FAULT LOCATION ON RAILWAY POWER LINES USING TRAVELLING WAVE TRANSIENTS

Xu Bingyin Xue Yongduan Li Jing Yan Tingchun
Kehui Electric, Zibo, P R China, 255049
xuby@china.com

P F Gale
Power Instrumentation Consultant, England
philipfgale@aol.com

ABSTRACT

Fault location techniques using fault generated traveling waves has been applied to transmission lines successfully. The adaptation of traveling wave method to railway power lines is presented. A prototype traveling wave system was developed. Field test results proved the adaptation is feasible.

INTRODUCTION

Railway distribution lines provide power for the signaling systems used in train traffic control. Fast and accurate fault location is critical to ensure power supply reliability and the safe running of trains. It reduces repair time and cost of a permanent fault. Even in the case of a temporary fault that represents the majority of the faults□ accurate fault location provides valuable information to discover trouble sports that may results a permanent fault eventually. In China distribution networks in railways employ non-solidly earthed neutrals. In the absence of a more reliable fault location method (especially for single phase to ground faults) many railway authorities are obliged to use visual inspection patrols to locate faults on their power lines.

An accurate D-type fault location method based on fault generated travailing waves has been developed and is now widely used on EHV AC/DC transmission lines throughout the world. It calculates the fault distance by measuring the times of first arrival of the fault initiated surges at opposite ends of the line. The actual fault location accuracy is batter than ±500meters. In principle, the D-type traveling wave method is applicable to any kind of power line. Nevertheless the actual scheme needs to be re-evaluated when used on railway power lines as the characteristics of the fault generated traveling waves are significantly different from transmission lines. The adaptation of D-type fault location principle to railway power lines is presented in this paper. The method of detection of fault initiated surges is introduced. A prototype traveling wave fault location system was designed based on the proposed method. The field trial results proved that the proposed technique is feasible and that it provides fault location accuracy better than ±1km.

RAILWAY POWER LINES

A typical configuration of railway power lines between two supply substations is as shown in Fig.1. There are usually two power lines that are constructed alone railway. One is called automatic blocking power line (ABPL) that is dedicated for providing power for automatic blocking signaling system. Another is called continuous power line (CPL) that provides power for other railway facilities and acts as back up source for automatic blocking system□In some cases there is only one ABPL that provides power for all railway facilities including automatic blocking signaling system. Generally there are two separated busbars allocated for ABPL and CPL to ensure supply reliability in substation. They are fed by two transformers which electrically isolate the railway power network with rest of system and adjust output voltage to ensure whole line voltage is within allowable range. Normally ABPL and CPL are fed by either one of two substations with circuit breaker open at other end.

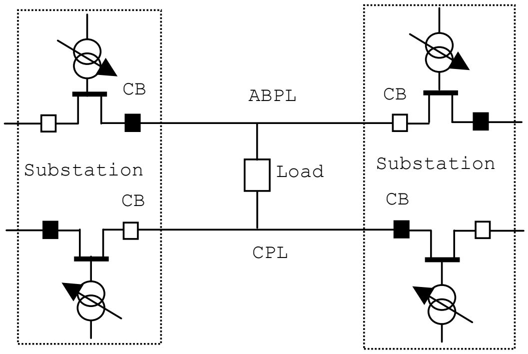


Fig.1 Configuration of railway power lines between two supply substations.

In order to ensure continuity of supply both ABPL and CPL will switch over to another substation when voltage on the line despairs. To detect " loss of voltage" a V-type transformer is installed in the line side of switchgear. The V-type transformer is connected to two pairs of phases (V_{AB},V_{CB}) as shown in Fig.2, and its outputs are three phase to phase voltages u_{AB}, u_{BC}, u_{CA}.

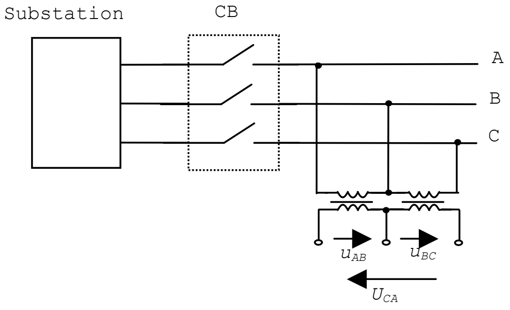


Fig.2 V-type VT installed in line side of switchgear

FAULT LOCATION METHOD BASED ON TRAVELLING WAVES

Fault location method using traveling waves has better accuracy than reactance method that has been widely used in microprocessor based relays and fault recorders. It calculates distance to fault by measuring traveling time of a surge from fault to busbar, and is free from influences of fault resistance, line structures, transducers errors, etc. In fact, traveling wave principle was first proposed in late 1950s. Several kinds of traveling wave systems classified as Types A, B,C, were developed then, but they were gradually abandoned due to their high cost, poor reliability and maintenance problems. With the progress of micro-electronic techniques, modern traveling wave fault location system has been developed. It measures fault generated current transients from conventional current transformer (TA) and makes use of very high speed (VHS) data acquisition and GPS time synchronization techniques. Hundreds of modern traveling wave fault location systems have been installed in AC and DC power system in the world. Real fault location results proved new traveling wave technique is very reliable and has accuracy better than 500 meters. The modern fault location based on traveling waves mainly operates in Type D and Type A methods discussed below.

Type-D (Double ended) method

A fault in transmission line generates voltage and current surges traveling towards two terminals, as shown in Fig.3. The time difference of first arrivals of fault surges at two terminals of the line can be used to determine the fault position. The formula for calculating distance to fault is

$$\begin{aligned} X_M &= [(T_M - T_N).v + L]/2 \\ X_N &= [(T_N - T_M).v + L]/2 \end{aligned} \qquad (1)$$

where X_M and X_N are distances to fault from terminals M and N respectively, T_M *and* T_N are times of first arrival of fault surges measured at two line terminals, v is velocity of traveling wave that is close to the speed of light for overhead lines, L is the length of the line.

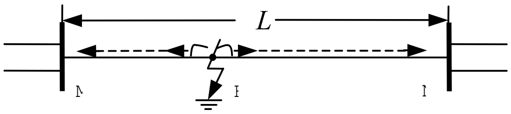


Fig. 3 Type D fault location method

Type A (Single ended) method

When the fault generated surge arrives at line terminal the first surge is detected, and a reflection is produced due to impedance discontinuity. The reflected surge then travels back to fault, and is reflected back again at fault point, as shown in Fig.3. Time difference Δt between initial fault surge and the corresponding reflected surge from fault is the time interval for a surge to travel from terminal to fault and back. It can be used to calculate distance to fault X_L:

$$X_L = \Delta t.\ v/2 \qquad (2)$$

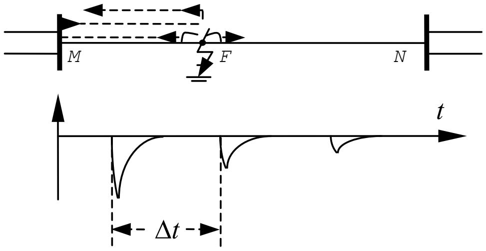


Fig.4 Type A fault location method

Type D method is simpler in principle as it makes use of only initial fault surge, and proved to be excellent in accuracy and reliability by field operation results. Its shortcoming is requiring two equipments to be installed at both ends of line. Type A is a single ended method and more cost effective, but its reliability is not very satisfactory. Reflections from other line terminals and nonlinearity of fault arc make the measured waveforms so complex that the fault reflection can not be effectively discriminated. In railway power line the transient waveform is even more complex as the results of server attenuation of zero mode waves and influences of tap transformers along the line. Moreover a railway power line usually contains several segments of underground cables. The joint between cable and overhead lines will generate significant reflections and add more complexities to transient waveforms. Therefore it very difficult to recognize the fault reflections from transient waveforms of a fault in railway power lines. The practical traveling wave method that can be applied to railway power lines is Type D.

MEASUREMENTS OF TRAVELING WAVES IN RAILWAY POWER LINES

Traveling wave systems developed early use voltage waves and need to install specially designed voltage transducers to measure traveling wave signals. Extensive simulation and test results show that current transformer (TA) can transform transient signals effectively. Nevertheless the capacitor voltage transformer (CVT) used in EHV network has a very low pass band mainly due to the shunt compensation inductor in primary circuit. Therefore modern traveling systems are generally based on the measurement of current waves using conventional TA. This new technique is more cost effective and can be easily adapted to field application.

The operation mode and installation of TVs and TAs of railway power system are different from normal EHV transmission system, and so is the method of measurement of traveling waves. In substation whose busbar railway power line is connected to both phase voltage and current waves can be measured using TVs connected to busbar and TAs installed in switchgear. The actual magnitude of voltage and current surges changes with termination impedance at the busbar that depends on number of lines connected and distributed capacitance at busbar. When no other lines are connected to busbar except the faulty line the termination impedance tends to be high and the magnitude of voltage surge will be much higher than that of current surge when fault initiated waves first arrives the busbar. Otherwise when more lines are connected to busbar the termination impedance will be smaller and the magnitude of current surge will be higher than that of voltage surge. Therefore detection of both voltage and current waves ensures sensitivity of measurement in any cases. In other end the line is open circuit. While it is obvious that the current wave can no longer be measured by TAs installed in switchgear, the voltage waves can be measured using V-type transformer. In fact the voltage waves will be doubled when arriving the open end, and the current waves is forced to zero.

From Fig.2 we know the outputs of V-type transformer are three phase to phase voltages u_{AB}, u_{BC}, u_{CA}. During a inter-phase fault it is quite obvious that all three phase to phase voltages will have significant transient changes. In case of a single phase to ground fault (SGF) there also exist significant transients in phase to phase voltages involving the faulty phase although their steady state values remain almost unchanged as results of a non-solidly earthing. This is because the distribution of high frequency transient voltage is mainly determined by line capacitance and a sudden drop of a phase voltage will subsequently result in transient changes in related phase to phase voltages. Detailed theoretical analysis and field test results proved above statements. Therefore the fault initialed surge can be detected effectively using three phase to phase outputs from V-type transformers for all kinds of fault in railway power lines.

FAULT LOCATION SYSTEM USING TYPE-D METHOD

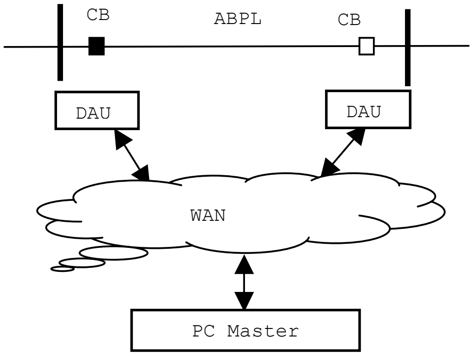


Fig .5 A traveling wave system for railway power line

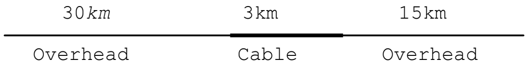
A prototype traveling wave fault location system was designed based on the proposed method. As shown in Fig.5, it consists of two transient data acquisition units (DAUs), installed at both ends of the line, with a PC based Master Station at the control centre. The Master Station collects fault data over the communication network and calculates the fault distance. The input signals to DAU are three phase voltage outputs from TV at busbar, three phase to phase voltage outputs from V-type installed in line side of switchgear and three phase current outputs from TA inside the switchgear.

FAULT DISTANCE CALUATION IN A LINE WITH CABLE SEGMENTS

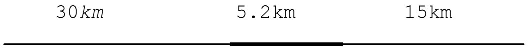
A railway power lines contains one or more segments of cable besides overhead line. The wave speed on cable is in the range of 50%-70% light speed, which is much smaller than wave speed on overhead line. Therefore Equation (1) can not be directly used to calculate fault distance in a line with cable segments. To calculate fault distance in a line with cable segments the length of every cable segment needs to be converted to virtual overhead length. Assume wave speeds on overhead line and cable are μ and λ respectively and the length of a cable segment is L_c, the virtual overhead length L_c^* of the cable segment is

$$L_c^* = L_c \frac{\mu}{\lambda} \qquad (3)$$

After every cable segment is converted to virtual overhead line in length, the power line becomes a virtual overhead line on which traveling wave has uniform propagation speed. The length L^* of virtual overhead line can be obtained by adding every length of overhead line segment and virtual overhead length of cable segment together. When a fault occurs, first the fault distance in virtual overhead line is calculated using Equation (1) . Then the faulty line segment is determined based on fault distance in virtual overhead line. The actual fault position can be located by calculating distance between fault position and the first joint in up stream in the virtual overhead line. If the fault is in a cable segment the actual fault position should be determined by the converting fault distance to joint back into actual cable length. The fault calculation method described above can be further explained using following example.



(a) A railway power line containing a cable



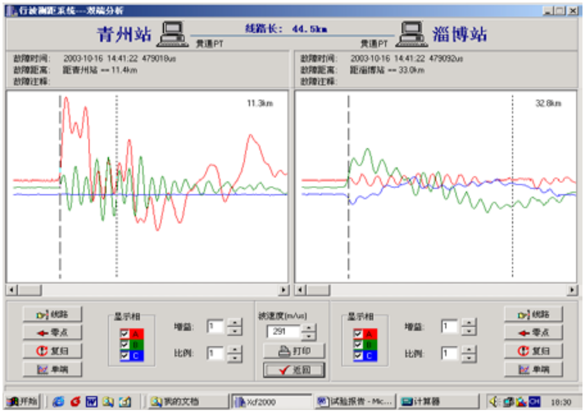
(b) A virtual overhead line

Fig.6 Calculation of fault position in a line with cable segment

A 48*km* long railway power line is shown in Fig. XX. It contains a segment of cable whose length is 3*km*, two segments of overhead lines whose lengths are 15*km* and 30*km* respectively. The wave speeds on overhead line and cable are 295*m/μs* and 170*m/us* respectively. The virtual overhead length of the cable segment is calculated as 5.2*km* according to Equation (3). The virtual overhead length of the line is 50.2 *km* as shown in Fig.xx. If the measured time difference of first arrival of fault surge is 50*μs*.The fault distance in virtual overhead line is about 32.5*km*.The fault is 2.5 *km* away from cable joint in upstream in virtual overhead line that corresponds to 1.4 *km* in actual cable length.

TEST RESULTS

The prototype traveling wave system was tested on an actual railway power network using both man-made and real faults. The field trial results proved that the proposed technique is feasible and that it provides fault location accuracy better than ±1km. Fig. XXX shows the waveforms obtained during a man-made single phase to ground fault on 16th October 2003 on the 44.5*km* long railway power line between Zibo and Qingzhou, Shandong, China. The line was connected to the busbar at Zibo substation but open at the Qingzhou end during the test. The 3 phase voltage transients at Zibo substation are shown in the lefthand window of Fig.2, with the 2 phase to phase voltage transients at Qingzhou in the righthand window. The fault location result is shown as 33 *km* away from Zibo while the actual fault distance from Zibo was about 32*km*.



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故障距离: 距青州站 --- 11.4km
故障注释:

故障时间: 2003-10-16 14:41:22 479092us
故障距离: 距淄博站 --- 33.0km
故障注释:

波速度(m/us) 291

Fig. 2 Transient voltage waveforms and fault location result of a railway power line fault

CONCLUSION

Traveling wave method that has been widely used in fault location of transmission lines can also be applied to railway power network. Voltage and current surges arriving at the source side substation are detected on the secondary side of a conventional VTs and TAs. At the remote end of the line the surges are obtained from the secondaries of the V-type transformer. The new technique provides an accurate solution to fault location problems of railway power line. It can applied to single phase to ground fault in non-solidly earthed fault, which by no means can be solved using conventional reactance method. The ts. Its appl lp to incr

Fig. 2 Transient voltage waveforms and fault location result of a railway power line fault

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REFERENCE

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