A Laboratory Validation Report of DCR Algorithm Model

Tested by: Shanghai Electric Cable Research Institute (SECRI)
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Objectives: Online computer algorithm based on DTS for DCR of power cable, which includes two implementation methods: Algorithm A: CIGRE cable thermal-circuit method (provided by SENSERNET Limited (UK)) and Algorithm B: heat transfer partial differential equation method (provided by Shanghai Bandweaver Communication Technologies Co., Ltd.); Both use cable heating formula of IEC60287 and IEC60853.

1. Test Purpose

Verifying the validity of algorithm models for DCR; The validation process comprises two parts:

- Construct cable/environment system in the lab to gather load and temperature response data;
- Compute the responsive temperature rise result of the load of above system using algorithm models; comparing it with temperature rise data of above test to get a validation conclusion.

2. Validation Content and Indicators

Validation Cases	*Known Conditions*	*Input*	*Output*	*Validation Indicators*
Real-time calculation of cable conductor temperature	Cable structure and layout condition	Cable surface temperature; load current	Current conductor temperature	Standard deviation; max deviation;
Conductor temperature prediction within 48 hours	Latest history data of cable surface temperature and current load of no less than 48 hours	Load current of future 48 hours	Cable surface temperature of future 48 hours, and calculate the conductor temperature according to above item	Standard deviation; max deviation

3. Test Sample and Equipment

Test Sample / Equipment Name	*Specification Description*
Cable test sample A	XLPE single core, 20 meters long, cross section of 630 square millimeters, voltage level at 110kv. Cable structure parameters and property parameters are all prepared.
Cable test sample B	XLPE single core, 20 meters long, cross section of 630 square millimeters,

	voltage level at 35kv. Cable structure parameters and property parameters are all prepared.
Laboratory	Good heat preservation without convection-wind from outside; natural air convection inside or forced convection by blowers; having cable bracket to support cable for no less than 0.3 meters up from the floor.
Low-voltage high-current generator	Generating adjustable stable current with a deviation within +/-1%.
Ammeter	Used to detect cable current, allowing the current larger than test current.
Multipoint temperature monitor	Having at least 9 thermocouples (or Pt100). The deviation is within +/-1.5 ^{O}C.
Axial flow blower	With a flow at 5000 m^3/hour; wind speed at 0.5 – 2.5 meter/second.
Control and data acquisition PC	A computer used to give load and record current and temperature data.
Foam heat-insulation coiled material	Industrial foam heat-insulation layer, with a temperature diffusion coefficient of 0.15~ 0.2 x 10^{-6} m^2/s, 2-4cm thick and can be evenly winded onto cables.
Connecting electric wire and joint	Used for connecting cables and current generator.

4. Test process

4.1. Test data acquisition

4.1.1. Data acquisition preparation

To ensure a rigorous validation, two kinds of test sample cables with different sizes and voltage levels have to be tested in different environments and conditions. Five cases of load and temperature response data will be acquired, as listed below:

Case	Test sample	Environmental Condition	Load status	Sampling Period	Duration
1	A	Bare/natural convection	Step	30 seconds	12 hours
2	A	Changing environment: bare/natural convection for 5 hours, then wrapped with thermal insulation material/natural convection	Random	30 seconds	12 hours
3	A	Bare/natural convection	Random daily load	30 seconds	72 hours
4	B	Changing environment: bare/natural convection for 4 hours, forced convection for 4 hours and wrapped with thermal insulation material/natural convection for 4 hours	Random	30 seconds	12 hours
5	B	Changing environment: bare/natural convection for 2 hours, forced convection for 2 hours, then wrapped with thermal insulation material/natural convection	Step	30 seconds	12 hours

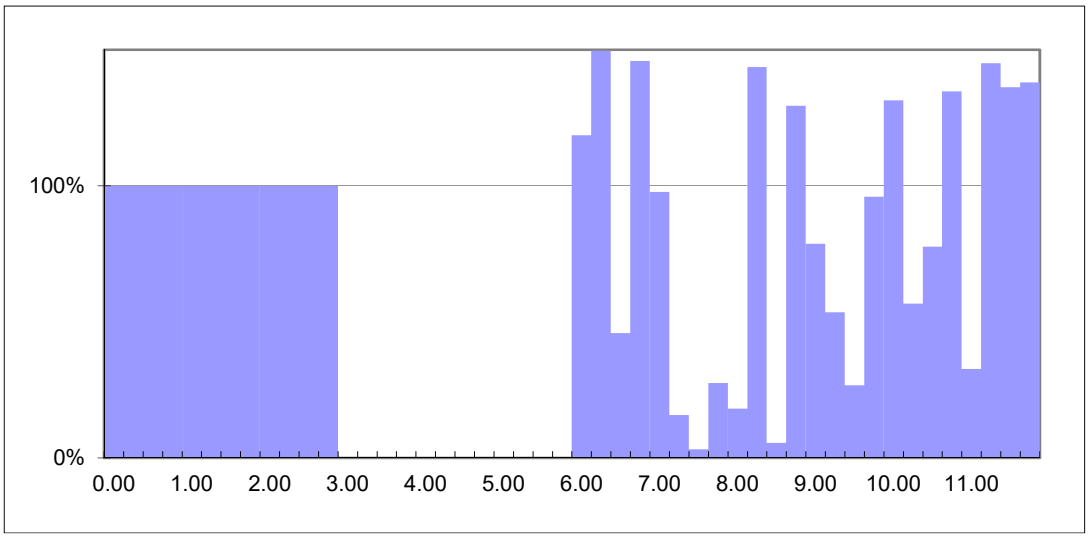
The test schedule can be arranged according to above table; expect for the group which needs the

duration of 96 hours to acquire the data, data acquisition of each group shall be accomplished per day.

4.1.2. Load Settings

4.1.2.1. Step Load and Random Load

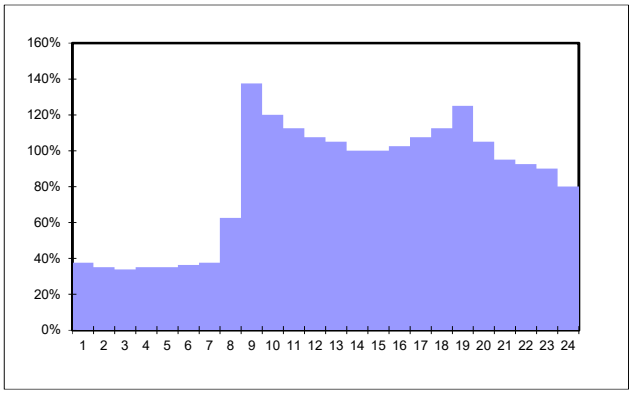
The duration of step load is no shorter than the thermo time constant of cable, which is about 3-6 hours; the random curve will be generated by the computer in advance, which is required to change significantly and partially exceed the rated carrying capacity in a short time; the graph below shows a sample of step & random load. At the stage of random, the current changes every 60 minutes between 0-150% of rated carrying capacity, and the conductor temperature shall reach its rated value.



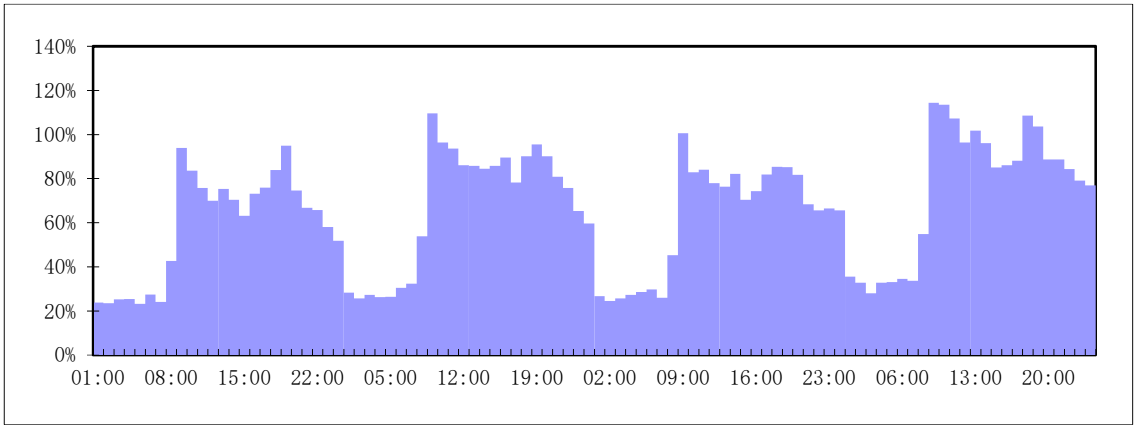
4.1.2.2. Random daily load

Add random changes to a daily load curve template. The load changes every one hour.

The graph below is a common daily load curve template



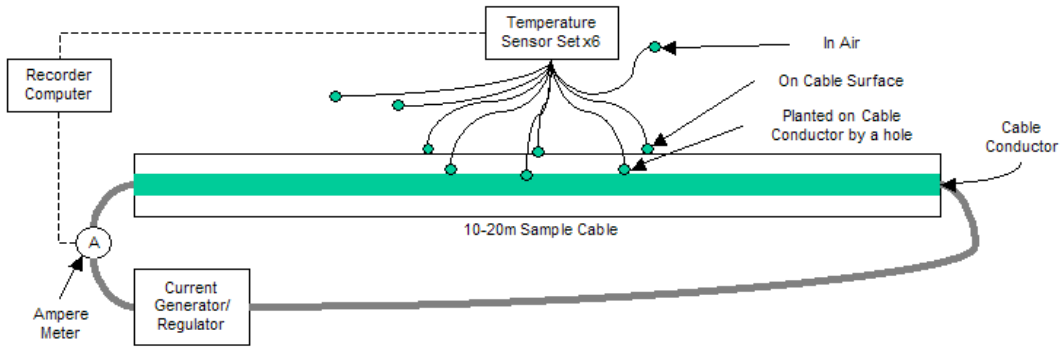
The graph below is a random daily load curve for four days (96 hours):



The random daily load curve shall be created in advance. The conductor temperature is demanded to approach the permitted value (90^{O}C) and exceed the rated carrying capacity in a short time

4.1.3. Data Acquisition Method

4.1.3.1. Construct the test system according to the system schematic illustration below.



4.1.3.2. Verify that the ammeter and temperature detector has been checked.

4.1.3.3. Connect two ends of test sample to a high current generator, and connect to the ammeter through a mutual inductor.

4.1.3.4. Drill 1-1.5 millimeter holes from the surface of cable's middle part (at midpoint and 1 meter away from its right and left) to conductor surface, insert thermocouples to contact the conductor, and fill silica gel into those holes until the cable surface; according to said method, place 3 thermocouples into appropriate locations of cable's middle part; 3 thermocouples shall be fixed on the cable surface of the middle part using tape; 3 thermocouples placed in room air and more than 1 meter away from the cable.

Test System

Layout of Thermocouples

(DTS optical fiber is also adopted to measure cable surface temperature)

4.1.3.5. Control and data acquisition PC is connected with temperature detector and ammeter in order to record all readings of detecting meters in real time.

4.1.3.6. Control and data acquisition PC is connected with current generator and regulator in order to regulate the current flow between zero and maximum test current.

4.1.3.7. The natural velocity of room air is less than 0.5 m/s, and its temperature is lower than 30 ^{O}C.

4.1.3.8. Based on this, other necessary settings shall be made to start the system according to the requirements of various data acquisition; control and data acquisition PC can regulate test currents and gather test data based on given load curves for each group of data.

4.1.3.9. Original data acquisition includes: recording time, current and 9 temperature values (3 for conductor, 3 for cable surface and 3 for air). A data list with the following format shall be obtained by working out the average temperature of all locations after removing abnormal values.

DURATION	CURRENT	CONDUCTOR TEMPERATURE	CABLE SURFACE TEMPERATURE	AIR TEMPERATURE

4.1.3.10. The detection precision is required as: time duration, accurate to second; current to +/- 1%; temperature to +/-1.0ºC.

Multipoint temperature detector

(1-3 points for conductor temperature acquisition, 4-6 points for cable surface temperature, 7-8 points for environmental temperature)

4.2. Validation of Algorithm Model

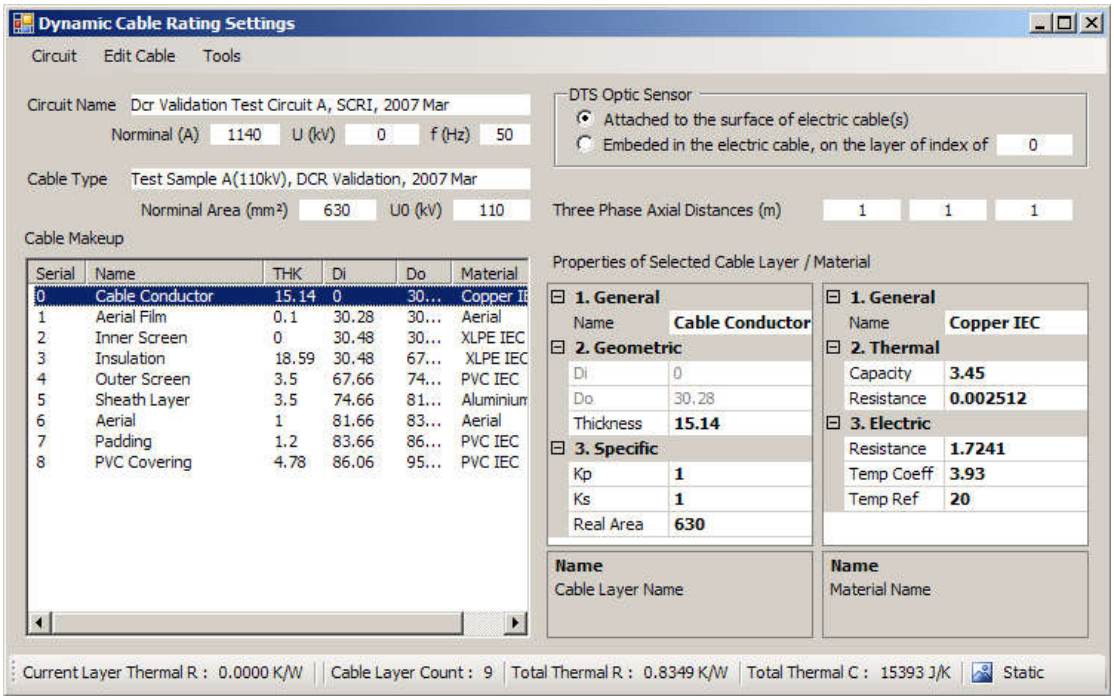
4.2.1. Principles

The said validation adopts random test method to provide some data to the operator of the algorithm model software to be tested for the calculation of necessary results which then will be compared with test measurements.

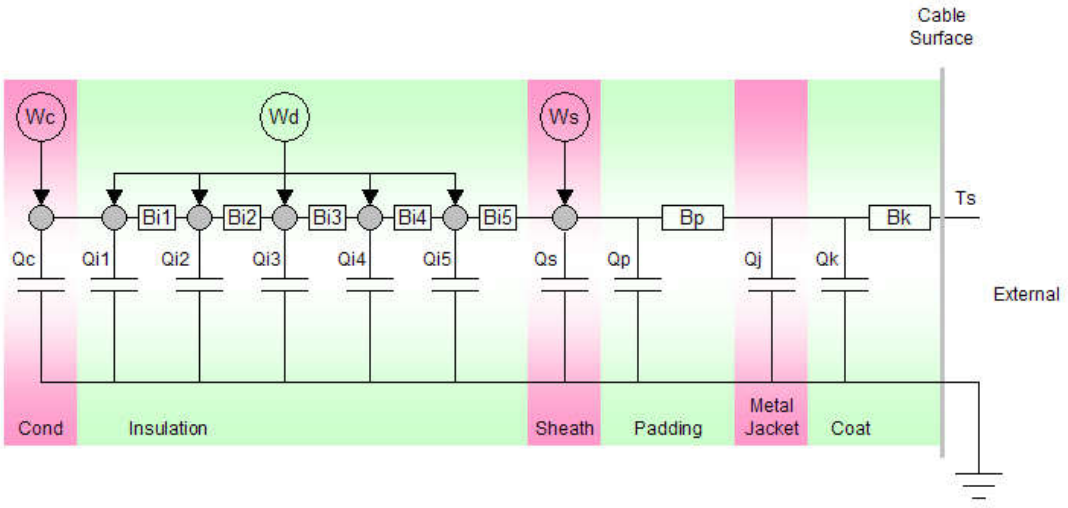
4.2.2. Steps

4.2.2.1. Loaded Cable Parameters

Input cable structure and loop parameters into the interface below to finish the computation of static carrying capacity and build the DCR model. All parameters (including material parameters) adopt ICE60287. The time step of calculation is 30 seconds. Both algorithm A and B divide the cable structure into 25 layers.



Input Interface of Cable Structure and Loop Parameters



CIGRE Thermal Circuit Model

4.2.2.2. Validation I: Real time calculation of cable conductor temperature

Provide the algorithm model software operators with all duration, current and cable surface temperature values of the 1st, 2nd, and 4th group for them to calculate the conductor temperature of corresponding duration.

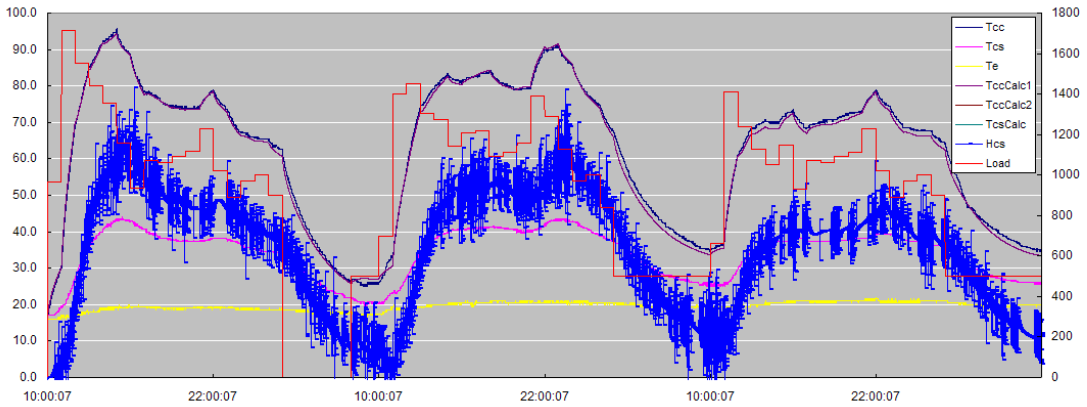
DURATION	CURRENT	CABLE SURFACE TEMPERATURE	CONDUCTOR TEMPERATURE
TO BE PROVIDED			TO BE CALCULATED

4.2.2.3. Validation II: conductor temperature prediction within 48 hours

Provide the duration and current values in 48 hours of the 3rd group to calculate the cable surface temperature and conductor temperature.

DURATION	CURRENT	CABLE SURFACE TEMPERATURE	CONDUCTOR TEMPERATURE
TO BE PROVIDED		TO BE CALCULATED	

5. Test data (see appendix for the detailed report)



Calculation Example (Case III)

6. Validation Result

6.1. As for the conductor temperature calculations using algorithm A and B, their maximum deviation is less than 0.3˚C and average deviation is less than 0.1˚C; since both have the same calculation accuracy and consistent dynamic response, they can be regarded equal in the table below.

6.2. The table below provides the comparison between calculation values and test values of all test cases:

DCR Algorithm Validation Test Result

CASE	Cable Sample	Load Senario	Environment	Duration	Tcc Arrange(°C)		DCR Calculated Tcc (°C)			
					Min	Max	Max Under	Max Over	AveDev	StDev
CASE 1	110kV, 630mm2	Step	In Static Free Air	16 Hr	14.0	96.6	2.94	2.51	0.81	1.09
CASE 2	110kV, 630mm2	Random	First five hours in static free air; The rest cable wrapped with 25mm THK thermal insulation material	21 Hr	32.0	95.3	4.13	0.20	0.94	1.05
CASE 3	110kV, 630mm2	Daily Patterned	In Static Free Air	72 Hr	16.7	95.3	3.69	2.01	0.60	0.78
						Average	**3.59**	**1.57**	**0.78**	**0.97**
CASE 4	35kV, 630mm2	Random	First four hours in static free air; Four hours ventilated (air velocity 1.0m/s); The rest hours cable wrapped with 25mm THK thermal insulation material	24 Hr	18.7	75.3	0.21	1.84	0.23	0.31
CASE 5	35kV, 630mm2	Step	First four hours in static free air; The rest hours ventilated (air velocity 1.0m/s)	12 Hr	11.7	91.7	2.59	1.57	0.62	0.78
						Average	**1.40**	**1.71**	**0.43**	**0.55**

Tcc calculations of DCR Algorithm Strategy A and B are of difference of less than 0.3°C. So these two strategies are treated as one in above table.
Tcc - Cable Conductor Temperature

6.3. With a known cable structure (object detection), both algorithm A and B for DCR model can calculate the conductor temperature accurately; the error of test equipment system is:

- Current generator/detector: +/-1%
- Temperature sensor: +/-1.0˚C
- Other errors

Under above conditions, the calculation error between the detected data and the calculated (by algorithm A and B) is less than +/-2.5˚C.

6.4. The stepping calculation cycle of algorithm B is less than 100ms and the calculation cycle of online DCR is commonly greater than 10s, hence both can be used for real time calculation.

7. Limitations and solutions of the test system are listed as below:

No.	Main differences of cable operated in test system and actual situations	Solutions
1	In actual situations, cable is laid out in (multi-) loop pattern, and the influence (shield/metal sheath loss) between cables may be complex	IEC60287 should be adopted to estimate the shield loss ratio as the model parameter; Both algorithm A and B can deal with the shield loss effect accurately; in case of increase or decrease in the amount of cables, the shield loss ratio shall be recalculated and the model shall be updated
2	In actual situations, cables operate in ultra-high voltage environment, which results in quite considerable insulation loss	Both algorithm A and B include insulation loss disposal process for accurate disposal of insulation loss effect

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(The End)