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Reversed Diode Earthing Scheme in DC Traction Power System

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Abstract- **Reducing rail voltage and stray current corrosion all at once is one of the challenging problems in DC electrified rail transit systems. Stray current is the main reason of corrosion in the metallic parts located in the proximity of the railway. Choosing appropriate earthing scheme is an effective way to decrease corrosion intensity and providing safety for personnel. This paper discusses a possible alternative earthing scheme for Tehran Metro Line 3. A new earthing scheme entitled Reversed Diode Earthed scheme is presented and compared with floating and diode earthed earthing schemes. A comparative simulation of the rail voltage and stray current corrosion level for the proposed scheme is presented. The results stipulate the excellence of the proposed method over the prevalent schemes.**

***Index Terms* - DC electrified railways, earthing scheme, stray current corrosion.**

I. INTRODUCTION

Historically due to economic problem running rails are being used as the return path for DC electrification systems. The voltage drop resulted from utilizing running rails as return path originates stray current problem. Stray current produced by the DC transit system plays an important role in corrosion of rails and buried metallic structures located in the proximity of the rails. It is proven that various schemes of earthing can change rail voltage and stray current quantity. Solidly earthed scheme, diode earthed scheme and floating scheme are different schemes [1] employed in earthing of traction substations.

The main goal of an earthing system is to provide means to ensure the permanence of the power supply and to guarantee that a person in the closeness of the earthed installation is not exposed to a critical electrical shock. Thus, the electrical resistance of an earthing system must be low enough to ensure that fault currents disperse mainly through the earthing electrode into the earth.

Solidly earthed scheme is the first utilized earthing scheme in subway systems and provide a direct connection between negative busbar and earth in substation. Despite low rail voltage produced by this scheme, utilizing solidly earthed scheme causes great corrosion damage in metallic structures [2]. Hence solidly earthed scheme is obsolete and not recommended in subway systems.

Later diode earthed scheme was appeared. There are numerous examples like [3-5] adopting diode earthed scheme. Because the diode provides a path for stray current, the magnitude of stray current can be easily and conveniently monitored and positive-pole earth faults can be inspected [6]. As a matter of fact in diode earthed schemes safety not only could not be provided the same as the solidly earthed schemes, but also it produces high level of corrosion damage around the rails. Low resistance path introduced by diode for the sake of faster fault clearing allows high amount of system leakage current to return to the substations thus intensifies stray current corrosion.

Nowadays most modern DC transit systems employ floating (unearthed) scheme. It has been proven that floating scheme has minimum corrosion damage among various earthing schemes [7]. Although it lowers rail voltage in proportion with diode earthed scheme, but safety especially in abnormal conditions is a disadvantage of the floating scheme. Generally unearthed scheme with protective devices seems to be a best choice among all.

This paper discusses a possible alternative earthing scheme for Tehran Metro Line 3. A new earthing scheme entitled Reversed Diode Earthed scheme is presented and compared with previous earthing schemes.

Appling a simplified model of DC electrified traction system different earthing schemes including floating, diode earthed and reversed diode earthed schemes has been simulated in this paper. Comparison of the rail voltage and stray current corrosion level for the mentioned schemes is presented. Finally using simulation studies it is argued that reverse diode scheme can improve both conflicting safety and stray current corrosion indices.

II. REVERSED DIODE SCHEME MODELLING

A. *Reversed diode scheme*

Reversed diode is a diode earthed scheme with a diode placed in a reversed direction as shown in Fig. 1. Reversing diode blocks the path for the most hazardous part of corrosive charge flowing from buried metallic structures into the negative pole of DC supply system. Thereby lowers the corrosion damage effectively. At the same time, high rail voltages produced due to the accelerative movements of trains is diminished in new scheme. Considering “Time of Violation” clarifies this matter in next part of this paper.

In normal diode earthed system the diode provides a low resistance return path for short circuit faults between live parts in the substation, and the earth bar [8]. Reversing direction of diode blocks this path. So as a view of protection issue against earth faults, there is no difference between floating and reversed diode earthed scheme and protective characteristics of these two schemes are similar.

B. Simulation Description

For a homogeneous rail to earth resistance, distributed line model can be used for simulation of running rails. Fig. 1 shows stray current model used for simulation. In this model R_{NG} is the earth resistance in substations and has been taken as 0.1 ohm. As shown in Fig. 1 in each section between the train and an adjacent station the current and rail voltage profile can be obtained from [9]:

$$i(x) = c_1 e^{\gamma x} + c_2 e^{-\gamma x} \tag{1}$$

$$v(x) = -R_0 (c_1 e^{\gamma x} + c_2 e^{-\gamma x}) \tag{2}$$

Where, c_x is the constant which is determined by boundary conditions. R_0 and γ are respectively characteristic impedance and propagation constant of the rail.

The movement of trains on the Tehran Metro Line 3 is simulated by multi-train simulator (MTS) software. The MTS software includes a train performance simulator, which simulates speed, distance and power against time for a single train, and an electric network simulator, which simulates the power flow in the traction system while all trains are running. The multi-train network simulation includes the information on voltage, current and power of each traction substation (TSS), as well as voltage, current and power of each train on the rails.

For simulating trains movement for Tehran Metro Line 3 by means of multi-train simulation software tool, the rail resistance has been taken as 0.047 Ω/km for one rail and the total trackbed to earth resistance has been taken as 0.01 S/km for uphill and downhill tracks. Crossbonding between running rails serves to equalize the traction return current, reduces individual running rail voltage and therefore reduces stray leakage currents. Crossbonding should be duplicated and installed at frequent intervals (typically 200 to 500 meters). So we can assume that rails make parallel electrical circuits. On the basis of this assumption equivalent rail resistance is 0.012. The value of contact rail resistance Rc is taken 0.07 Ω/km. This model assumes that the resistance of the contact rail to earth is very high and there is no coupling between the positive circuit and earth.

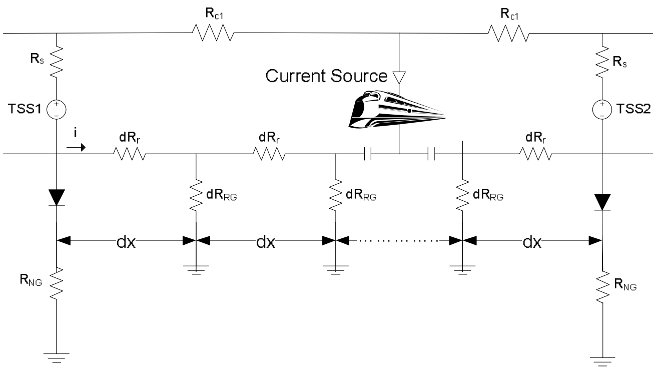

Fig. 1 Reversed diode earthing diagram

Because MTS software does not have any simulation program to analyze stray current, the results of simulation from MTS software is more processed using codes written in MATLAB environment. The Current drawn from contact rail versus train position is simulated by MTS and plotted in Fig. 2 which illustrates different modes of the train movement. In acceleration and deceleration modes, high values of current flow through the rail. The train consumes power in acceleration mode while regenerates power in deceleration mode. In deceleration mode, dynamic brakes are applied up to their limit and then the mechanical brakes are used if necessary. During dynamic braking, the traction motors run as generators and feed energy back to the power supply system. This energy is damped in on-board brake resistors or consumed by another train. In constant state, the train is moving at 80 km/h. The consumed current is for overcoming the air and rails friction and also AC electric system losses. In this mode the current is rather low and close to 800A.

III. SIMULATION RESULTS

A. Running rails voltage

Employing diodes in earthing scheme, depending on the polarity, raises or lowers the rail voltage. Diodes behave as an open circuit while their voltage is below the threshold level.

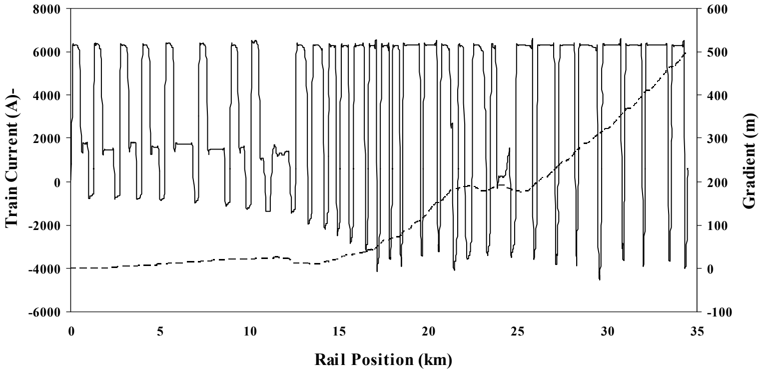

Fig. 2 Current drawn from contact rail when a train is moving on the track

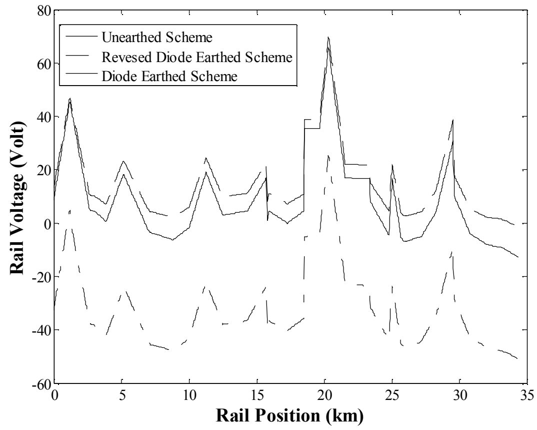

Fig. 3 Reduction of rail voltage in reversed diode earthed scheme

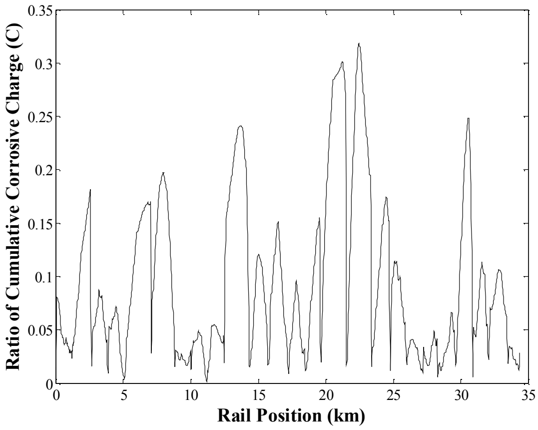

Fig. 4 Ratio of stray charge for reversed diode earthed over floating scheme during train moving between stations

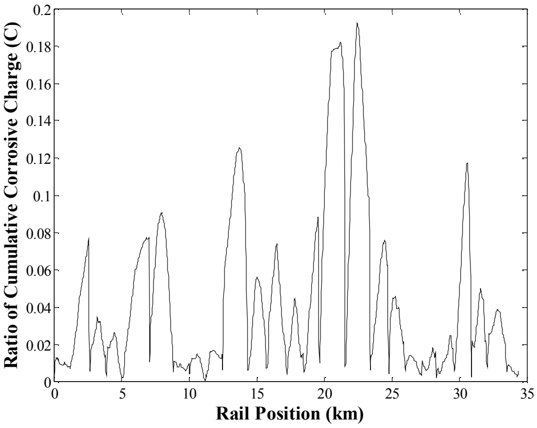

Fig. 5 Ratio of stray charge for reversed diode earthed over diode earthed scheme during train moving between stations

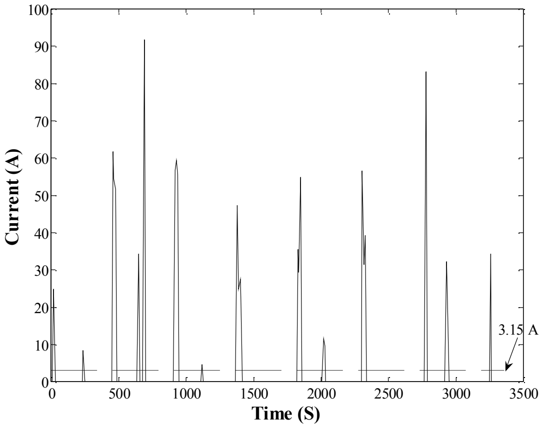

Fig. 6 Flowing current from earth to negative in diode earthed system

Upon diodes are forward biased, they start to conduct with a small forward voltage across them. When installed diodes on earth conductor are forward biased, rail voltage will change to be near zero at substations. Turning on the diodes, raises the rail potential at substation for normal diode direction scheme. In the case of using reversed diode direction scheme, switching on causes positive voltages to fall near zero. Owing to exponential relation for different points of rail voltage in equation (2), the rail potential in other parts of the path will change correspondingly. Thus it can be said, diode acts like a shifter. A comparison of rail voltage among earthing schemes for a sample instance of time is presented in fig. 3. This figure clarifies diode performance in earthing schemes. Employing diode earthed scheme increases rail voltage and adopting reversed diode earthing scheme decreases rail voltage.

Since intensity and duration of accelerative movements is more than decelerating mode, high positive voltages occur more often. Hence, decreasing rail voltage by utilizing reversed diode diminishes occurrences of dangerous voltages along the rail.

B. Corrosion problem in DC traction systems

Stray current deviates from its intended path to a parallel and alternative low resistance route, such as metallic structures buried in the soil. Underground pipelines can pick up current strayed from a railway system at some point remote from the traction substation and discharge the current to the soil and then back to rails near to the substation. In electric railway systems stray currents are random, dynamic and bipolar in character [10]. Flow direction depends on the instantaneous parameters of stray current sources, including the actual momentary load of the electric traction. Corrosion hazards exist in the areas where current leaves the metallic structure. The distance between anodic and cathodic zones can be as short as few meters or as long as several kilometers depending on the source type and metallic structure position [11].

Corrosion level is another criterion to investigate an earthing strategy. All metallic structures including railway's facilities and other metallic structures located around the rails can be corroded [12].

Positive rail voltage causes current leaks off the rail and trackbed to the earth. This leaving current redound to trackbed and at-grades metallic structures corrosion. On the other hand, negative rail voltage draws current from earth toward rails. This type of leaking current may corrode any buried metallic structures located in the vicinity of railway.

However, if the current collection mat is utilized the corrosion problem in buried metallic infrastructure will not serious except traction substations and depots and places where a low resistance connection links earth and negative [7, 13]. Therefore, due to creation of low resistance path against stray current via diodes (when they turn on) in earthing systems, the behavior of stray current corrosion varies near the traction substations. Presence of a low resistance path, make corrosive leakage about more than one thousand times greater in the immediacy of traction substation rather than other places of the track [7]. Due to intensity of current transferring off the metallic structures close to substations, corrosion damage is more common in these places rather than other sites of the rail. Then for investigating corrosion damage, it is more important to compare various schemes as this point of view.

Figs. 4 and 5 show the ratio of the accumulative positive corrosive charge [14, 15] (charges leak off the trackbed) for reversed diode scheme respectively over floating and diode earthed schemes. The positive corrosive charge is proportionate to inflicted corrosion damage on trackbed and at-grades metallic facilities. The average ratios of 0.12 and 0.05 clarify the performance of the proposed method over two typical methods. It means total expected corrosion damage in mentioned area is 0.012 and 0.05 lesser than two other schemes on the whole line.

Fig. 6 shows large amount of returning stray current to the negative pole via diodes when they switched on. Dashed line shows average corrosive current equals 3.15 ampere flowing from earth to negative during multi train operation simulation in subway system. It corresponds with 10600 coulombs corrosive charge. Such a great volume of stray charges leaving infrastructures intensifies the corrosion damage around substations. Utilizing reversed diode not only reduces rail voltage, but also blocks this path and inhibits the occurrence of corrosion in embedded infrastructures. However, because unearthed schemes have no such connection, no similar corrosion treats exist.

Table. 1. Safety and corrosion damage to infrastructures of reversed diode earthed scheme

	Safety (rail voltage)	**Corrosion Damage**
Reversed diode earthed	**0.11**	**1**
Floating	**1**	**1**
Diode earthed	**1.65**	**>1000**

C. *Comparison and evaluation*

Safety (produced rail voltage) and corrosion damage to infrastructures of reversed diode earthed scheme are compared with two other typical earthing schemes in table 1. Normalized values of the "time of violation" are used for safety evaluation. Time of violation is the duration of time when standard value [16, 17] for rail voltage (120 V) is trespassed. According to table 1 duration of dangerous rail voltage presence is about ten times lesser for proposed scheme in comparison with floating earthed scheme. This ratio is bigger regarding diode earthed scheme.

Earthing schemes are compared as a view of creating corrosion damage in second column. Normalized corrosion damage states the total expected corrosion damage in the case of utilizing earthing schemes in relation with floating scheme. As mentioned the major factor for corrosion is the low resistance path between earth and negative. Because there is no such a path in floating and reversed diode schemes, their expected corrosion damage is approximately equal and far below the diode earthed scheme. The results stipulate the privilege of the proposed method over the prevalent schemes.

IV. CONCLUSION

Safety and corrosion are two contradict factors in DC traction system earthing. Several measures are proposed in literature and industry to decrease the harmful effects of rail voltage and stray current corrosion. Choosing appropriate earthing scheme is an important way to attain this goal. The authors tried to introduce a new earthing scheme on the basis of improvement mentioned factors.

Due to introducing short resistance by activated diodes and thyristors and also in solidly earthed scheme, major part of corrosive current leaves the third party structures at the proximity of the traction substations. This current, flows through the low earthing resistance then enter negative pole of power supply system. Due to high values of this returning current, corrosion damage is more intense near to traction substations, rather than other places of the track.

Reversed diode is similar to diode earthed scheme but the diode is placed in a reversed direction. Reversing diode blocks the path for the most hazardous part of corrosive charge flowing from buried metallic structures into the negative pole of DC supply system. Thereby lower the corrosion damage effectively. At the same time, produced high rail voltages due to the accelerative movements of trains are diminished in new scheme. Considering “Time of Violation” clarified this matter from the safety point of view.

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