Section Selection Software Design for Submarine Cables

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Abstract：In order to improve the efficiency and accuracy of ampacity calculation and submarine cable's section selection, this article improved the shortage of IEC(International Electrotechnical Commission) norms when calculating the ampacity of submarine cables, developed hierarchical principles and established accurate thermal circuit model of the various types of cables. This article realized accurate calculation of ampacity and achieved the ampacity calculation software module's design. Finally this article firstly developed a section selection software for submarine cables combined with the heat-stable calibration module. After verified the accuracy and effectiveness of software in the typical layout conditions, this software can provide good guidance for practical engineering.

1. Introduction

In recent years, the construction of offshore wind farms develops rapidly. Literature[1-4] shows the important hub connect it with terrestrial grid,the submarine cable transmission has urgent research needs and application prospect, and how to reasonably select the model number and section of the cable becomes the important problems that many electric power designing enterprises need to solve.

At present, there is less study on submarine cables,literature[5-10] introduce two mainly methods on ampacity calculation of submarine cables,which are Numerical analytic method and Function analytic method,the Numerical analytic method is the equivalent thermal resistance calculation based on IEC standards, it has high accuracy and efficiency when calculate the ampacity of terrestrial cables.But due to the change of laying environment, in order to ensure good mechanical strength and corrosion resistance, the structure of submarine cables are different with terrestrial cables,as there is no calculating standard in IEC for submarine cables, so it will influence the accuracy if we use the ampacity computing method of terrestrial cables in calculation of submarine cables, which would not provide guidance for engineering practices. According to the thermal resistance of the materials, this article layers each type of submarine cables and establishes accurate thermal circuit model, so that ensure the accuracy of ampacity calculation. At the same time, this article combines the module of thermal stability calibration, which provides good data reference for section selection of submarine cables with good accuracy.

2. Cable ampacity algorithm improvements

2.1 Accurate thermal circuit model of submarine cable

In order to ensure the stability of submarine cable laying in its environment, its internal cushion and armored structures are different from terrestrial cables.This article chooses the HYJQF41-F-26/35kV

XLPE AC three-core cable used in the project as an example, explains the layered method and thermal circuit model,as its structure is in figure 1 and structure size in table 1.
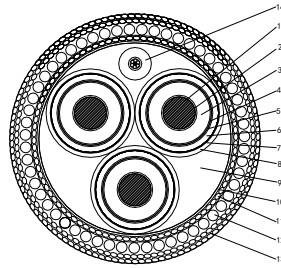

Figure 1. Structural Profiles of Submarine Cables

Table 1. Structure Tables of HYJQF41-F-26/35kV XLPE Submarine Cable

Serial number	Structure	$70\,mm^2$	
		Thickness/mm	Diameter/mm
1	Copper conductor	/	10.0
2	Conductor screen	0.8	11.6
3	XLPE insulation	10.5	32.6
4	Insulation screen	1.0	34.5
5	Waterblocking tape	0.5	35.5
6	Alloy lead sheath	2.2	39.9
7	The auticorrosion coating		
8	Semi conductive PE sheath	1.8	43.5
9	Fill（Light unit(14), asphalt）		
10	Cable bag	0.5	96.5
11	PP inner bedding	1.5	99.5
12	Steel wire armouring	5.0	109.5
13	PP outer serving	4.0	117.5

In the IEC standards,the structure between the conductors and metallic sheath are usually unified to the insulation layer so as to simplify the calculation.But taking the differences in thermal resistance coefficient of different materials and influence of cable processing into account,now it is divided into three layers for accurate calculation,which is conductor layer, insulating layer (including conductor shield, insulation layer and insulation shield) and barrier water layer;Besides,IEC standard usually merges thermal resistance between metal sheath and armored in calculation of thermal resistance of inner liner,due to the special processing technology in submarine cable,its inner liner usually contains cable bag(polyethylene sheath), asphalt PP rope layers,and the thermal resistance coefficient are different from each other,so it's necessary to be calculated separately.To sum up,the accurate thermal circuit model of submarine cables is as shown in figure 2.
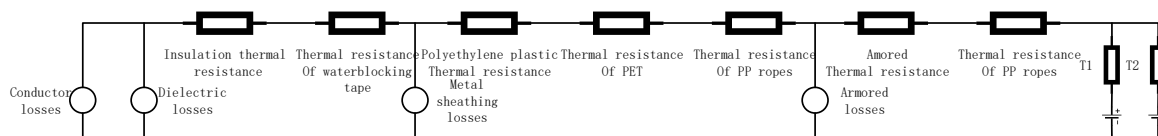

Figure 2. Accurate Thermal Circuit Model of Submarine Cables

2.2 Computing theory based on accurate thermal circuit model
Based on the accurate thermal circuit model, calculation of ampacity is divided into four main steps:① Conductor resistance calculation(including the calculation of skin effect and proximity effect, and DC cables omit this step);②Loss calculation, the cable loss mainly includes dielectric losses, metal screen losses and armored losses(DC cables omit this step); ③thermal resistance calculation,it includes insulation thermal resistance, thermal resistance of inner liner, thermal resistance of outer sheath and external thermal resistance.Unlike terrestrial cables, it is necessary to follow the layered principles in

the process of calculation of thermal resistance,thermal resistance of all materials should be calculated separately and merged in the end;④ampacity calculation,the ampacity can be calculated in the equation (1)with the result from first three parts of calculation.

$$I = \left\{ \frac{\Delta\theta - W_d\left[0.5T_1 + n(T_2 + T_3 + T_4)\right]}{R \cdot T_1 + nR(1+\lambda_1)T_2 + nR(1+\lambda_1+\lambda_2)(T_3+T_4)} \right\}^{\frac{1}{2}} \qquad (1)$$

In the formula, W_d means the dielectric losses, λ_1 and λ_2 means metal screen loss factor and armored loss factor.

2.3 Computing theory based on thermal stability calibration
In accordance with IEC986 standards, the formula to calculate allow short-circuit current of cable conductor and metal screen is as shown in the equation (2):

$$I_{AD}(K,S,\theta_f,\theta_i,\beta,t) = K \cdot S \cdot \sqrt{\frac{ln(\frac{\theta_f + \beta}{\theta_i + \beta})}{t}} \qquad (2)$$

In the formula,*K* is a constant that depends on the current-carrying materials,*S* presents the copper conductor nominal section, t is short circuit duration, θ_i and θ_f present the initial and final temperature, β is the countdown of temperature coefficient of resistance of carrier in $0℃$.

3. Design and implementation of software

3.1 Software function design
The software contains two main modules:the submarine cable ampacity calculation module and the thermal stability of calibration module.

The submarine cable ampacity calculation module is based on the method of equivalent thermal resistance,and it has the following functions: this module contains various types of accurate thermal circuit model,which realizes the thermal resistance calculation of each part of the AC and DC submarine cables,and all calculation results can be stored and printed output;this module covers all types of submarine cables ampacity calculation in variety of laying method as direct burial, "J" shaped tube, aerial laying and cable duct,and according to the different laying path segment,the direct burial divides into three parts as land, intertidal and underwater segment.

The thermal stability of calibration module has the following features:the maximum short-circuit current calculation of conductor and metal screen, the calculation of minimum cable cross-section meet the thermal stability conditions,and it supports save the results and output.

3.2 Software architecture design
Submarine cable section select software is base on Visual Studio,and its interface is designed with Windows Forms and its built-in programs is written with the C# language. Software structure is divided into three layers，the presentation layer shows software interface parameters,which is the interact window for user with software;the analysis of control layers presents the implementation of software interface to user’s actions;the layer of cable calculation model stores the model for each type of cables in different laying conditions,and here is the software architecture diagram shown in figure 3.
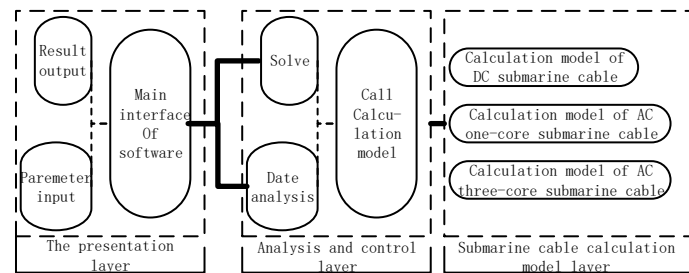
Figure 3. Architecture of Calculation Software Design of Carrying Capacity of Submarine Cables

3.3 Software module design

Through the establishment of model of thermal resistance, the submarine cable ampacity calculation module calculates process date in order and then then call these data to calculate the final result,and its process is shown in figure 4.

   The thermal stability of calibration module establishes calculation model based on standards and call the parameters to calculate the results.Its process is shown in figure 5.
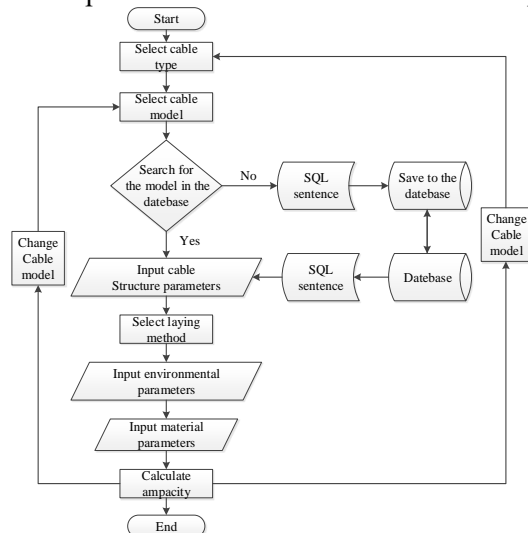

Figure 4. Calculation Flowchart of Carrying Capacity of Submarine Cables
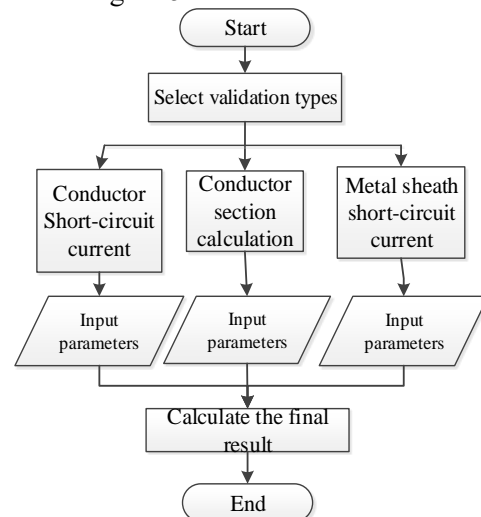

Figure 5. Calculation Flowchart of Thermal Stability Calibration of Submarine Cables

4. Software introduction

4.1 Structural and installation environment parameters settings of cable

The figure 6 is the calculation interface for AC three-core cable, the structural parameters of a submarine cable is on the left page,and a cable model can be selected directly in the database or according to the actual situation to save new cable type;the middle position is set for the installation of environmental parameters,which contains cable's laying scene specifically;the interface for cable material parameters is on the upper right side,which will provide default values to each type cable and parameters can be modified;if there is a frame with no data,the software will pop up position tips before the calculation of ampacity.Software calculation results can be saved as an Excel file output for user's future review.

4.2 Parameters setting of thermal stability of calibration

As is shown in figure 7, the parameters for short-circuit current calculation of a submarine cable is on the left page,and the current values can be calculated after the input parameters in the software.The calculation interface of minimum section that meet the heat-stable conditions is on the right

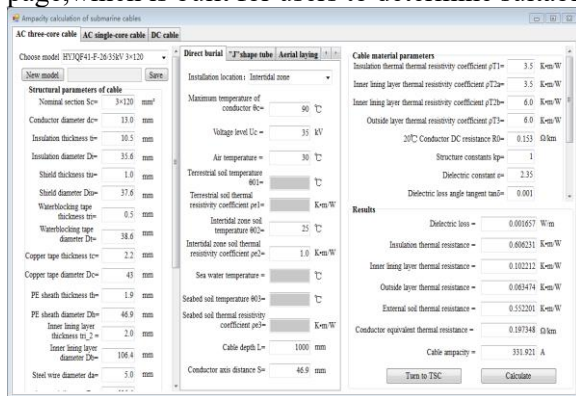page,which is built for users to determine suitable section for cables in actual conditions.

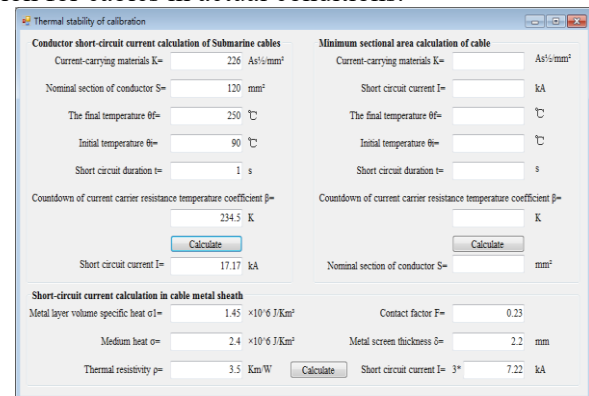**Figure 6.** Carrying Capacity calculation interface of Submarine Cables

Figure 7. Thermal Stability Calibration interface of Submarine Cables

5. Numerical example

Here takes the HYJQF41-F-26/35kV AC three-core submarine cables for example,this article calculated the ampacity in different section area of this type submarine cables in three typical installation environment:direct burial, "J" shaped tube and aerial laying,and compared with actual test data to verify the accuracy.Here is the specific environmental parameters of each installation environment,the ambient temperature of aerial laying is 40℃;the ambient temperature of "J" shaped tube is 40℃;and the depth of direct burial is 2m and the ambient temperature is 25℃,and the calculations results are shown in table 2.Besides,this article calculated the maximum short-circuit current calculation of conductor and metal screen and compared with manufacturers guidance to verify the accuracy,and the calculations results are shown in table 3.

Table 2. Result of Carrying Capacity of Submarine Cables

Model		HYJQF41-F-26/35kV				
Section（mm^2)		3*70	3*120	3*185	3*240	3*300
Aerial laying	Measurements（A）	279	379	478	550	615
	Calculated values by software（A）	269.61	368.74	467.79	542.62	603.54
	error（%）	3.36	2.70	2.13	1.34	1.86
"J" shaped tube	measurements of（A）	246	334	422	487	546
	Calculated values by software（A）	240.588	327.654	420.170	480.226	528.421
	error（%）	2.20	1.90	0.43	1.39	3.21
Direct burial	measurements of（A）	251	335	416	474	525
	Calculated values by software（A）	248.23	331.92	412.34	470.52	520.145
	error（%）	1.10	0.92	0.89	0.73	0.93

Table 3. Result of Permissible Short-Circuit Current of Submarine Cables

Model		HYJQF41-F-26/35kV				
Section（mm^2)		3*70	3*120	3*185	3*240	3*300
Allow short current values of conductor (KA/1s)	measurements	10.0	17.2	26.5	34.3	42.9
	values by software	10.02	17.17	26.45	34.34	42.93
	error（%）	0.2	0.17	0.19	0.12	0.06
Allow short current values of metal screen	measurements	3*6.66	3*7.20	3*7.76	3*8.17	3*8.52
	values by software	3*6.67	3*7.22	3*7.78	3*8.20	3*8.50

(**KA/1s**)	error（%）	0.15	0.27	0.25	0.36	0.23

From the comparison with actual measured values, we find that the software results of both the ampacity and the maximum short-circuit current are in the context of engineering tolerances,which ensures a good accuracy and shows that this software can meet the actual needs of the project.

6. Conclusion

Calculation of ampacity is actually to determine the conductor section,we should determine cable type, voltage levels, types and specifications according to the grid voltage and environmental conditions,and verify the correctness through thermal stability of calibration.

This article studied on submarine cable structure and improved the IEC standard limitations of submarine cable ampacity calculation,established accurate thermal circuit model for each type of submarine cables.Then developed a cable ampacity calculation module based on this method;

This article developed the module of thermal stability calibration，which contains the function of maximum short-circuit current calculation of conductor and metal screen and minimum section calculation;

Based on the improved ampacity calculation method of submarine cable and the two modules,this article developed a new software for section selection of submarine cables,and tested its accuracy from the comparison with actual measured values.

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