Process Report, Dec 2007

DCR Validation Test

Definitions:

DCR – Math Model or Algorithm for Cable Dynamic Rating

Tcs – Cable Surface Temperature

Tcc – Cable Conductor Temperature

Tbn – Temperature Bottle-neck Detected by DTS Optic Sensor Cable

Tam – Environment Temperature (Ambient Air Temperature)

Load – Cable Loaded Current

DcR – Cable Electric DC Resistance

Ys – Conductor Skin Factor;

Yp – Conductor Proximity Factor;

AcR – Cable Electric AC Resistance, equal to DcR x (1+Ys+Yp);

Hcc – Heat Generated from Cable Conductor

Duration: Dec 10th – 14th, 2007

Objectives:

To check customer's rating test system and rating capacity of sample cable by employing DTS based Cable Dynamic Rating (DCR) Computerized Algorithm, which is based on IEC60287 and CIGRE Thermal Network. It was developed by Sensornet.

1. Test Diary

1.1. Day 1 (Dec 10th, 2007), Preparation; Setting-up *Test System A*;

1.2. Day 2 (Dec 11th, 2007), Initial Test and Finding a question; Initial test of sample cable and at once finding real Tcc much higher(>10C) than it should be (Tcc calculated by DCR);

1.3. Day 3 (Dec 12th, 2007), Static Test and Confirming the question; Static test of sample cable to get a static state of test cable as 1000A/74.6C/33.2C/11.2C(Ld/Tcc/Tcs/Tem); According to Electric Heating Formula Hcc = I^2xAcR, Hcc is about 36W, while according to Thermal Networks Formula Hcc = ΔT/R(Thermal) = 64W; Since the latter is more reliable than the former, I^2xAcR was focused on;

1.4. Day 4 (Dec 13th, 2007), System Check And Finding the cause of the question; Modified the test system into *Test System B* and double-checked of Current I and AcR; AcR = DcR x (1+Ys+Yp); Ys = f(Frequency); When checking wave shape, it was found the load generator is of SCR – Silicon Controlled Rectifier that gives tri-angle shaped current output. That explains why the cable seemed to be over-heated, for tri-angle current contains a lot of high frequency energy which greatly increases Ys;

1.5. Day 5 (Dec 14th, 2007), Dynamic Test Trial and Conclusion; Checked another available load transformer and found still not ideal for cable rating test. At the same time a dynamic rating test was conducted on Test System B to get more information of the system. A meeting then was held to conclude above tests and make improvement plan.

2. Sample Cable

The below table gives the structure of the test cable sample and the thermal resistance for each layer.

132kV Cu 1Cx630sqmm XLPE cable

No.	Description	Material	THK	Di	Do	Thermal r	Thermal R
1.	Conductor	Plain annealed copper wires	N/A	0	30.2	0.0	0.0000
2.	WB tape	Semi-conducting water swellable tape	0.25	30.2	30.7	6	0.0157
3.	Binder tape	Semi-conducting tape	0.13	30.7	31.0	6	0.0081
*	Air Layer		0.12	31.0	31.2	34.5	0.0424
4.	Conductor screen	Extruded semi-conducting XLPE	1	31.2	33.2	3.5	0.0346
5.	Insulation	Extruded XLPE	16	33.2	65.2	3.5	0.3761
6.	Insulation screen	Extruded semi-conducting XLPE	1.2	65.2	67.6	3.5	0.0201
7.	Bedding tape	Semi-conducting water swellable tape	0.55	67.6	68.7	6.0	0.0154
8.	Metallic screen	Uncoated copper wires	2.05	68.7	72.8	0.0025	0.0000
9.	Metallic binder	Copper tape	0.1	72.8	73.0	0.0025	0.0000
10.	Bedding tape	Semi-conducting water swellable tape	0.5	73.0	74.0	6.0	0.0130
*	Air Layer		0.15	74.0	74.3	34.5	0.0222
11.	Metallic sheath	Extruded lead alloy	2.9	74.3	80.1	0.01	0.0001
12.	Anti-corrosion	Bituminous compound	0.1	80.1	80.3	5.0	0.0020
13.	Jacket	Extruded black polyethylene	3.75	80.3	87.8	6.0	0.0853
14.	Conductive layer	Graphite coating	0.02	87.8	87.8	6.0	0.0004
					Total		0.6356

Here an air layer is added for each water swellable tape because the latter is a kind of fabric/paper which is not solid, containing air, becoming a contact thermal resistance. it is considered by DCR for accurate calculations.

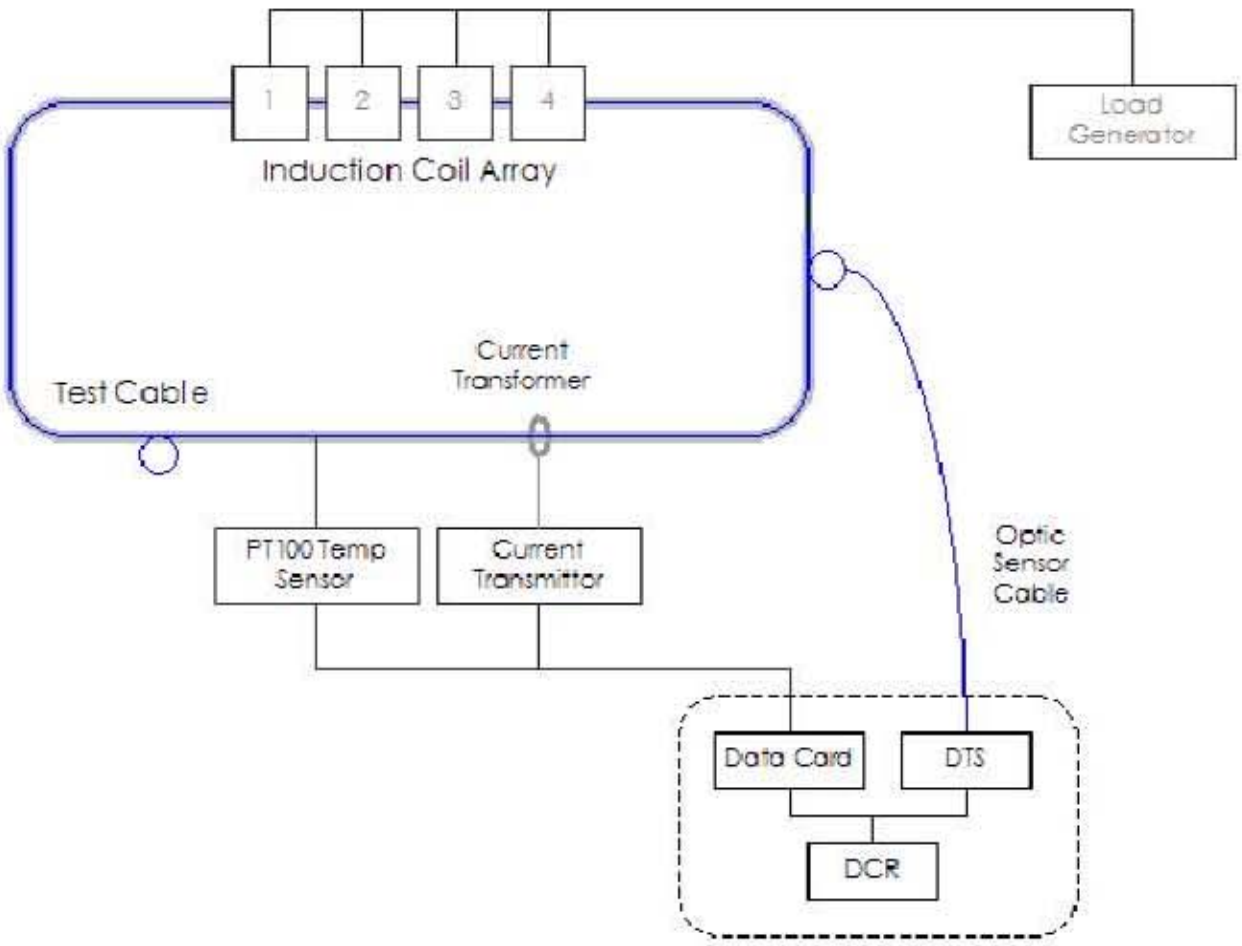
Length is the test cable is 11.0m.

3. Test System

3.1.1. Test System A

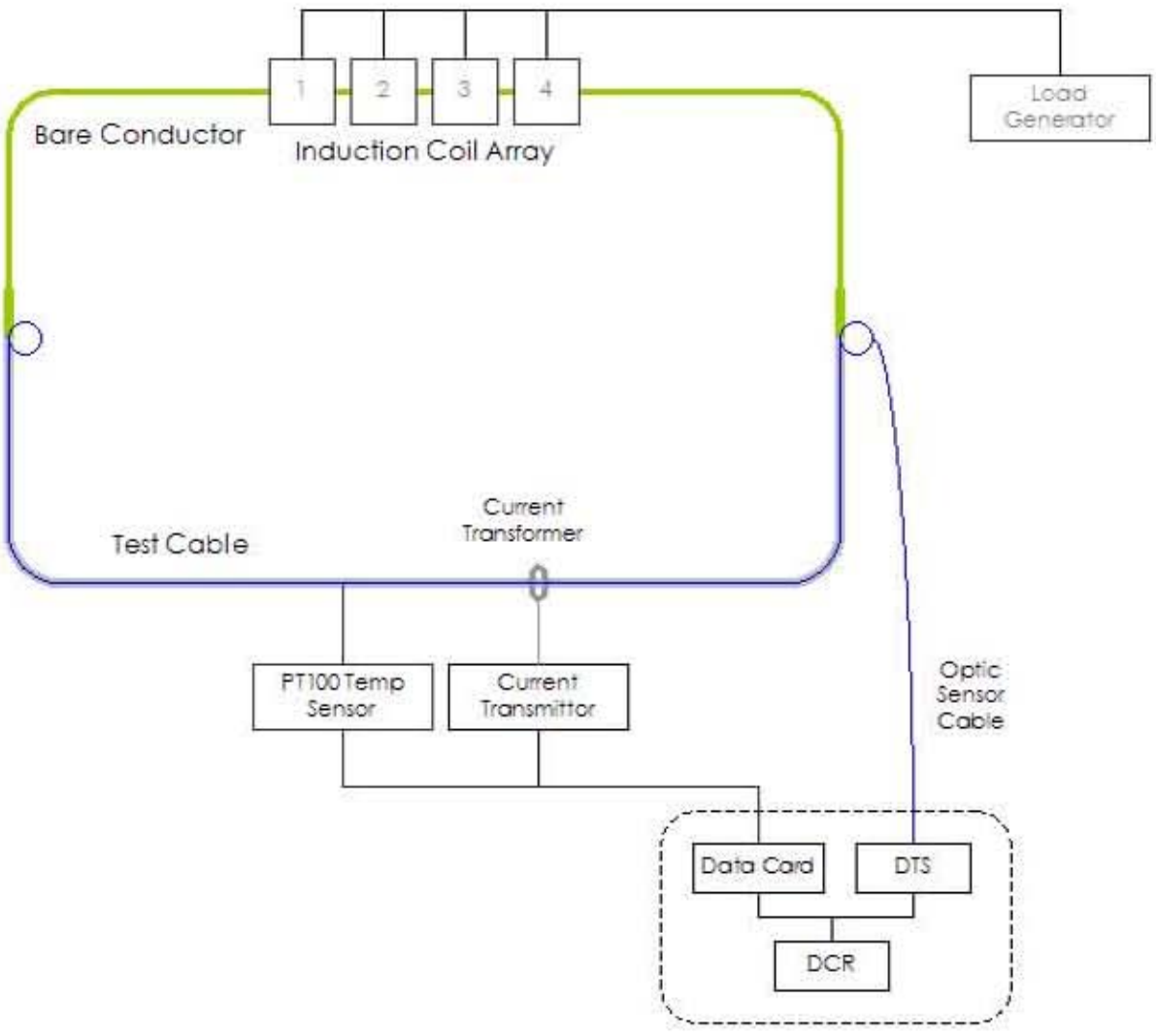
The test cable is formed into a circle with one connection. DTS optic sensor fiber is attached to test cable surface. One PT100 temperature sensor is planted into cable conductor via a 2.5mm hole. One 4000A Current Transformer/Transmitter detects cable current. Both of them are connected to DCR via a USB Data Board. All sensors have been calibrated before test starts.

It is found by DTS in the initial tests that the Induction Coils seem to heat the cable unevenly along the length of test cable. There is a temperature peak along the test cable just at the part which goes through the Coils, which brings about a modification of the system into Test System B.



3.1.2. Test System B

A modification based on Test System A is to add an about 11m long bare conductor to bridges the two ends of the test cable and go through the Coils. The modification solves the problem of test cable being unevenly heated by Coils in Test System A.



4. Test Data Result and Analysis

4.1. Static Test, Test System A

Duration: 1:30pm – 10:00pm, Dec 12th, 2007

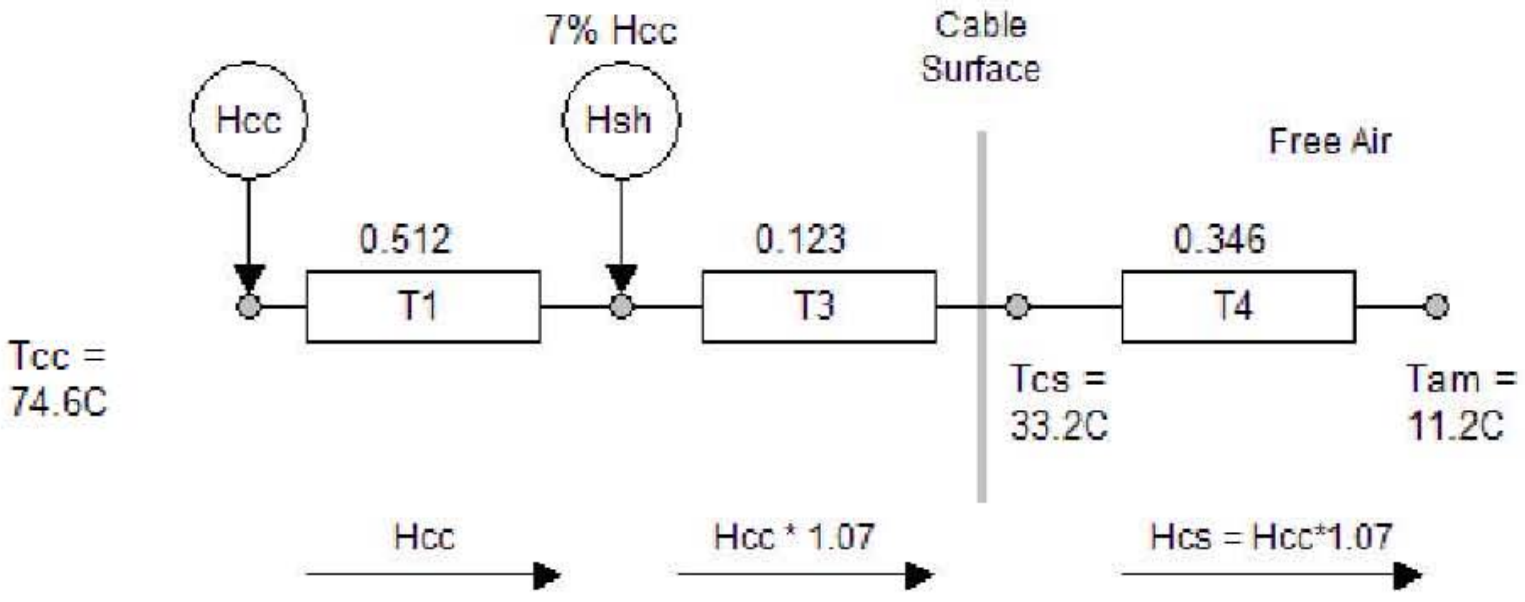
Measurements		
Tcc	74.6	Temperature, Cable Conductor
Tcs	33.2	Temperature, Cable Surface
Tam	11.2	Temperature, Ambient Temperature
Ld	1000	Static Constant Current
U	0	Working Voltage

Given/Assumptions		
Rr20C	1.7241E-8	Elec Resistance Rate@20C, Copper
a	0.00393	Temperature Coeff for Elec Resistance Rate@20C, Copper
Acc	630	mm2, Sectional Area of Cable Conductor
Do	0.0878	m, Cable Outer Diameter
Ys	6.0%	Skin Effect Factor
Yp	2.4%	Proximity Effect Factor
WsR	7%	Metallic Layer Loss Rate against Hcc
Z	0.21	Heat Transfer Factor Z, Single Cable in Free Air
E	3.94	Heat Transfer Factor E, Single Cable in Free Air
g	0.6	Heat Transfer Factor g, Single Cable in Free Air

Derived		
Wd	0	W, Dielectric Loss
DcR	0.0332	Oum/km, Conductor DC Resistance@Tcs
AcR	0.0360	Oum/km, Conductor AC Resistance@Tcs
Hcc	36.03	W, Heat Generated by Cable Conductor per m, I x I x AcR
Hme	2.52	W, Heat Generated by Cable Metallic Sheath per Metre
T1	0.512	K*m/W, Thermal R, Conductor to Sheath, (0.457 Given by TEC)
T3	0.123	K*m/W, Thermal R, Sheath to Surface(0.08 Given by TEC)
T4	0.346	K*m/W, Thermal R, Surface to Air

Findings		
HccC	64.27	Heat Generator, Calculated based on Tcc, Tcs, T1 and T3
Hcs	63.63	Heat From Cable Surface, Calculated based on Tcs, Tam, T4
LdC	1336	Calculated Load

While the Hcc Calculated above is 36.03W, and Load is 1000A



Static Thermal Networks

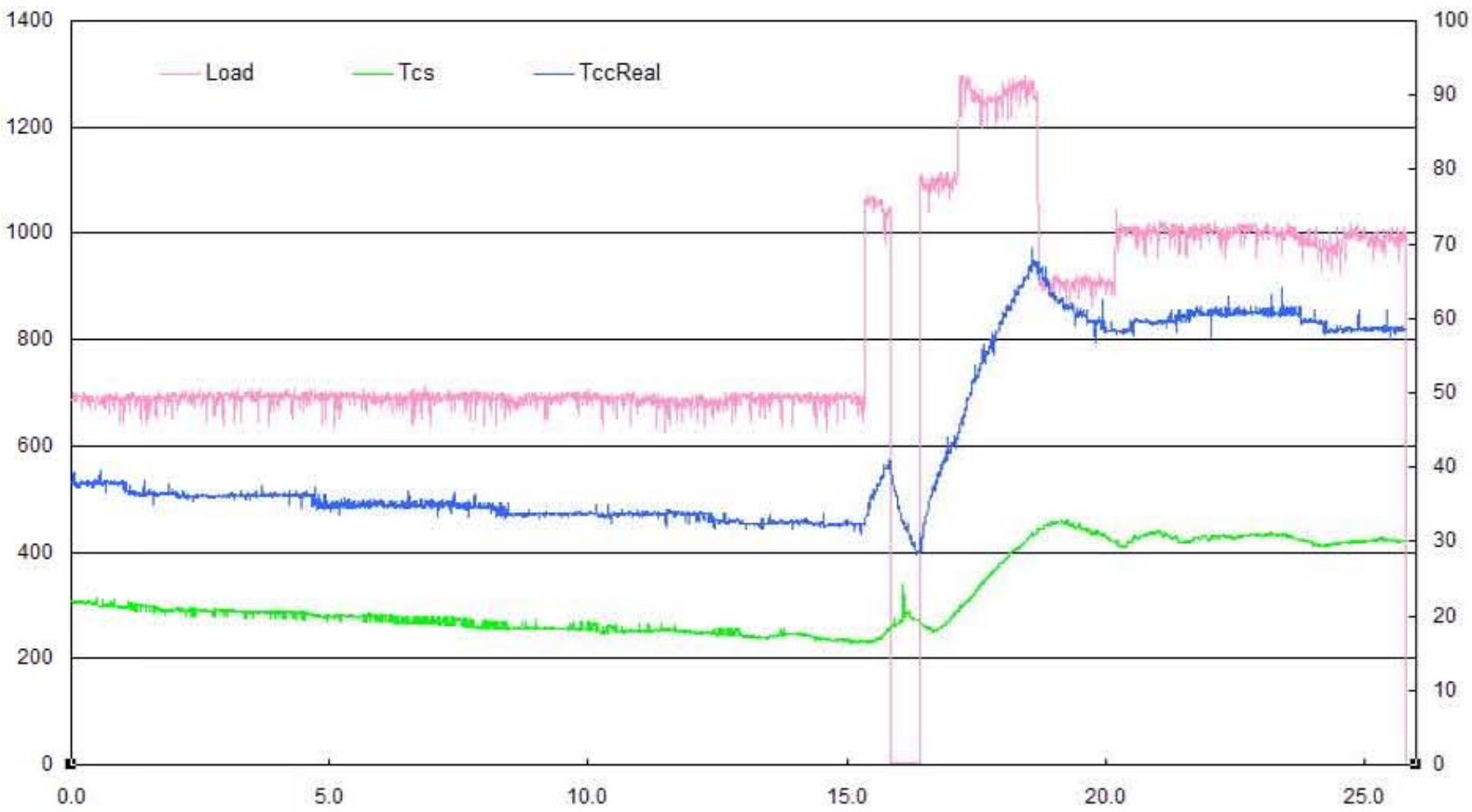
Here two approaches are used to cross-check.

- ✓ Thermal Networks : Heat Flow = ΔT/ Thermal Resistance, which gives Total Heat Generated by Conductor Hcc = 64W;
- ✓ Electric Heating Formula: Heat = I x I x AcR, which gives Total Heat Generated by Conductor Hcc = 36W;

Since all sensors have been calibrated before the test and double-checked after the text, the inconsistency of the test results or measures implies there is something does not comply with IEC60287.

4.2. Dynamic Test, Test System B

Duration: 26 Hours; 5:10pm, Dec 13th, 2007 – 7:10pm, Dec 14th, 2007



This test provides another static state as 700A/32.4C/16.7(Ld/Tcc/Tcs)

- ✓ Thermal Networks : Heat Flow = ΔT/ Thermal Resistance, which gives Total Heat Generated by Conductor Hcc = 24W;
- ✓ Electric Heating Formula: Heat = I x I x AcR, which gives Total Heat Generated by Conductor Hcc =

15W;

It also shows the remarkable gap between the results by two heat calculation approaches.

4.3. Cause of Above Discrepancy

Approach of Thermal Networks had been cross-checked with the cable design calculation sheet provided by manufacturer and found no question. And then the other approach of Electric Heating Formula had been checked carefully as per procedures:

- ✓ Measured DcR of the test cable; It was normal;
- ✓ Double-checked Load Transformer; It gave right reads;
- ✓ Checked current wave shape with an oscillo-scope, and found it showed as in below picture:

The load is generated by an SCR (Silicon Controlled Rectifier) Type Load Generator, which generates tri-angle like shape of load. It could output a smoothly rectified current, while not ideal for cable rating test. Because cable conductor Skin Effect Factor Ys is a function of frequency:

$$Y_s = \frac{x_S^4}{192 + 0.8x_S^4};$$

$$x_S^2 = \frac{8\pi f}{R} \times 10^{-7} k_S$$

Output of SCR contains a lot of high frequency energy, which can greatly raise Ys. According to IEC60287, load shall be of a pure 60Hz/50Hz frequency with Ys around 6% for the test cable, while under this test environment, Ys tends to be more than 60% due to this high frequency issue involved. That explains why the real Heat Generated by Conductor Hcc is much more than that according to IEC60287.

Another load generator available in customer factory had been checked. Although it is not SCR Type, its output is not good. See below picture. Its primary shape is tri-angle like, not exactly a cosine curve.

5. Conclusions and Outstanding

5.1. Sensornet DTS

As a proven technology, Sensornet DTS provides powerful means for cable monitoring. In the tests, Sensornet DTS is able to measure the cable distributed temperature with 0.1C Accuracy @0.5 spatial resolutions every 10s, which helped to locate a cable connection defect during beginning stage of the tests;

5.2. DCR Application

DCR is designed to calculate Tcc in real-time and give short term Tcc prediction. Since it is strictly according to IEC60287, it found the Question of Hcc shortly after it was started. Although at the beginning we didn't know the cause of the question, DCR showed the cable was somehow over-heated;

5.3. Outstanding

Present Test System needs to improve before Rating Tests for the three test cables(132kV/230kV/345kV) as originally planned. The improvements may include:

5.4. Load Generator: It shall be modified or purchased so as to provide an good cosine load curve.

5.5. Test Hall: If possible, it shall be a separate room or division (20m x 20m) with no wind;

5.6. Tcc Detection

It is found that present practice for customer factory to plant temperature sensor into cable conductor as:

- Remove area10cm x 4cm outer layers of the cable to conductor;
- Make a slot in conductor and place a thermal couple in; The thermal couple is of big dimension with area >=2.5mm^2, which could be a good thermal conductor;
- Re-fill with melted XLPE and band with adhesive tape;

We think the above method impacts the cable structure and might lower the accuracy of the Tcc measurement. As a substitute, what we suggest is as:

- Drill a 1.5mm-2.5mm hole just onto conductor;
- Insert thermal couple into conductor via the hole; This requires thermal couple to be small enough;
- Refill the hole with adhesive material;