EVALUATION OF ELECTRICAL SURGE TESTS ON SUBMARINE CABLE SIMULATOR

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Abstract: The electrical surge will cause severe damage to the submarine products when cable breaks occur. The surge protection is a key technical point in product design. A surge-generator is usually used in labs to investigate the surge susceptibility performance. Compared with the surge generator, the simulator composed of resistors, capacitors and inductors is closer to the actual submarine cable scenario. In this paper, we describe the theoretical model of an electrical surge, the method of a surge simulation and the tests carried on the simulator to evaluate the surge protection capability of a submarine product.

1. INTRODUCTION

The submarine fibre communication system is usually constant current power feeding system. When a shunt fault in a cable happens (due to trawler damage, for example) a large-amplitude current pulse can be generated by the discharge across the shunt of the stored energy[1].

The surge current calculation formula is as below:

$$x = \frac{\mathrm{CVo}}{\sqrt{\mathrm{LC}}}$$

Where C is the capacitance of the cable, L is the cable inductance and V_o is the voltage of shunt fault point.

If we choose the typical parameters as below:

Cable Resistance	1.0 ohm/km
Cable Capacitance	0.2 uF/km
Cable Inductance	0.13 mH/km

In the worst case, the system is single-end power feeding and the shunt fault point near the PFE, then the Vo could be up to 15 kV.

The LTSPICE simulation model with same parameters of typical cable shows the surge current simulation result.

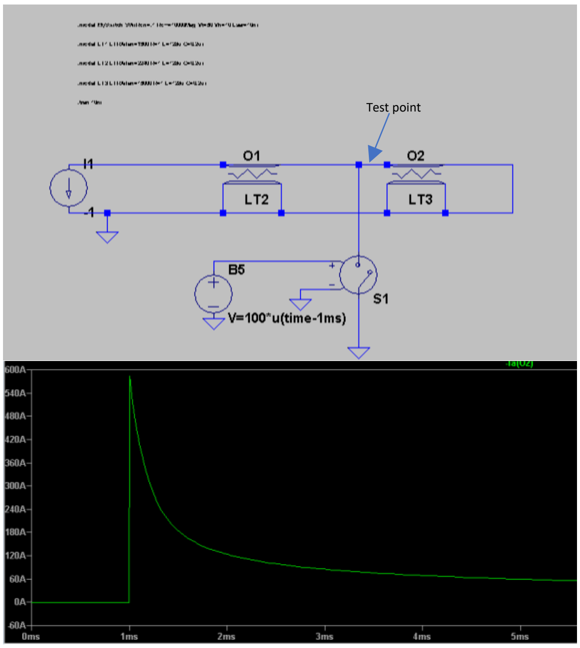

Figure 1: Surge simulation model and result in LTSPICE

The current surge pulses can have amplitudes of up to 600 A, with rise times of several microseconds and durations of 250 us or more for full width at half maximum (FWHM).

2. ARTIFICIAL LINE DESIGN AND TEST

The submarine cable can be deemed as a distribution parameter system, in which distributed capacitors, resistors and inductors lie in every inch of the cable. And these distributed parameters will have a great impact on the behaviour of the current and voltage when the system is in normal operating state. This distribution parameter system can be simulated by lumped parameter system, i.e. by a series of actual capacitor, resistor and inductor.

We have built a cable simulator system which called artificial line to simulate the current surge. Compared with the surge generator instruments, the artificial line is closer to the actual submarine cable scenario. According to typical submarine cable parameter:

R=1ohm/km, L=0.13mH/km, C=0.2uF/km, we choose:
R=10ohms, L=1.3mH and C=2uF as a cable simulation unit and each unit represent 10km submarine cable.

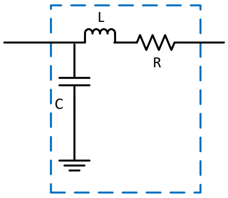

Figure 2: Unit of the artificial line

Additional discharge resistors are required in the artificial line system. After the cable broken or shunt fault, a large amount of charge may be left in the capacitor because there is no discharge path in the high voltage capacitor C. The residual charge may reduce the efficiency of artificial line, even more unsafe to the test staff. So we design an additional discharge path r for the unit. The artificial line unit model change to Figure 3 below.

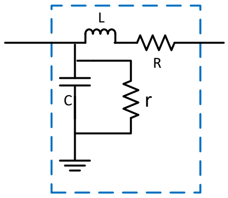

Figure 3: Optimized unit of the artificial line

The discharge resistor r is relative with the discharge current which is relative with the target discharge time.
Assumed the voltage on capacitor at time t is Vt:

$$Vt = Vo * \exp(-t/rC)$$

Where V_o is the voltage before discharge, r is the discharge resistor and C is the capacitance of artificial line.

If we consider the safety voltage as Vs, the discharge time t is:

$$t = rC * \ln(Vo/Vs)$$

The discharge time will last too long if the discharge current is too small, meanwhile it may affect the normal working status of the system if the discharge current is too large.

After the calculation and lab test, we choose the balanced discharge resistor parameter as 150Mohms and then the discharge time of artificial line is about 30min.

Then we get the specifications of artificial line system as the table below:

Items	Parameters
Max voltage of the system	15,000V
Power supply requirements	Bipolar
Distributed capacitance	0.2uF/km
Distributed inductance	0.13mH/km
Distributed resistance	1ohm/km
Characteristic impedance	25 ohms

Table 1: Spec of the artificial line system

Figure 4 shows the photograph of artificial line unit. 3 units represent 30km submarine cable are fixed in 1 rack.

We choose 4 pcs 50W resistors in parallel to form an equivalent 10ohms resistor and choose 2 pcs 8 kV capacitors in series to form an equivalent 16 kV capacitor in an artificial line unit.

Figure 4: Photo of the artificial line unit

The following test system as Figure 5 is set up to verify the effect of artificial line.

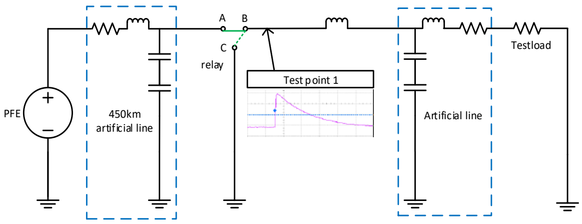

Figure 5: Surge current test system

A relay is used to simulate the cable break or shunt fault. The relay is A-B state when the system is in normal operating status. When the relay switched to B-C status, a surge current will flow through the line. The surge current curve of the artificial line is shown below. We can get that this waveform consistent with the curve get from LTSPICE software and the theoretical calculation result.

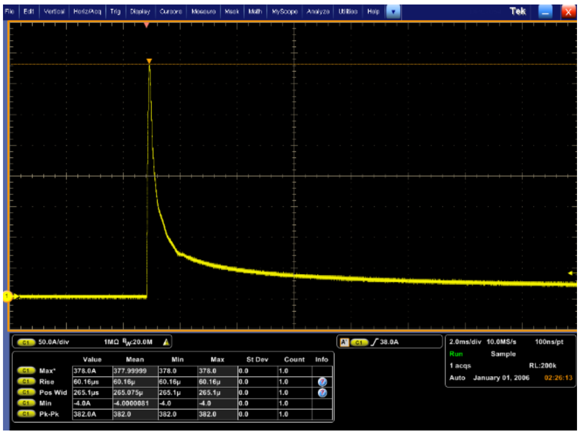

Figure 5: Surge current test result on artificial line

The detailed test data shown in the table below:

No.	Voltage of test point 1 /KV	Theoretical surge current (A)	surge current (A)	Rise time[1] (us)	Half time (us)
1	3.529	141	134.0	48.64	250
2	4.293	172	168.6	44.26	250
3	5.468	219	215.0	45.70	250
4	6.753	270	261.0	50.61	250
5	7.580	303	290.0	51.61	250
6	8.860	354	341.2	48.60	250
7	10.483	419	378	50.50	250

Table 2: Test result of the artificial line

In conclusion, the artificial line is consistent with the theory model and can be used for surge simulation.

3. SURGE PROTECTION UNIT DESIGN AND TEST

The surge protection function is required in the undersea product. In the worst case, the product should cover the surge current up to 600 A.

For example, a repeater circuit can be simplified as following units: Surge Protection Unit, Rectifier Bridge and Pump Driver Unit. The Surge protection unit is used to prevent the circuit damage from surge current impact. The unit is composed of Transient Voltage Suppressors (TVS), inductors and resistors.

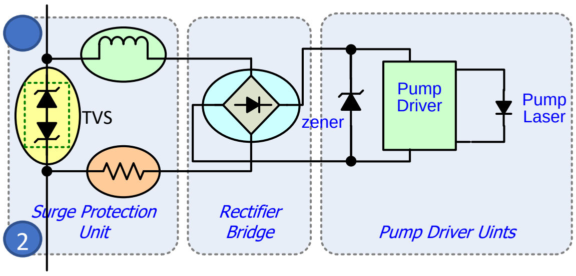

Figure 6: Function unit of repeater

The TVS has a very low conduction voltage on positive status and high impedance on negative status. At the same time, when the TVS undergoes a transient high negative energy impact, the impedance of TVS will decrease sharply at a very high speed of ns, so the large surge current can pass through from the TVS. The TVS will become a short-path circuit to protect the rectifier bridge and pump driver unit.

We set test points before and after TVS (ref test point ① and test point ② in Figure 6). The result shows the surge current difference before and after TVS is less than 10 A when the surge current up to hundreds amperes.

Considering the high reliability requirements of submarine product, the TVS is designed in redundancy mode. The main failure modes of the TVS are short circuit failure and open circuit failure. Therefore, the series and parallel TVS redundant architecture is used in the surge protection unit design. In addition, to ensure reliable design margin, we removed the TVS redundant architecture and explored the surge limits of products without redundancy. From 600A to 1000A, TVS components were not damaged without redundancy, the product design margin is sufficient.

The detailed test data is shown in the table below.

No.	Theoretical surge current /A	Tested Surge current /A	Residual current on zener /A	Residual voltage on zener /V
1	600	620	12.96	7.44
2	-600	-608	12.16	7.52
3	650	664	13.44	7.52
4	-650	-664	12.64	7.52
5	700	716	13.6	7.52
6	-700	-716	12.8	7.4
7	800	816	14.08	7.48
8	-800	-812	13.28	7.44
9	900	908	14.24	7.44
10	-900	-904	13.44	7.44
11	1000	1024	14.88	7.4
12	-1000	-1008	14.08	7.44

Table 3: Surge current test result of TVS without redundancy

Then we added a repeater in the artificial line system. Figure 7 shows the test system.

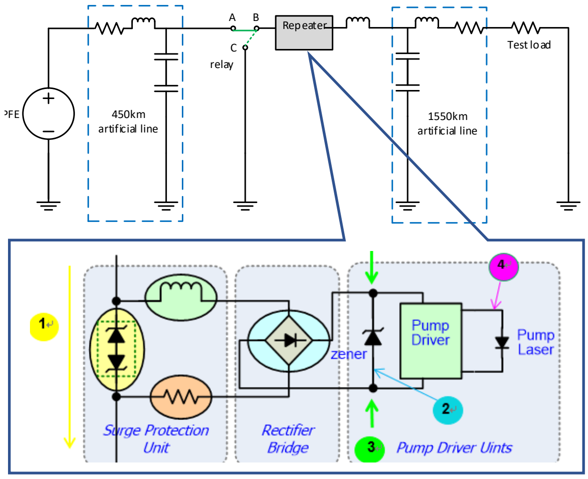

Figure 7: Repeater surge protection unit test system

We add test points on the system (ref Figure 7):
Test point ①(yellow): Surge current.
Test point ②(blue): Residual current on zener.
Test point ③(green): Voltage on zener
Test point ④(pink): Pump drive current.

The Figure 8 shows the test result in the worst case 600 A surge current.

Figure 8: Surge current protection test result

When the surge current is 600A. The residual current[1] on zener is 12 A maximum (the current limit of zener is 200 A according to the spec). The voltage on zener is 7.4 V maximum which is 7 V in normal operating status. The pump driver current is 1120 mA which is 1300 mA current limit according to the spec.

Note:

1. All the data in the table is Peak value.

The optical spectrum of repeater before and after surge test are consistent.

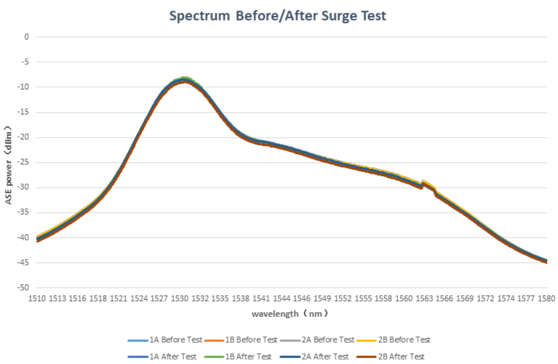

Figure 9: Optical spectrum before and after surge test

4. 15KV HOT SWITCH DESIGN AND TEST

In recent years, in the technology trend of the submarine cable industry, 15kV high voltage switch (hot switch) BU has become a new technology direction.

We also built a LTSPICE simulation model to simulate the hot switch scenario.

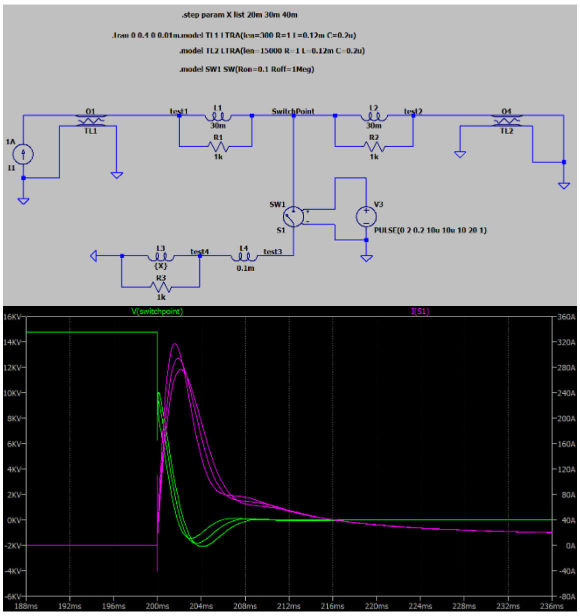

Figure 10: Hot switch simulation model and result in LTSPICE

The simulation result shows the different peek current when the current suppressor selects different inductance values in the 15kV hot switch BU.

Then we built a test system on artificial line system based on the simulation result. Figure 11 shows the test system.

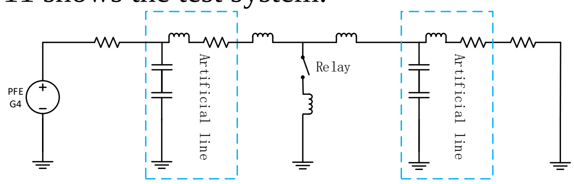

Figure 11: 15 kV hot switch test on artificial line system

A relay is used to simulate the hot switch BU. The relay is open state when the system is in normal operating status. When the hot switch occurs, the relay will switch to closed status.

Figure 12 shows the test result on artificial line system when switching voltage is 15 kV. The yellow curve is the switching voltage and blue curve is the peek current.

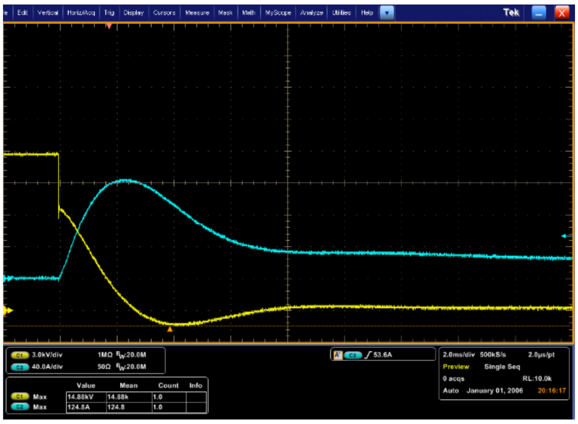

Figure 12: 15kV hot switch test result

We can observe that this waveform is consistent with the curve get from LTSPICE simulation result.

5. CONCLUSION

The artificial line composed of resistors, capacitors and inductors is consistent with the theory model and closer to the actual submarine cable scenario compared to the test instruments.

The surge protection test carried on the artificial line shows that the undersea product can resist the 15 kV surge impact and has a large design margin.

The hot switch test carried on the artificial line system shows the 15 kV hot switch technology is verified in the DEMO system in the lab and ready for the next generation product.

6. REFERENCE

[1] Neville J. Hazell et al., "Undersea Fiber Communication Systems", VOL.9, 2002