CAPABILITIES OF ELECTRICAL SUPERVISION SYSTEMS FOR SUBMERGED EQUIPMENT

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Abstract: An electrical repeater supervisory has been a key feature of many optically amplified repeater systems installed over the last ten years. The operation of this system is described and a number of fault location case histories discussed. The historical data is compared with the budgeted allowances for 25 year ageing performance. Other uses of the electrical supervisory system will be considered, e.g. control of Branching Units, and finally further applications are considered.

1 INTRODUCTIONI

Optically Amplified Repeaters have been in service for over ten years and several methods of shore-based supervision have been developed. This paper will focus on the ‘Electrical Supervision’ system that takes direct measurements at each amplifier within the repeater and relays them to the shore management system. Alcatel has worked closely with its customers through the period that this system has been operational, reviewing the field performance of the extensive installed base of over 4000 repeaters in 40 Optically Amplified Systems. These measurements can be used both to precisely locate faults and to accurately analyse long-term trends and performance.

Firstly, the operation of the electrical supervisory system will be described. A number of case histories demonstrating the effectiveness of the fault location system will be presented. Similarly, examples of long-term trends and performance of the submerged equipment, in particular repeater and cable, will be presented. This paper will look at the merits and uses of the historical data and the data will be compared with the budgeted allowances for 25 year ageing performance.

Additionally, other uses of the electrical supervision system will be discussed. It has already been used as a key technology in Active Equalisers and Branching Units: - other potential applications will be reviewed.

The overall capabilities and features of the Electrical Supervision System will be reviewed and the next evolutionary steps considered.

2 ELECTRICAL SUPERVISORY SYSTEM DESCRIPTION

The Electrical Repeater Supervisory System extends the normal terrestrial facilities of control and condition monitoring to the active submerged equipments in submarine systems. An operator, located in any location, a terminal station, a Network Operations Centre, or another remote operator point, can readily review the system status, using one of the standard, familiar operator tools. For more detailed analysis, the system can be configured to permit remote access by Alcatel Submarine Networks staff and data may be analysed off-line.

Condition monitoring is typically periodic, e.g. a monthly global scan, with the data stored to archive, or as required, responding to a specific operator request. A command is sent from the server or operator position, over the necessary networks and LANS to the appropriate transmission equipment. The transmission equipment then transmits an interrogation signal over the specific fibre pair to the relevant repeater. Only the repeater specifically addressed in the message will respond:- this means that all data, and in particular any system fault, is instantly & precisely located to either a specific repeater or a specific span, with no ambiguity. After the repeater has taken the requested measurements, the return message is sent via the same transmission equipment back to the server or operator that initiated the action. If the operation is unsuccessful, alternative routes across the network are used, e.g. to the transmission equipment at the far end. The transmission penalties associated with the signalling between the transmission equipment and repeater are minor, < 0.5 dB. For a periodic scan, the same operation is automatically repeated across all the subsea equipment. The data is flagged as healthy or alarmed if preset limits are exceeded.

The following repeater parameters are routinely monitored:-

- Send Light Level (SLL)
- Received Light Level (RLL)
- Pump Current A
- Pump Current B

The Send Light Level is the main indicator of the repeater health, the pump currents provide diagnostic information about pump and control circuit changes that could be affecting repeater output. The received Light Level measurement essentially indicates the state of the preceding repeater span. It may be used together with the Send Light Level of the previous repeater to calculate the span loss. Additionally, during a cable repair, it may be used to measure the splice loss of joints as they are completed.

The resolution and accuracy of the measurements are good and carefully verified during repeater manufacture by calibration to NPL, for example RLL measurement reproducibility of better than 0.1 dB is regularly achieved. For long term condition monitoring stability is vital, careful ageing tests have shown that no measurable ageing occurs in any of the key components:- the integrated circuits, photodiodes and optical couplers.

The Electrical Supervisory System provides a complete facility that is:

- Easy to access & use
- Quick to provide accurate specific locations for key events
- Comprehensive in providing the fundamental parameters of an optically amplified system

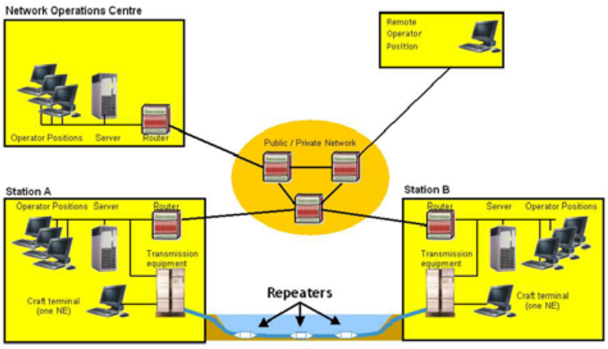

Figure 1: Supervisory System Overview

3 FAULT MANAGEMENT CASE HISTORIES

3.1 Cable fault location and repair

Even with the major improvements in installation practice, cable faults still occur. For a typical cable repair the electrical repeater supervisory provides key information for both fault location and for rapid splice loss measurement during cable jointing. For the first step, accuracy is of key importance, the simple address mapping of the repeaters, together with the Receive Light Level measurement, correctly identifies the faulty span every time. For the second step, accuracy of measurement is assured, the splice loss is typically measured within an uncertainty of less than 0.3 dB, but equally importantly each splice loss can be measured instantaneously. This is of huge importance when the repair ship needs to be correctly, and expeditiously, released from the final splice.

3.2 Repeater fault analysis

There is strictly limited experience in the accumulation of data from repeater faults; the only data available is from a repeater repair in 2001, where there was progressive degradation of output power to the point where a repair had to be scheduled. The key data from this event is shown in Figure 2. The graph shows the graceful degradation, over several months, of the output power from one output of an amplifier pair. Analysis of the pump currents and the other output and receive light levels helped to pinpoint the failure within the amplifier pair. In particular, the extra diagnostic information readily confirmed that the fault was in the repeater, not an adjacent cable span or joint, enabling the repair to be specifically targeted at repeater replacement. Ongoing analysis of the trend of output change allowed an appropriate ship repair to be scheduled. The recovered repeater was examined, and a faulty component replaced.

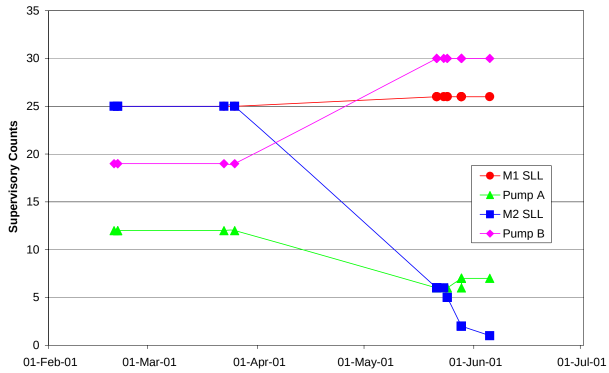

Figure 2: Repeater Supervisory Trends

3.3 Long term trends & Analysis

The analysis of the long term performance of equipment has been achieved by specific engineering initiatives over and above the normal operation and maintenance actions, which analyse data for specific events, for instance those described in the previous section (the extensive long term databases required for long term analysis in practice have little operational benefit). This approach has been reinforced by the general stability seen, both in the repeater supervisory data and in transmission performance. However with the Apollo System, a Trans-Atlantic system commissioned in early 2003, ASN have been more extensively involved in the maintenance and have been able to complete some trend analysis, which is invaluable in quantifying the ageing allowances in the system budget.

3.4 Cable loss

The span loss of a fibre pair of the Apollo system has been analysed for the four years 2003 to 2006 inclusive.

It shows a slight decrease in loss of ~ 0.0008 dB/km, as shown in figure 3 below.

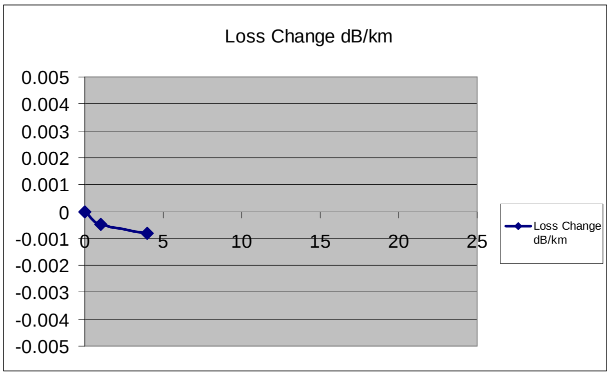

Figure 3: Cable loss change with time

The shore end spans are excluded, the losses in the terminal station connectors do not allow satisfactorily secure measurements. The average change per span is actually less than the resolution of the repeater supervisory A/D conversion, however taking the average of the changes is valid because the signals are uniformly distributed across the A/D levels.

The typical loss ageing budget, for a system life of 25 years, is a increase of 0.005 dB/km, representing 0.003 dB/km for radiation loss increase and 0.002 dB/km for cable ageing. The Apollo data shows a loss decrease that is likely to be asymptotic to a level between ~ 0.001-0.002 dB/km. The actual 25-year performance is confidently expected to be better than the budgeted performance.

3.5 Repeater Output Power

The average repeater output power of a fibre pair has been analysed for the same four years:- 2003-2006 inclusive. The data shows a negligible change of order ~ 0.01 dB, even after four years. It appears unlikely that there will be any significant change even with a linear extrapolation to 25 years.

3.6 Pump current changes and reliability

The pump currents can be monitored through the supervisory system. This function was included for a number of reasons:- an original concern to provide operation and maintenance information on the the pump laser, which has been considered the most advanced technology in the repeater. As the reliability was considered to be in the area of 1 in 100 failures in 25 years, pump redundancy has been used. This, together with the behaviour of the pump control circuits (Automatic level control and Mean power control), implies detailed analysis is required to interpret the average pump current required and also pump failures. The analysis of a fibre pair of Apollo has shown:

A small change in pump current consumption over 4 years, from 75% to 77% of the available current. It is believed that this change reflects minor changes in pump efficiency. There is no change in repeater output power because the output power control circuit maintains it constant.

The accumulated hours of 980 nm pump operation confirm a field reliability of ~ 50 FITS, consistent with the budgeted failure rate of 100 FITS.

4 CONTROL

The active repeater supervisory system has the capability to control submerged equipment. The internal electronics can be readily adapted with interface circuits, so that the specific messages, after decoding within the repeater, can control any function with the system. Since the introduction of optically amplified systems, this approach has been used for:

- Repeater power output management. For the early WDM systems with upto 8 channels, this feature was used, in conjunction with the terminal channel, for channel power management as the system was upgraded from a few channels to full capacity. The supervisory system is readily linked with the output power control circuits to provide the control.
- Active Tilt Equalisation (ATEQ) control. For wide bandwidth optical systems, the addition of loss to the system from repairs and cable ageing can result in significant tilt of the optical spectrum. For the longest systems, this cannot be managed soley at the terminal stations, in-line control is also required. A specific optical equaliser, which provides the required optical tilt compensation is readily driven by the supervisory circuits.
- WDM Branching Unit (BU) – Control of Add channel power. The first WDM systems used amplifers at WDM BU’s to manage the channel powers as the two, trunk and spur, spectrums were combined. As fine control was required, an extended version of the repeater power output management described above was used.
- Branching Unit Electrical State Control. As systems evolved, different needs were identified for the Electrical States of the BU power circuit. It is not possible to support all these needs with a BU circuit that is managed by the applied line currents, it is necessary to provide extra controls:- these can only be delivered by the active electrical supervisory system. The supervisory circuits were interfaced to the HV relays using proven, qualified, power electronics and a truly generic BU achieved.

5 EVOLUTION

It can be seen that the control requirements have already evolved through the last 10 years of optically amplified submarine systems. It is expected that the evolution in the features of supervision will continue as higher capacity long haul systems are developed.

Certainly higher capacity systems have always required more precise specification and production control, this trend will be maintained for future, higher capacity, systems and potentially this can also require some active control within the transmission path to reach a fully toleranced, but manufacturable system. A number of potential requirements can be conceived:

Higher bandwidth systems may require more advanced emphasis monitoring.

Raman repeater systems may require accurate monitoring and control of pump power.

High Bandwidth systems may require active shape equalisation.

6 CONCLUSION

The active electrical supervisory system for control & monitoring of the submerged equipment achieves many goals that are important to the efficient operation of a submerged system over 25 years. In contrast to a terrestrial system, where a truck roll is an inexpensive exercise, and the active electronics is located in easily accessible terminal stations, a submarine system repair requires an expensive ship mobilisation and contains electronics within the transmission cables. In addition, because the transmission distances are longer, and the system powering is critical, some specific control of submerged plant is essential.

System Monitoring can be viewed in two ways:- either the simplest approach should be adapted that just support fault location and repair, or more detailed facilities, such as those provided by the active electrical supervisory system, may be provided, that additionally allow a more analytical approach to system analysis and monitoring. The fuller information provided by the active supervisory system is invaluable in validating the reliability figures and ageing allowances that are a vital part of the highest standards that are required for Submarine System design.

These capabilities will be more, not less, necessary for future higher capacity systems.