Conductive and Inductive Interferences of 25kV Railway Traction Power System on Train Signalling System – A Case Study

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Abstract: - This paper presents a case study of the impacts of 25kV traction power system on railway signalling system using copper cables as communication links. Several forms of interferences including electromagnetic including and conductive have been investigated and remedial measures implemented, with satisfactory results.

Key-Words : - Traction Power System, electromagnetic interference, railway signalling system, EMC.

1. INTRODUCTION

Similar to many other 25kV a.c. railways in the world, the newly commissioned West Rail in Hong Kong uses trackside screened copper cables with twisted pairs as communication links for the train signalling system. During trial operation in the second half of last year, West Rail had encountered many failures arising from interference from the 25kV traction power system. This paper reports on the investigation undertaken and the subsequent remedial measures and results.

2. BACKGROUND

2.1 Brief Description of West Rail

West Rail is a commuter railway linking the Northwest New Territories to the urban Kowloon area in Hong Kong, and is approximately 32 km in length. It has 9 stations and an ultimate capacity of 90,000 passengers per hour per direction when operating at 33 nine-car Electric Multiple Unit (EMU) trains per hour per direction. West Rail Traction Power system uses 25kV with Overhead Line distribution. As shown in Figure 1, it is supplied by two feeder stations located part way along the line. There is no booster transformer and the return current path is designed to utilize the rail (~ 30%), the aerial earth wire (~ 20%) and earth (~ 50%). The WR earthing system comprises the Traction Earthing System for the 25kV traction power system, and the Low Voltage Main Earthing System for the building services installation. The WR traction power overhead line system employs multiple point earthing system to contain the touch- and step-potentials within the limits as specified in various international standards [1, 2, 3] under normal and fault conditions.

2.2 Train Signalling System

An Automatic Train Control (ATO) System based on SELTRAC System had been implemented on West Rail. SELTRAC is a computer-based and centralized system (Figure 2). SELTRAC is a moving block system based on continuous track-train bi-direction communication, in which the safe separation behind the preceding train is dynamically calculated based on the maximum operating speeds, braking curves and the reported locations of the trains on the guideway (Figure 3).

3. INTERFERENCE VOLTAGES

3.1 Modes of interference voltages

Trackside communication copper cables are susceptible to interferences from the a.c. current in the overhead line through capacitive, inductive and conductive coupling. Despite the 25kV, interference through capacitive coupling has been found to be negligible, and the dominant modes of interference remain to be conductive and inductive coupling.

3.2 Prediction of Induced Voltage

Induced voltages have been predicted during the design stage based on the methodology in [4] and [5].
Results of the prediction are as follows -

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Section 4</th>
<th>Section 3</th>
<th>Section 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault current on Catenary, I (Amp)</td>
<td>3400</td>
<td>3200</td>
<td>3300</td>
</tr>
<tr>
<td>Return current on each rail (I/4) (Amp)</td>
<td>850</td>
<td>800</td>
<td>825</td>
</tr>
<tr>
<td>Return current on Aerial Earth Wire (I/10) (Amp)</td>
<td>340</td>
<td>320</td>
<td>330</td>
</tr>
<tr>
<td>Length of parallel cable runs (km)</td>
<td>8.2</td>
<td>10.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Induced Longitudinal Voltage Vl (V)</td>
<td>309.0</td>
<td>346.7</td>
<td>286.1</td>
</tr>
</tbody>
</table>

Based on the results, under short-circuit fault condition, the induced longitudinal voltages are within the 430Vrms as specified by the CCITT Directives.

4. THE PROBLEM

When West Rail started trial operation in June 2003, the data communication network of the Train Signalling System connecting the central and the field equipment experienced excessive electrical noise, which disrupted the flow of data messages, leading to stoppage of part of the system and emergency braking of trains as a fail-safe feature of the system. With full timetable operation the situation had worsened to the extent that train punctuality fell to below 50% which was substantially below the acceptable criteria of 95%. A taskforce was subsequently formed to investigate the problem and to find out remedial measures.

5. INVESTIGATIONS

5.1 Circuits Check

Circuit checking has been carried out in order to spot out any observable circuit deficiency leading to the problem. The checks have focused on the communication circuits, field equipment interface and the cabling details. The circuit details are summarized in Figures 4. Each central – field communication circuit consists of two V.23 modems, connected at the ends of a twisted-pair cable. To protect the modems from being damaged by high energy surge, surge arrester is installed at each modem input. The modem signal is a Frequency Shift Keying (FSK) signal composing of two frequencies, the 1.3kHz and the 2.1kHz signals. The 1.3kHz signal denotes a logic “0” while the 2.1kHz signal denotes a logic “1”. Track – Train bi-directional communication are performed by dedicated circuits working at three frequencies, the 9kHz, 36kHz and 56kHz signals. Line amplifiers have been installed to boost up the signals at regular intervals to maintain the Signal-to-Noise (S/N) Ratio. Same as the modem lines, surge arresters have been installed at the cable ends for protection purpose.

5.2 Circuit Measurements

Measurements have been carried out on the communication circuits with typical results as shown in Figures 5 and 6. From the results, it has become obvious that the frequent stoppages of the system was due to interference signals jamming into the modem line and disrupting normal data communication. The magnitude of the interference signal varies from time to time but could be up to several tens of volts depending on the measurement location, which was significantly higher than the normal 200 – 300 mV of the V.23 modem signal. When reviewing the noise pattern, it has been discovered that it is similar to the power consumption pattern of trains. In addition to 50Hz, high 2.6kHz signals with two side-band components have also been noted. After reviewing the EMU traction equipment, it has been confirmed that these 2.6kHz signals have been generated from the propulsion and braking of the trains.

5.3 Possible Causes of the Problem

Based on analysis of the measurement results, four possible causes of the problem have been identified -

Cause 1 – inrush of traction earth return current via earth terminal of the modem surge arresters through conductive coupling

Part of the traction earth return current is suspected to have been injected into the modem circuits through the earth terminals of the surge arresters which have been inadvertently fired, thus jamming the signal into the modem lines. Figure 7 shows the mechanism supporting the assumption.

Cause 2 – Induced current circulating on modem lines via the surge arresters earth terminals through inductive coupling

As shown in figure 8, current is suspected to have been induced into the modem wires by the traction current on the Overhead Line System. When the induced power is high enough to fire the surge arresters at both ends of the modem wires, a complete circuit will form which enables the induced current to circulate.
Cause 3 – Traction noise is coupled through the power supply of the equipment

It is suspected that traction noise is conductively coupled into the power supply system via the supply network. If the modems are sensitive to the supply fluctuation, the noise will be “modulated” onto the modem signals. In fact, on measuring the power supply output of the Vehicular Control Centre (VCC) modems, a 2.6kHz signal was observed.

Cause 4 – The resonance of surge arresters

It is suspected that the surge arrester circuit resonates with some of the frequency components in the modem line signals. This is based on the observation that the surge arrester circuits consist of coils, varistors and gas discharging devices.

5.4 Tests for the possible causes

5.4.1 Dummy Line Tests

To test out the possible causes, a dummy circuit consisting of a spare twisted pair is chosen between a selected field equipment and the Central Equipment Room. To simulate the modem line, surge arresters are connected at both ends of the twist-pair and earthed. A 600 Ω resistor had also been connected at each end of the dummy line to simulate the modem. Measurements were made across the 600Ω resistor at the Central Equipment Room. As there is no active component on the dummy line, it is expected that the voltage across the resistor will be at milli-volts level. If a higher voltage appears on the load, it will imply that possible causes 1, 2 or 4 may be valid. The result is shown in Figure 9 in which a fluctuating voltage on the dummy line is recorded. The result confirms that the unexpected noise in the modem line is mainly from external interference.

5.4.2 Earth Voltages

Voltages have been measured between different earthing systems at selected locations with independent earths. The results indicate that the potential differences (ranging from 4V to 7V Peak to Peak) between the earth systems are insignificant.

5.4.3 Test for possible cause 1

This possible cause is based on the firing of surge arresters at both ends of the modem line due to the high earth potential appearing at the surge arrester earthing points. As the arrester rated voltage is 24V, to enable the flow of current via the two arresters, an earth potential up to 48V between the two earths which is not supported by the results described in section 5.4.2 above.

5.4.4 Test for possible cause 2

The screened cables used in West Rail employs single ended earthing which can only provide electro-static protection to the cable but not against electro-magnetic induction. In theory, multiple-point or double-ended earthing scheme can provide better protection for the cables, which is installed in environments with potentially large electro-magnetic induced voltages, by allowing an induced current to flow on the cable screen and to generate an opposing field to neutralize the interfering source. Based on this theory, if the unexpected voltage appearing in the modem line is due to electro-magnetic induction, earthing the cable screen at both ends should reduce the induced voltage on the cable core significantly. A test has been carried out and the results indicate that with double ended earthing, the interference voltage in the twisted pair could be reduced almost by half. This confirms that the noise voltage mainly comes through inductive coupling.

5.4.5 Test for possible cause 3

Possible cause 3 assumes that the unexpected modem line voltage is the result of conductive coupling through the power supply system. To prove the hypothesis, an operating modem line is selected with the surge arrester connected in its normal configuration. A passive low-pass filter is designed and fitted into the power supply of the modems. If the assumption is correct, the noise appears in the modem line is expected to attenuate significantly. Although the laboratory test confirms that the low-pass filter can significantly attenuate the 2.6kHz signal, there is no observable improvement on the modem line noise after the filter is connected to the modem power supply. In addition, on analyzing the power supply output, it is observed that there is no obvious reduction on the 2.6kHz noise component. This phenomenon can only happen when the noise is coupled into the power supply from the modem rather than vice versa. Hence, the possibility of cause 3 being the actual cause of interferences is not established.

5.4.6 Test for possible cause 4

Possible cause 4 assumes that the surge arrester resonates with some of the frequency components in the modem line, causing spurs of large voltage...
magnitudes to appear on the modem line. To verify this, two surge arresters are connected via one pair of twisted wires to simulate the actual circuit. Signals and noises are injected to the circuits by frequency generators. In addition, to determine whether the surge arrester will resonate at around a few kilohertz, the surge arrester was also tested through a frequency range sweeping from several Hz to 100kHz. No voltage spur can be reproduced in the simulated modem line and no resonance phenomenon appears during the tests. Hence, it can be concluded that possible cause 4 is also not valid.

6. FINDINGS

6.1 First Finding

It has been established through the tests as described in section 5 above that the unexpected noise voltage in the modem lines mainly originates through electro-magnetic induction. It is also proved that by taking out the surge arresters on the modem line, one can significantly reduce the occurrence of the system stoppages. All the evidences are pointing to a design mistake that the surge arresters used are under-rated. A series of measurements on the longitudinal voltages at all locations along the railway have been conducted in order to find out the induced voltage on the cable cores under normal railway operation scenario. 20 trains have been arranged to run on the railway during the measurement. From the results, it is seen that while the longitudinal voltages are well within the CCITT limit of 60Vr.m.s., which is equivalent to a peak-to-peak voltage of 170V. Such magnitude of recorded voltages are substantially higher than the rated voltage of 24 V in the surge, resulting in advertent firings and the jamming of the modem signals.

6.2 Second Finding

The railway is normally fed from two feeder stations. When one of the substations is down, the remaining one will take care of the failed section. Under this abnormal scenario, voltage spurs up to 100 – 110V r.m.s i.e. peak-to-peak value of 283V – 311V, start to appear on the test circuits. It is seen that the longitudinal voltage under the single feeder station configuration would exceed the CCITT recommended limit of 60V. This would affect the safety of the maintenance personnel working on the modem circuits.

6.3 Third Finding

While the replacement of the surge arresters has significantly reduced the occurrence of the problem, it has not totally eliminated it. To investigate the residual problem, a multi-channel voltage recorder is connected to the operating modem lines of the Station Control System (SCS) and Platform Screen Door Interface Unit (PDIU) to monitor any anomaly. In addition, as it is known that there is a significant 2.6kHz noise in the modem line signal, a Signal to Noise (S/N) ratio check has also been conducted. In each PDIU and SCS, there are four modem lines, two for transmitting and the other two for receiving. Such an arrangement is to provide sufficient redundancy on the modem circuits to cope under failure scenarios. In central, the VCC will send data signals to both modem lines no matter which lines the field PDIU and SCS is listening to. However, the field PDIU and SCS units will only transmit data back to VCC through only one of the lines. Figure 10 shows a typical PDIU modem line switchover phenomenon involving two different PDIU signals. It is observed during the measurement that back and forth switching of the modem signals is mostly associated with the stoppage of the system. It has also been discovered during the measurement that if one of the modem lines of the PDIU or SCS is disconnected, the system will be much more stable. Based on the results from circuit analysis and site measurements, it can be concluded that the in-band noise in the standby modem lines are unexpectedly “decoded” by the modems and leading to data corruption. The corrupted data are transmitted to the VCC, causing frequent modem line switchover, resulting in all sort of system disruptions and stoppages.

7. REMEDIAL MEASURES

7.1 Replacement of Surge Arresters

To address the first finding, the surge arrestors have been replaced with another type rated at 350 volts. Detailed assessment has been carried out to confirm that there would be no adverse effects on the insulation co-ordination of other parts of the modern circuits.

7.2 Use of isolation transformer

To address the second finding, the electrical length of the communication links are chopped into sections using isolation transformers, the principle of which are as illustrated in figure 11.
7.3 **Use of coupling transformer**

To address the third finding, the simplest solution is to have the standby modem line “filled up” by the data signals such that there will not be random bits generated to the VCC. This purpose is achieved by having a coupling transformer connected across the modem line pairs. The final modem line circuit is indicated in Figure 12.

8. **CONCLUSIONS**

After implementing the remedial measures as described in section 7, the performance of the train signalling system in West Rail is resumed to its normal standard. In early December 2003, the acceptance criteria of trial operation were met and West Rail commenced passenger operation on 20 December 2003. Up to the present moment the average punctuality of West Rail has been consistently above 99%, which confirms that the remedial measures have successfully addressed the problems identified through the investigations. The results also confirm that through careful design copper cables can be used successfully as communication links for train signalling system in metro type 25kV railways without the need for booster transformers.

References:


[3] CCITT Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines Volume VI Danger and Disturbance


[5] CCITT Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines Volume II Calculating Induced Voltages and Currents in Practical Cases


[8] Report on West Rail Signalling System EMC issues – Parsons Brinkerhoff

[9] Study on EMI issues of the Signal Cables in West Rail – Hong Kong Polytechnic University
Figure 1 West Rail Traction Power Feeding Arrangement

Figure 2 – SELTRAC System Architecture

Figure 3 – SELTRAC Moving Block Principle
VCC

SA: denotes Surge Arrester

*1: multi-drop configuration

Figure 4 – Schematic for the communication circuits of SELTRAC

Figure 5 – Typical Voltage Signal Measured from Modern Line

Figure 6 – Frequency Spectrum of modem line signal
Figure 7 – Assumption of Traction Current Injection

Figure 8 – Assumption of Induced Current Circulation

Figure 9 – Unexpected Voltage Appear on the Dummy Modem Line
Figure 10 – PDIU Modem Line Switchover (Typical)

Figure 11 – Use of Isolation Transformer to Reduce Induced Longitudinal Voltage

Figure 12 – Interference Mechanism leading to Corruption of field Data