltage classes 35kV through 138kV. In the early 1960s we standardized on HVK for all cable constructions and the HTK insulation was made obsolete. All Kerite cables produced since the early 1960s through today are constructed using our HVK insulation.

Kerite chose to offer a unique cable design that was not covered by industry consensus standards. This changed starting in 1996 and led to the current revisions to AEIC CS8-00 and ICEA S-94-649-2000, which included provisions for "DISCHARGE RESISTANT" medium voltage cable designs. The very high resistance to electrical discharge (corona) that is inherent in Kerite cable designs allows for features and performance that are only available in Kerite cable. The electrical properties of our original HTK insulation did result in higher dielectric loss levels. Although we no longer use HTK insulation, this has been an area of commercial focus for our competitors and is a misrepresentation of the current Kerite product. This paper is presented to thoroughly explore the issue of dielectric losses, to present the issue in proper perspective, and to correct blatant misrepresentations.

Dielectric Losses

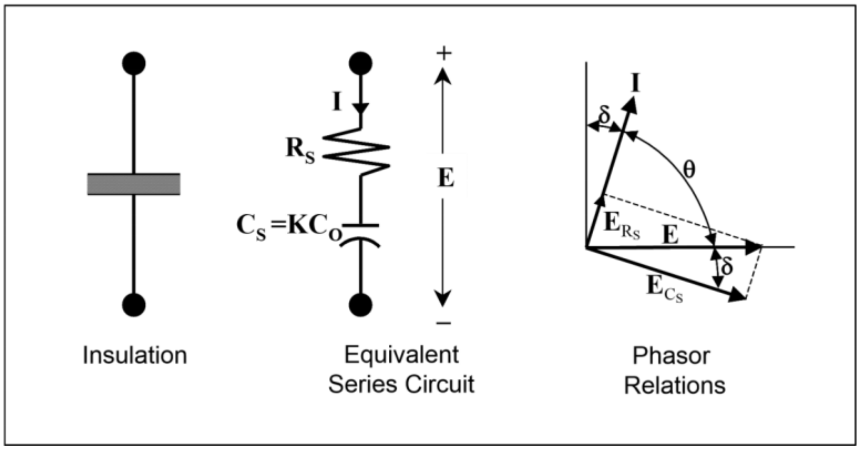
Any dielectric material may be characterized as a series capacitance and resistance. The conduction aspects of these elements can be measured in terms of the following parameters:

1. Capacitance
2. Tangent δ

Knowing the insulation geometry (inner and outer diameters) the material's relative dielectric constant (relating the material's electric flux density/electric field intensity ratio to that of free space with the same geometry) can be established. The relative dielectric constant is alternately called permittivity, SIC (Specific Inductive Capacity) or K.

Tangent δ (Tan δ or Dissipation Factor) is a measure of the voltage-current relationship brought about by the material's equivalent series resistance and capacitance. δ, the loss angle, is the compliment of θ, the power factor angle.

The interrelationships of the foregoing are illustrated as follows:



The power consumed (or dissipated) in cable insulation can be reduced to the following relationship in terms of geometry, dielectric constant and dissipation factor.

$$P_L = [0.00638*(kV)^2 *K *\tan\delta] / [\ln(D_O/D_I) * (1 + \tan^2\delta)] \text{ watts/linear foot}$$

Where: D_O = outer diameter
D_I = inner diameter

The above equation can be used for cable constructions with a single dielectric layer, which is typical for our competitors' products. Since Kerite MV-UD cable is designed with a high K insulating conductor shield (our Permashield™), we need to use the more general form of the equation – which allows for multiple dielectric layers:

$$P_L = \frac{0.00638 *(kV)^2\{[\tan\delta_1 * \ln((D_1/D_C)/K_1] +\ldots+ [\tan\delta_N*\ln(D_N/D_{N-1})/ K_N]\}}{\{[\tan\delta_1 * \ln((D_1/D_C)/K_1] +\ldots+ [\tan\delta_N*\ln(D_N/D_{N-1})/ K_N]\}^2 + \{ \ln(D_1/D_C)/K_1 +\ldots+\ln(D_N/D_{N-1})/K_N\}^2}$$

Where: D_C = diameter of the conductor
D_1 = diameter of the first layer
D_N = diameter of the Nth layer

The constant in the equation (0.00638) is a function of the power frequency. The value shown is for 60hz. Losses increase with frequency – a point that becomes important later in this discussion.

The K and Tan δ values are, to varying degrees, temperature dependent. Typical values at operating and emergency temperatures for Kerite Permashield, HTK and HVK compounds are as follows:

Material	K = SIC					Tan δ = D. F.				
	23°C	40°C	75°C	90°C	130°C	23°C	40°C	75°C	90°C	130°C
Permashield	9.35	9.38	10.24	11.78	19.43	0.0634	0.0760	0.2841	0.4318	0.6454
HTK	2.83	2.90	3.04	3.10	3.27	0.0068	0.0109	0.0286	0.0431	0.1296
HVK	2.69	2.67	2.64	2.62	2.58	0.0022	0.0032	0.0066	0.0091	0.0214

Losses for various constructions and conductor sizes, in terms of watts per linear foot computed using the development described, are provided for 40°C (which represents the high-side URD primary cable operating conditions):

Dielectric Losses in Kerite Cable in watts/linear foot

Temperature in Degrees C = **40**

Permashield	Tanδ =	0.0760	SIC =	9.3829
HTK	Tanδ =	0.0109	SIC =	2.8952
HVK	Tanδ =	0.0032	SIC =	2.6719

Diameters (in mils) for Concentric Neutral Cables with Compressed Conductors per ICEA S-94-649-2000

Conductor Size	Cond. Nom	15 kV Cable (100% Level) Insulation Diameter		15 kV Cable (133% Level) Insulation Diameter		25 kV Cable (100% Level) Insulation Diameter		35 kV Cable (100% Level) Insulation Diameter	
		Min	Max	Min	Max	Min	Max	Min	Max
#2 awg	0.283	0.635	0.72	0.725	0.815	—	—	—	—
#1 awg	0.322	0.675	0.76	0.765	0.855	0.835	0.925	—	—
#1/0 awg	0.362	0.715	0.8	0.805	0.895	0.875	0.965	1.045	1.145
#2/0 awg	0.406	0.76	0.845	0.85	0.935	0.92	1.01	1.09	1.19
#3/0 awg	0.456	0.81	0.895	0.9	0.985	0.97	1.06	1.14	1.24
#4/0 awg	0.512	0.865	0.95	0.955	1.045	1.025	1.115	1.195	1.295
250 kcmil	0.558	0.92	1.005	1.01	1.1	1.08	1.175	1.25	1.35
350 kcmil	0.661	1.025	1.11	1.115	1.2	1.185	1.275	1.355	1.455
500 kcmil	0.789	1.15	1.235	1.24	1.33	1.31	1.405	1.48	1.58
750 kcmil	0.968	1.34	1.425	1.43	1.52	1.5	1.595	1.67	1.77
1000 kcmil	1.117	1.485	1.575	1.575	1.67	1.645	1.74	1.815	1.92
Permashield/HTK		8.3 kV L-G		8.3 kV L-G		14.4 kV L-G		21.1 kV L-G	
#2 awg	0.012	**0.0201**		**0.0170**		—		—	
#1 awg	0.012	**0.0217**		**0.0183**		**0.0498**		—	
#1/0 awg	0.012	**0.0234**		**0.0196**		**0.0533**		**0.0938**	
#2/0 awg	0.012	**0.0252**		**0.0212**		**0.0570**		**0.0999**	
#3/0 awg	0.012	**0.0273**		**0.0228**		**0.0614**		**0.1070**	
#4/0 awg	0.012	**0.0297**		**0.0246**		**0.0663**		**0.1149**	
250 kcmil	0.016	**0.0329**		**0.0272**		**0.0725**		**0.1252**	
350 kcmil	0.016	**0.0371**		**0.0306**		**0.0815**		**0.1393**	
500 kcmil	0.016	**0.0428**		**0.0349**		**0.0926**		**0.1575**	
750 kcmil	0.02	**0.0518**		**0.0420**		**0.1107**		**0.1863**	
1000 kcmil	0.02	**0.0585**		**0.0471**		**0.1244**		**0.2074**	
Permashield/HVK		8.3 kV L-G		8.3 kV L-G		14.4 kV L-G		21.1 kV L-G	
#2 awg	0.012	**0.0075**		**0.0062**		—		—	
#1 awg	0.012	**0.0081**		**0.0066**		**0.0175**		—	
#1/0 awg	0.012	**0.0086**		**0.0070**		**0.0186**		**0.0316**	
#2/0 awg	0.012	**0.0092**		**0.0075**		**0.0197**		**0.0334**	
#3/0 awg	0.012	**0.0099**		**0.0080**		**0.0211**		**0.0355**	
#4/0 awg	0.012	**0.0107**		**0.0086**		**0.0226**		**0.0379**	
250 kcmil	0.016	**0.0127**		**0.0100**		**0.0261**		**0.0433**	
350 kcmil	0.016	**0.0141**		**0.0112**		**0.0291**		**0.0476**	
500 kcmil	0.016	**0.0162**		**0.0127**		**0.0327**		**0.0534**	
750 kcmil	0.02	**0.0205**		**0.0159**		**0.0407**		**0.0653**	
1000 kcmil	0.02	**0.0230**		**0.0177**		**0.0455**		**0.0722**	

Economic Considerations

Dielectric losses have to be viewed in context with total cable losses. Dielectric losses are independent of the current (except for its impact on operating temperature). There are two types of current related losses – those that occur due to the resistance of the center conductor, and those that result from the magnetic flux of the AC current flow inducing voltage and current flow in the metallic shield (e.g. neutral wires). The current flow in the center conductor results in I^2R losses. Industry standards set a minimum cross sectional requirement for stranded conductor of 98% of nominal. The difference in I^2R losses resulting from the typical range of conductor size variation exceeds the dielectric losses. The focus on dielectric losses, which amount to less than the losses resulting from statistical variation of conductor dimensions, has no real merit, and would be reasonable to neglect.

That said, dielectric losses are real, are measurable, and present an ongoing expense to the user, making losses a fair commercial issue. In order to present an accurate picture of Kerite's relative losses, we will look at 1) a misleading commercial presentation by one of our competitors, and 2) a total system view.

1. Unfortunately one of our competitors is using incorrect and misleading information to discourage customers from using Kerite. They incorrectly use Kerite's discontinued HTK insulation in their comparison because it has much higher dielectric losses. They also use incorrect inflated values to exaggerate the results. Below is a reproduced table with their view of the cost of dielectric losses as presented in their flier.

(COMPETITORS VIEW)

PRESENT VALUE of DIELECTRIC LOSS

($ per 1000 ft. over 40 years)

Conductor Temperature	(R.T.) 23°C	60°C	90°C
EPR-P	$87	$95	$119
EPR-C	$162	$215	$354
EPR-O	$244	$280	$377
EPR-K	$1178	$2056	$3907
TRXLP	$11	$35	$40
Based on 1/0 awg 25kv, .260" insul. 4% inflation, 6% interest, $0.05/kwhr.			

Clearly the values presented for "EPR-K" are supposed to represent Kerite. Using the same equation but with the actual values for Kerite insulation, the Kerite numbers would be:

(ACTUAL KERITE VALUES)

PRESENT VALUE of DIELECTRIC LOSS

($ per 1000 ft. over 40 years)

Conductor Temperature	(R.T.) 23°C	60°C	90°C
HTK (obsolete)	$278	$799	$1900
HVK	**$114**	**$257**	**$507**
Based on 1/0 awg 25kv, .260" insul. 4% inflation, 6% interest, $0.05/ kwhr.			

Before leaving this topic, the subject of Present Value should also be discussed. Present value (or worth) is a way to describe a future expense in today's dollars. The higher the rate of inflation – the higher the present worth. The higher the interest rate (or the cost of capital) – the lower present worth. The values of interest and inflation (6% and 4% respectively) are not very realistic, and were chosen by the competitor to give emphasis to the cost of dielectric losses. In the case of investments, utilities generally relate capital costs to their historic return on equity. If more reasonable values (e.g. 10% and 3%) were used in determining present worth, the numbers would change dramatically:

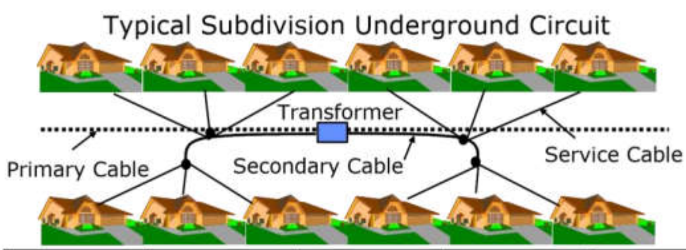
PRESENT VALUE of DIELECTRIC LOSS

($ per 1000 ft. over 40 years)

Conductor Temperature	(R.T.) 23°C	60°C	90°C
HTK	$43	$123	$293
HVK	**$18**	**$40**	**$78**
Based on 1/0 awg 25kv, .260" insul. **3% inflation, 10% interest**, $0.05/kwhr.			

Clearly, the assumptions that are made when calculating the dielectric losses can greatly impact the results. In this case, the assumptions were used to make results appear much more significant than they actually are. The corrected present values of dielectric loss highlight the fact that they are not a significant source of expense and can be disregarded.

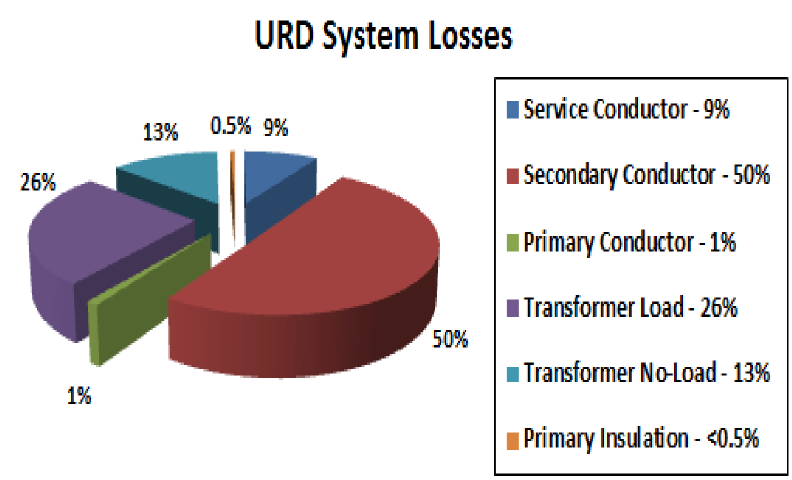
2. Dielectric losses are only a part of system losses. Just how small a part can be given perspective by the following analysis:



	Service	Secondary	Primary	Transformer
Conductor	1/0 AWG AL	4/0 AWG AL	1/0 AWG AL	--
Voltage	240 volts	240 volts	8,000 volts	8kv/240v
Avg. Length	840 ft	400 ft	600 ft	--
Peak Demand	10kW	40kW	60kW	60kW(50kW)
Load Factor	50%	60%	75%	75%
Avg. Load	21 Amps	98 Amps	6 Amps	6 Amps
Load Loss	120 Watts	633 Watts	18 Watts	339 Watts
No-load Loss	0	0	**4 Watts**	166 Watts

4 Watts with HVK insulation at ambient temperature

What the above chart shows is that, when viewed as part of total system losses, dielectric losses do not merit a lot of scrutiny. Primary cable dielectric losses represent less than 0.5% of total losses. Transformer and conductor losses are the areas where total losses can best be optimized. It should also be noted in the above analysis that the current in the primary cable was assumed to be only that needed to service the single transformer – in fact, depending on the transformer's place in the loop, the cable would be carrying current to other transformers. This would add to the cable's current related losses, making the dielectric losses an even smaller part of the total.



Permashield™

Kerite HVK Insulation actually has one of the lowest loss factors (K*DF) of the available EPR cable insulations. Instead of using semicon as a conductor shield, like other manufacturers, Kerite cables use Permashield™, a proprietary nonconducting stress control system that is proven to enhance cable reliability. Permashield™ provides capacitive stress grading while adding to the ac dielectric strength of the cable. Permashield™ reduces the impact of damage caused during cable preparation, reducing the likelihood of premature failure at terminations and splices due to workmanship. Because Permashield™ is an insulator and not a semicon, it does add to the dielectric losses of the cable and was factored in to the earlier loss calculations.

Summary

Dielectric loss associated with Kerite underground cable has been grossly misrepresented by our competitors by using the discontinued HTK insulation for their calculations. Kerite discontinued their HTK insulation in the early 1960's and now uses HVK insulation. Kerite's HVK insulation actual losses are in line with other EPR cables. Kerite's HVK insulation is the only insulation to meet the "Discharge Resistant" classification. Dielectric loss from the cable insulation is insignificant compared to total system losses and can be disregarded.