ELECTRICAL POWER – GREENER SOLUTIONS WITH MINIMAL COMPROMISE

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Abstract: This paper examines some ways to reduce the power consumption of submarine cable, showing that this is nearly always good for the environment and often has financial and other benefits.

1. INTRODUCTION

Environmentally sensitive solutions ideally need to consider everything from the initial manufacture to end-of-life disposal. This paper focuses mainly on how to minimise equipment and power consumption, which are clearly only parts of the overall environmental picture. This is a way of simplifying a highly complex problem, but it is clear that such solutions will generally reduce environmental impact providing that one checks that there are no obvious disadvantages. In most cases this approach also lowers costs and improves reliability; this is important as "greener" solutions which come with a financial or operational penalty are unlikely to be adopted.

A typical system

At its simplest, a submarine system consists of two sites connected by a subsea cable.

Figure 1: Simple subsea link

Except for systems shorter than ~500 km, the cable includes repeaters (R) which require Power Feed Equipment (PFE) at each site. Also required is Terminal Transmission Equipment (TTE), which handles the traffic-carrying wavelengths and there may be other equipment such as ROADMs etc. All of this consumes electrical power, which produces heat, so (except in cold regions) some form of cooling system is required. Most cooling systems also require electrical power, so it's clear that reducing the consumption and heat produced, in turn reduces the consumption and cost of the cooling systems.

Consumption – some examples

It is hard to define a "typical" subsea system, so let's consider three examples:

1. 7000 km, 6 pairs each with 100 x 100G
2. 1000 km, 6 pairs each with 50 x 100G
3. 1000 km, 2 pairs each with 10 x 100G

For convenience we assume that the repeaters require 10W per amplifier-pair, are spaced 100 km apart and the cable has a resistance of 1 ohm/km. The TTE consumes 100 W per wavelength, plus 250 W for the common functions. The 7,000 km system uses 8QAM, while the shorter systems use 16QAM. The numbers are not intended to be precise, but to show the order of power consumption.

Example	Total voltage	PFE power	TTE power
1	11.7 kV	7 kW	42 kW
2	1.7 kV	2 kW	17 kW
3	1.3 kV	2 kW	2 kW

Table 1: Approximate consumption

From this it would seem that, except for case 3, the power of the TTE is significantly greater than that of the PFE.

Extending inland

Many systems will in fact contain significantly more TTE because of the need to re-transmit the traffic inland. The following figure shows how this roughly doubles the amount of equipment, and thus the power consumption, in a typical Cable Landing Station (CLS).

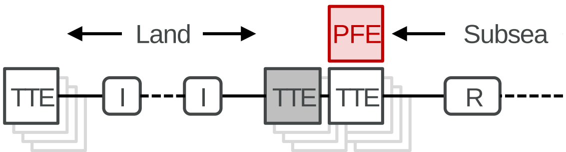

Figure 2: Equipment for re-transmission [I = In-Line Amplifier (ILA)]

The obvious solution is to replace the TTEs in the coastal site with amplifiers.

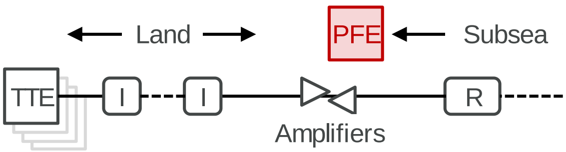

Figure 3: Direct delivery to end-point

This has a dramatic impact on the consumption and space requirements at the coastal site – the equipment at the inland site is required in either solution. Effectively, all the TTE, which would require a number of racks, is replaced by a few optical amplifiers which will require <1 kW and will fit in a single rack. In case 1 the power consumption drops from ~90 kW to ~8 kW. The heat produced drops even more: from ~85 kW to ~3 kW, thus reducing the cooling required. Air-conditioner consumption depends on the external temperature and in a warm country the cooling may consume the same power as the equipment being cooled. Even assuming that each 1 kW of heat requires 0.5 kW of cooling would give 135 kW for equipment plus cooling, or 1.2 million kW hours per year. Electricity costs range from 0.03 to 0.35 USD/kWh [1,2], but assuming for convenience 0.10 USD/kWh the potential saving is around 100,000 USD – in many countries it will be more than this, although it's worth noting that the latest DSP modules are somewhat better the 100W/wavelength values used here.

There is a further benefit to be gained; the battery capacity and size of back-up generator and air-conditioning units are also smaller, as is the building needed. This reduces the environmental impact of both manufacture and ultimate disposal.

The reduction in overall terminal equipment also makes for a more reliable system and (because there are fewer stages of regeneration) gives a small improvement in latency.

It's important, however, to appreciate that all this doesn't come completely for free. Linking land and subsea segments with an amplifier instead of regenerating reduces the Signal to Noise Ratio (SNR), which in turn reduces the potential capacity of the system. This could be addressed by reducing repeater spacing and/or by improving the Noise Figure of the ILAs, but both will add a little cost. Unless all the capacity is required rapidly, a better solution could be to ignore this issue initially. Technology is improving and prices eroding, so there is likely to be a better, cheaper solution in the future and from a financial viewpoint it's generally better to defer costs until they need to be incurred.

2. FURTHER IMPROVEMENTS

From the previous section it's clear that removing TTE from the coastal site lowers power consumption and equipment footprint very substantially and one might imagine that further improvements will be hard and expensive to achieve. There are, however, still possibilities which merit investigation.

To have resilience against the failure of electricity supply it's normal to have batteries with capacity for a few hours of operation and a diesel generator to cover longer outages. Manufacture and carriage of both have obvious environmental impacts. Worse still, it's normal practice to check the generator quite frequently by running it for a while. Running an internal combustion engine from cold – when it is at it least efficient and most polluting – is clearly not green. Could it be better to look for a solution without a generator? If the battery autonomy is increased, then the probability of needing to use the generator will be reduced and at some point it would be possible to reason that it's not required at all. If the equipment could run for 24 hours or so, then it would be possible to use a portable generator to cover long-term conditions, such as the AC power lines being damaged. In this case it would be prudent to have a contractual arrangement in place to guarantee availability at a time when the demand for generators would naturally be high.

Since the cost of high quality batteries is relatively high, this idea may appear somewhat expensive, but there are two factors which can make it less costly. Power and cooling are often estimated on a somewhat simplistic worst-case basis. A PFE, the major element at an unmanned station, would be assumed to be operating at full voltage and to have one converter connected to the test load. While this approach makes sense in terms of dimensioning circuit breakers, it risks being over-kill if the numbers are then used to calculate the battery and generator capacity.

The following figure shows PFEs, each with two power converters (1 & 2) for 1+1 protection; the shading shows the relative consumption of the two converters. In normal operation power is shared more-or-less equally between all the converters. In the worst case, with a fault at one end of the system, one converter will be powering the cable while the other is connected to the Test Load (TL); the PFE close to the fault will produce only a very low voltage and consume relatively little power.

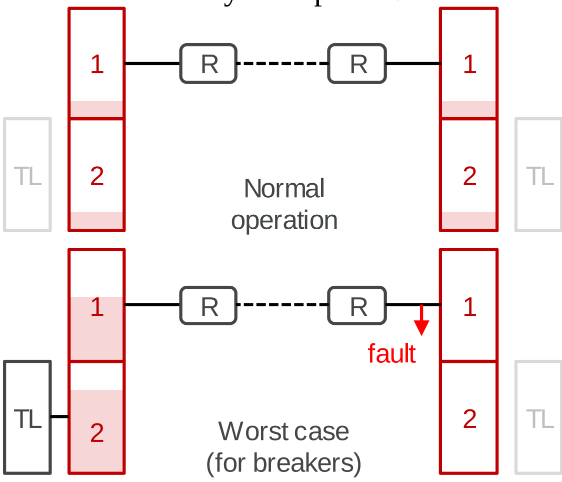

Figure 4: Normal and worst case PFE

Comparing the normal and worst case conditions, it turns out that the normal operating current is around 20% of the worst case breaker current – and the difference is even greater if (as sometimes happens) the calculation is done using the maximum voltage that PFE can produce.

If the Cable Landing Station (CLS) contains only amplifiers and a PFE, then most of the power is consumed by the PFE, which in normal operation is running at half the system voltage. It would not require much engineering to create a very-low power mode which is used only if the CLS electric supply is cut. If the PFE is turned down and other loads removed / reduced, then the cable station consumption would be very low and the autonomy of the battery extended very significantly. Could this be a strategy which makes it possible to remove the back-up generator?

A potential problem is that if there is now a shunt-fault or PFE failure at the far-end of the system, then this PFE will need to run at full voltage to restore normal operation. Although the probability of a shunt fault coinciding with a power-cut is small – at least in countries with good electricity infrastructures – the consequences are an outage of significant duration and there is a good case for ensuring that the battery size is sufficient to power the PFE at maximum required voltage for at least the mean electrical outage time. If this is long, then the generator may be required – or it may be worth looking at greener alternatives, such as solar power in conjunction with a correctly dimensioned battery.

3. POTENTIAL ISSUES

So far it's been suggested that minimising power consumption and equipment, which clearly improves the environmental footprint, also aligns with financial interests. However, this is not always the case.

Copper, used as a power conductor and hydrogen barrier in many cables, is an expensive metal and so some suppliers are offering cables with less copper or with an aluminium power conductor and thus higher resistance, typically 1.5-1.8 ohm/km. This increases the overall system voltage and thus the PFE consumption, but the increase is only 0.8-1.3 kW per 1,000 km compared with 1 ohm/km. A more significant factor is that a bigger PFE may well be needed, thus increasing manufacture and disposal impacts. However, moving from 1 ohm/km to 1.5 ohm/km saves 50 kg of copper per km which is clearly an environmental and financial win on a system with many km of cable.

Another case where power saving and financial concerns don't align, is when system design is driven by cost per unit capacity. Here the financial logic is that there are several fixed costs – permits, survey, marine operations – so to minimise cost per unit capacity one must aim for the highest possible capacity. The extra fibres, amplifiers, bandwidth etc. needed to achieve this will increase the power needed by the subsea link. In addition, getting the highest capacity is achieved by placing the transmission equipment at the shore to minimise the link length. There is, however, an argument that it is better for the environment to build one very high capacity cable systems than two lower capacity ones. There would be significantly less marine activity, burning of fuel and short-term disruption to the shore-end eco-systems.

4. SUMMARY

Lowering power consumption clearly helps the environment and can generally be achieved without compromising cost or reliability.

One of the best ways to reduce both environmental impact and cost is to move the submarine Terminal Equipment to the point where the traffic needs to be delivered. This reduces overall power consumption, size of air-conditioning plant, DC power plant and the total space needed for the equipment.

If this is done, then the Cable Landing Station need contain little more than PFE, a few amplifiers and DC power plant. Accurate determination of the actual power consumption is then worthwhile, as this avoid purchasing more battery capacity than is actually needed.

A further step forward would be an "intelligent" PFE capable of switching into a low power mode when external power fails. This could increase the power autonomy to the point where a back-up generator is not needed. This could be very worthwhile, as there are obvious environmental benefits of removing an internal combustion unit which is periodically run simply to verify that it is capable of supplying power when needed.

In general, reducing power requirements and equipment is good for the environment. It is often a route to other benefits, such as improved reliability and lower cost, but it's important not to lose sight of other objectives. It may be necessary to compromise, for example in order to get higher capacity or to use cables with lower copper content.

5. REFERENCES

[1] "Average electricity prices around the world," https://www.ovoenergy.com/guides/energy-guides/average-electricity-prices-kwh.html
[2] "World Energy Prices: An Overview," https://www.iea.org/publications/freepublications/publication/WorldEnergyPrices2018Overview.pdf