International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 1 (2016) pp 105-110

Effect of Topography at the Proximity of AC Electric Traction Line on the Earth Fault Distance Locating Algorithm.

Ravi Kumaran Nair.C.
Divisional Electrical Engineer, Electric Traction Distribution Branch,
Indian Railways, Trivandrum Division, Trivandrum, Kerala, India.
E-mail: nair.ravikumar@rediffmail.com

Dr. Devender Kumar Saini
Asst. Prof. Dept of Electrical & Electronics Engineering, College of Engineering Studies,
University of Petroleum & Energy Studies, Dehradun, India.
E-mail: dksaini@ddn.upes.ac.in

Prof. (Dr.) Jayaraju.M
(Former Director, Agency for Non-conventional Energy and Rural Technology,
Ministry of Power, Govt of Kerala), India.
E-mail: jayarajum@gmail.com

Abstract
Electrification of railways became necessary in suburban areas in 19th century itself due to worsening of air pollutions by the fossil fuel driven locomotives. Modern electric traction lines established for railways all over the world are mostly of 25 kV 50 Hz or 60 Hz systems. Railway tracks in suburban area shall generally be laid on plane surface. But in developing countries, the momentums to electrify their railway track continue at non-suburban areas also, where tracks are laid through earth cuttings, tunnels, over line structures etc. Such areas become the reasons for frequent earth faults on traction lines. Earth fault distances located by the relay system in those areas are found potentially deviated in irregular fashion from the actual. Existing models for high voltage AC traction are made with different impedances for different configuration of railway tracks; but with constant impedance angle only with the presumptions that the shunt admittance existing between earth and traction lines are not considerably high, and are uniformly distributed along its entire length. The protection schemes and fault distance locating algorithms are designed accordingly. Experimental studies conducted on a real electric traction network system of Trivandrum Division of Indian Railways and some of the experimental study results, which are beneficial to the railway traction system, are summarized in this paper.

Keywords: AC electric traction, Constant impedance angle, Earth cuttings, Over Head Equipment (OHE), Shunt admittance, Tunnels.

Introduction
Traction Electrification System provides electrical power to the trains by means of the traction power supply system, traction power distribution system, and traction power return system. Traction Power Supply System includes Traction Sub Stations (TSS) located along the railway track at theoretically equal distance. This distance may vary slightly with some other factors, like availability of grid sub station nearby the proposed TSS, availability of suitable land to build up the TSS etc.. Traction Power Distribution System, also called as Over Head Equipments (OHE), is fed at single end consists of the catenary system, along track feeder system, intermediate auxiliary transformer stations (ATSs) and end-of-feeding Sectioning Post (SP). The length of the OHE fed with electric supply through a circuit breaker shall normally be 35 to 40 km. The working voltage shall be below 28 kV. Traction Power Return System comprised of the running rails, impedance bonds, cross bonds, and the ground (earth) itself.

Even though the physical appearance of high voltage AC power line of railway traction has no similarity with the short length AC power transmission line, its modelling is done at par with the short length AC power transmission line.

Literatures [1][3][5][7][10][12][13] on power lines characteristics indicate that the model for short length power transmission lines (of length 80 km or lesser, and with voltage 66 kV or below) comprise an inductive reactance in series with line resistance per unit length as shown in Fig.1. Effect of shunt admittance exiting between power line and earth is conveniently neglected due to reason that the height of lowest live conductor itself is strung at considerably high altitude, which practically eliminates the effect of shunt admittance. Also, the presence of earth or earthed structures at the proximity shall not be there for a longer stretch.

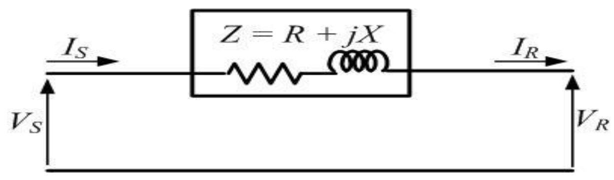

Figure 1: Generalized model of short AC power transmission line

But, the generalized model (Fig.1) can't be fit as it is on AC power high voltage traction lines for developing the algorithm for protection scheme, even when the working voltage and the length of traction line is far below the standard stipulated for short transmission line. Electric traction lines have some unique features, like, its altitude is as low as 4.58 M from the ground (rail level), and slope profiling (earth cuttings made through hillocks to lay railway tracks, with vertical height maximum 18 M) may be available within 3 to 4 M radial distances for a longer stretch. The presences of tunnels further reduce the clearance between traction conductors and earth to 0.25 M, that too, for very lengthy stretches in hilly terrain. Fig. 2 is the generalized model of an AC traction system.

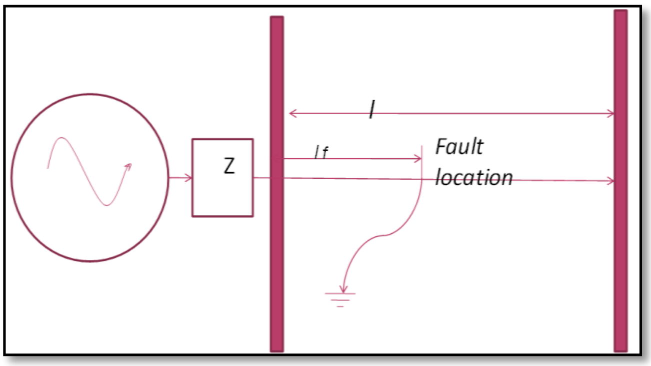

Figure 2: The generalized AC power electric traction network system, under earth fault condition

In Fig. 2, Z is the impedance of the traction power source, **l** is the length of the traction system, and $\mathbf{l_f}$ is the distance of fault from the TSS. Here, the traction line parameters are assumed to be uniformly distributed [9], where the per unit length resistance, inductance, and capacitance are R_0, L_0, C_0 respectively. Where R_0 is 0.1 to 0.3Ω/km, L_0 is 1.4 to 2.4 mH/km and, C_0 is 10 to 14 nF/km [8]

The prevailing algorithms [9][11][14] for measuring the fault distance by the Distance Protection Relay (DPR) in electric traction were made based on the loop impedance or reactance under different fault type condition of OHE. The assumption is made that the impedance angle of OHE is constant, and the impedance of the line is uniformly distributed [11]. The impedances of traction line for different layouts of railway tracks [4] are given in Table.1

Table 1: Impedances of traction line for different layouts of railway tracks

Sl. No.	**Layout of track & OHE**	**Impedance / kilo meter**
1	Single line track OHE with return conductor	$0.70 \angle 70^0\,\Omega$
2	Single line track OHE without return conductor	$0.41 \angle 70^0\,\Omega$
3	Double line track OHE with return conductor	$0.43 \angle 70^0\,\Omega$
4	Double line track OHE without return conductor	$0.24 \angle 70^0\,\Omega$

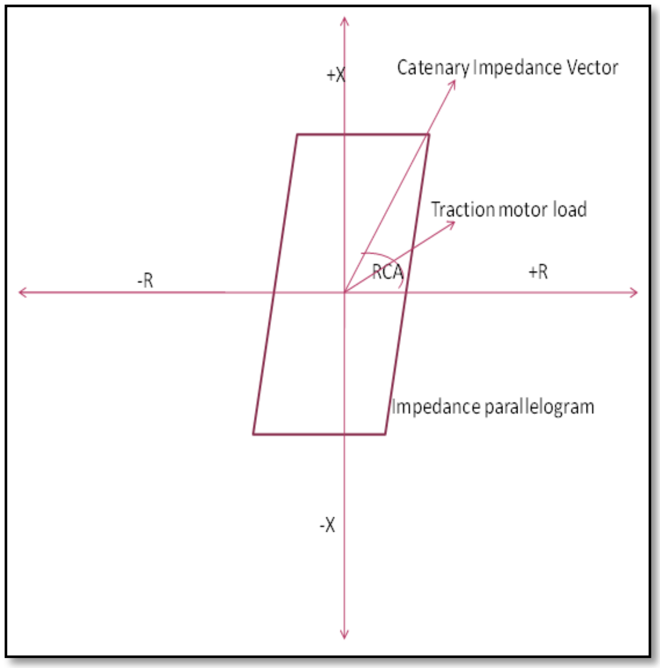

Figure 3: Impedance parallelogram of Distance Protection Relay

Fig.3. shows how the resistive reach settings are arrived. The magnitude of the impedance of traction line is calculated using general expression, Z = V/I , where V is the system voltage, and I is the fault current occurred with zero impedance load.

The Relay Characteristic Angle (RCA) plays the crucial role in differentiating a fault current, and the load current contributed by the electric locomotives.

The angle of load current of the locomotive shall be around 40^0, whereas the angle of earth fault current is taken as 70^0 for all fault distance calculation [4]. The RCA is so determined that the relay does not act at the higher traction load current contributed by the electric locomotives, and it acts when earth fault current occurs even at lesser magnitude. The angle of the earth faults current, which is determined by the angle of loop impedance of OHE, if varies; the magnitude of minimum current required to actuate the DPR shall also vary. Distance between dead earth fault and the source of supply is being determined by the magnitude of the fault current, which is directly related to the loop impedance of OHE.

Table.2 is the records [15] kept at Traction Power Control Room of Indian Railways at Trivandrum Division on naturally occurred incidents of earth fault on OHE. It can be noted from Table-2 that the DPR indicates fault distances differently for different terrain for the similar distance of fault location from the TSS. The variation from the actual was observed to be more or less linear with progressing offset value (span error) where tracks are laid on plane areas. The least variations, but in highly irregular manner, was observed at the sections where railway tracks are laid at terrain where steep slope profiling and tunnels are present at the proximity of OHE.

Figure 4: OHE at plane ground

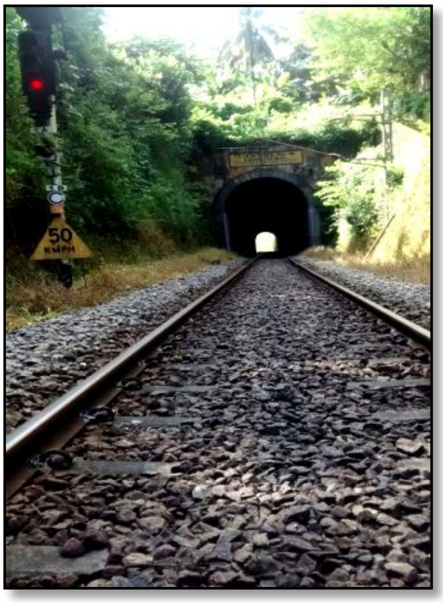

Figure 5: OHE at Tunnel

Figure 6: OHE at steep slope profile

Table 2: Actual Earth fault distance and distance indicated by DPR in kilo meter, for two different terrains

Railway track laid on plane ground		**Railway track laid on area where steep earth profiling are available**	
Actual Fault distance, in km	**Fault distance indicated by DPR**	**Actual Fault distance, in km**	**Fault distance indicated by DPR**
5	7	7	7
7	9	8	8
9	11	9	10
17	19	20	21
29	32	32	32

Prolonged power supply interruption on electric traction system even at a smaller stretch of railway section will disrupt the train services badly in a wide rail network. Hence, it is accounted to be disastrous. Some persisting earth fault like, flashover of insulators happened with the electrocution of snake like reptiles, could not be detected from the ground. In the event of such faults on OHE, the technical staffs looking after the maintenance of OHE have to move immediately to the fault location(s) and to clear them off for the re-energization of OHE to resume normal train traffic. For which, the exact location where the earth fault persist is essentially to be informed to the maintenance staffs. In practice, the prevailing algorithms are found inadequate in precisely indicating the fault distance.

Experimental studies

Experimental studies were conducted at two distinct sections of railway traction lines by creating earth faults on OHE with practically zero impedance load (short circuit test) using discharge rod at ten different feasible locations. Six locations were at the section between Eraniel and Thovala railway stations in Tamilnadu state of India where tracks are laid on level ground (Fig.4), and four at the section between Eraniel and Balaramapuram railway stations where railway tracks are laid through steep earth cuttings & tunnels (Fig. 5 & 6) at the valley of Western Ghats in India. Geographical maps of experiment zone are shown as Fig. 8 & 9. Even when the authority is vested with the first author to conduct short circuit tests on OHE for assessing the healthiness of the protection systems, the opportunities to conduct experiments in controlled ambience duly satisfying many test conditions like, (i) to ensure no rolling stocks or trains shall be present in the entire length of experiment zone (ie, from the supply point to the farthest end of OHE), (ii) to conduct experiment only on non-rainy day, (iii) to get other power lines switched off, which run in parallel and across at the vicinity of OHE etc. was very rare. All the ten controlled experiments were conducted in between 2nd October 2014 and 12th October 2015. The sequence of experimentation was, (i) bottom clamp of discharge rod was rigidly connected to the rail, which is earthed through many earth pit electrodes, (ii) the OHE supply was switched off, (iii) spring loaded top end hook of the discharge rod was rigidly clipped on OHE, and (iv) the OHE supply was switched on for observing the supply trip and fault distance indicated by the DPR. The earth fault distances indicated by the DPR on plane ground are shown in Table.3 and on terrain with earth cuttings & tunnels are shown in Table. 3 A

Table 3: Fault distance indicated by DPR in experimental studies on plane ground

Distance of fault indicated by DPR for the OHE at plane ground (with some minor earth cuttings of short length on en-route), fig. 4		
Experiment Date	**Fault created distance, in KM**	**Fault distance shown by DPR in KM**
02/10/2014	35	40
29/10/2014	20	23
06/02/2015	14	16
26/03/2015	20	23
02/07/2015	19	22
12/10/2015	9	10

Table 3A: Fault distance indicated by DPR in experimental studies at cuttings & tunnels

Distance of fault indicated by DPR for the OHE at terrain where deep & long earth cuttings & tunnels are available on en-route, fig.5 & 6		
Experiment date	**Fault created distance, in KM**	**Fault distance shown by DPR, in KM**
14/06/2015	34	33
27/06/2015	16	18
30/06/2015	37	37
25/08/2015	19	19

Table 4: Nature of topography of the section between Eraniel and Thovala railway stations

Distance from TSS	Nature of terrain through railway track is laid
0 to 05 KM	Plane ground
05 to 10 KM	Slope profiling of length 320 mtrs and peak altitude 4 mtrs at 8^{th} km from TSS
10 to 15 KM	Plane ground
15 to 20 KM	Plane ground
20 to 25 KM	Plane ground
25 to 30 KM	Plane ground
30 to 35 KM	Plane ground

Table 5: Nature of topography of the section between Ernaiel and Balaramapuram railway stations,

Distance from TSS	Nature of terrain through railway track is laid
0 to 05 KM	Plane ground
05 to 10 KM	Plane ground and minor slope profile, one tunnel of 80 mtrs length at 9^{th} km
10 to 15 KM	Plane ground and ten gradual slope profile of altitude max 3 mtrs, and of short lengths
15 to 20 KM	Fifteen minor slope profiles with altitude less than 3 mtrs, short length, Five steep slope profile of altitudes 6, 8, 8, 9 & 13 mtrs, of lengths 250, 350, 450, 900 and 450 mtrs respectively, and two tunnels of length 130 mtrs and 40 mtrs are available in this stretch.
20 to 25 KM	Eight minor slope profiles with altitude less than 3 mtrs , short length, Four steep slope profile of altitudes 22,11,14 & 6 mtrs, of lengths 600, 300,750 and 550 mtrs respectively, and one tunnel of length 201 mtrs are available in this stretch.
25 to 30 KM	Six minor slope profiles with altitude less than 3 mtrs, short length, six steep slope profile of altitudes 11,7,6,10,8 & 5 mtrs of lengths 500, 200, 350, 300, 360 & 350 mtrs respectively are available in this stretch.
30 to 37 KM	five minor slope profiles with altitude less than 3 mtrs, short length, six steep slope profile of altitudes 8, 6, 5, 6, 5 & 7 mtrs of lengths 250, 60, 210, 400, 350 & 400 mtrs respectively are available in this stretch.

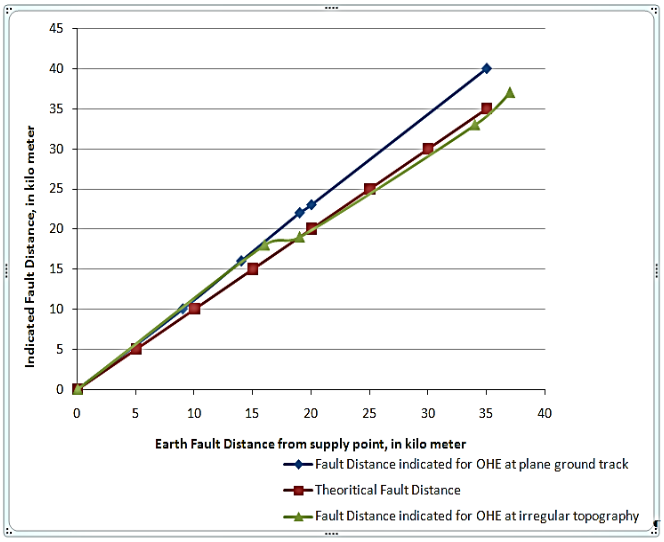

Figure 7: Plots on fault distances indicated by DPR for plane area, irregular terrain, and ideal situation

Result and Analysis

Earth fault distances indicated by DPR for the two distinct terrains and the theoretical curve are plotted as Fig. 7.

The graph plotted on the earth fault distance indicated by the DPR for the OHE at plane area (Fig.4) is more or less linear, and show a span error over and above the actual. The span error is attributed with the incorrect calculation of the shunt admittance present in between the entire length of OHE and the ground. The shunt admittance so calculated is found to be higher than the actual. The theoretical value of shunt admittance is derived from the average height of OHE from the ground, which is lesser than the actual height of OHE at that experimental area.

The graph plotted on the earth fault distance indicated by the DPR for the OHE at terrain where steep earth cuttings and tunnels are present (Fig.5 & 6) is almost linear with positive span error from the actual at its initial 15 KM long stretch due to the reason that topography at those stretch is generally plane ground with some minor gradual slope profiling of short lengths and a short length tunnel. A sudden shift towards the theoretical value is observed at 15 KM to 19 KM, due to the reason that many steep earth cuttings with high altitude & length, and two lengthy tunnels are available in this stretch. Besides, the height of the OHE is very close to its minimum permitted value due the constraints experienced in the tunnels and over head bridges to maintain more clearances. In the remaining stretches upto 37 KM, combinations of plane grounds, few minor slope profiles, large number of steep slope profiles, and one tunnel of length 201 M are available enroute (Table-5).

From the Tables 4 & 5, and from Fig. 7, it can be understood that the significant variations in the fault distances indicated by the DPR from the actual are attributed by the dynamic nature of the shunt admittance existing between the earth/earthed structure and the OHE. But, the prevailing algorithms [9][11][14] use the optimized value of shunt admittance for the fault distance calculation for all the terrains. Chances of significant variations in it due to the variations in topographical features, and variations in the clearance of OHE from ground are yet to be addressed rigorously.

From the above analysis, it is apparent that the slope profiles of earth cuttings, clearance of tunnels & over line structures in the proximity of OHE, variations in height of OHE etc. influence its shunt admittance significantly, and cause the variations in earth fault distances indicated by the DPR.

Conclusion

Each erratic data originated by the Distance Protection Relay on the distance of persisting earth fault on traction power systems cause serious delay in detecting them, which in turn adversely affect the electric traction systems' reliability to a large extent. Monitory loss due to prolonged disruption of train traffic shall also be too high. Hence, locating the exact position of earth fault on railway electric traction lines is a must, for which, foolproof algorithms are to be developed duly formulating the variations of parameters of traction lines contributed by the various topographical features. The relation of shunt admittance of OHE with the surrounding earth & earthed structures for various physical conditions like, size, clearances from OHE, angle of slope, alignment of track etc. are to be formulated to modify the railway traction system more realistic.

Geographical maps of the experimental zone

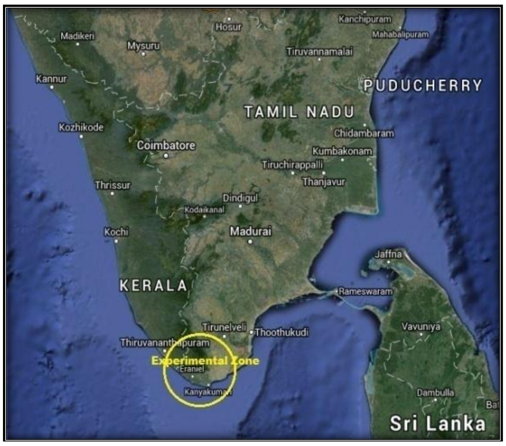

Figure 8: Map of South India

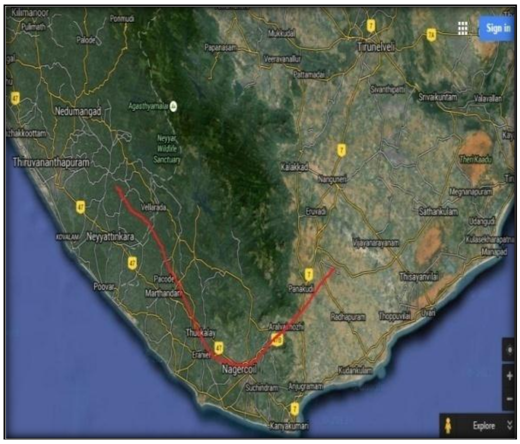

Figure 9: Railway traction line indicated in red

References

[1] M.V.Deshpande, "Electrical Power System Design", Tata McGraw Hill, New Delhi. 1984

[2] Gonen. T, "Electric Power Transmission System Engineering, Analysis and Design", John Wiley & Sons, New York. 1988

[3] "Modern Power Station Practice, EHV Transmission", Pergamon Press: Oxford, UK, Chap. 9. 1991 "AC Traction Manual for Indian Railways", vol.II, Part-II., pp 101, 1993

[4] "Flexible AC Transmission Systems (FACTS)", IEE Power series, no. 30, UK, 1999

[5] A.R.Bergan and V.Vittal, "Power System Analysis", Pearson Education Asia, New Delhi, 2001,

[6] Glover. J.D., and Sarma. M.S, "Power System Analysis and Design", Thomson Asia Pvt. Ltd. Bangalore, 2003

[7] Mariscotti.A. , Pozzobon.P, “Synthesis of line impedance expressions for Railway traction system”, IEEE Trnas. Vehicular Technol. Vol 52, pp 420 – 430, 2003

[8] Cheng.W., Xu.G., and Mu.L, “A novel fault location algorithm for traction network based on distributed parameter line model”, Proceedings. CSU – EPSA, Vol 17, pp 66-63, 2005

[9] William.H.Kerstring, “Distribution System Modeling and Analysis”, CRC Press, USA, 2006

[10] Lin.X., Weng.H., and Wang.B.A., ,“A generalized method to improve the location accuracy of the single- ended sampled data and lumped parameter model based fault locators”, Electrical Power Energy System, vol 31, pp 201-205, 2009

[11] Kothari.D.P., and Nagrath. I.J,“Power System Engineering”, Tata McGraw-Hill Publishing Company limited, New Delhi, India, Chap. 5, 2011

[12] Singh.S.N,“Electric Power Generation, Transmission and Distribution”, PHI Learning Pvt. Ltd,, New Delhi, India, Chap. 11, 2011

[13] Yimin Zhou., Guoquing Xu., Yanfeng Chen, “Fault Location in Power Electrical Traction Line System”, Energies Journal, pp.5004, 5005, Nov.2012

[14] “Log of Events on Earth faults”, Traction Power Control room, Indian Railways, Trivandrum Division, 2013-14 and 2014-2015