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Distance Protection Settings in Electrical Railway Systems with Positive and Negative Feeder

M. R. Ganjavi, R. Krebs
SIEMENS AG, PTD SE PT5
P.O.Box: 3220, D-91050 Erlangen
Germany

Habil. Z. Styczynski
OTTO-VON-GUERICKE-UNIVERSITY MAGDEBURG
Faculty of Electrical & Information Technology
Universitätsplatz 2, D-39106 Magdeburg
Germany

Abstract: **-** Electric railway systems have complex configurations of overhead lines, protected by distance relays. The protection philosophy for this system considers low cost maintenance, control and protection in autotransformer stations and advanced control and protection in supply stations.
The paper discusses some heuristic rules for settings of distance relays in railway systems with positive and negative feeder configurations. The experience is formulated as a set of rules (if condition then effect) and stored in an expert system for fast access.

Key-Words: **-** Expert System, Traction Supply, Catenary Protection

1 Introduction

Negative and positive feeder arrangement is an overhead contact line system [2] for energizing trains with AC voltage (see Fig. 1). In this system, there are two traction supply station at the beginning and end of each track and there are several autotransformer stations between supply stations. There are two or more main railway tracks between supply stations and sometimes there are local tracks at each autotransformer station. Supply stations provide single-phase a.c. medium voltage to positive and negative feeders with 180 degree phase difference. At each autotransformer station all positive feeders, all negative feeders and all railway tracks are connected to an autotransformer via positive busbar, negative busbar and earth busbar respectively. In addition positive feeders are designed to provide enough energy to trains but negative feeders are designed to compensate voltage drop of positive feeder via autotransformer stations. Therefore, the current flows in positive and negative feeders are not balanced during and after acceleration of trains.
As mentioned, in this system three sets of conductors per railway track exist.

Positive Feeder: The positive feeder is the total interconnected system consists of contact or catenary wire and mechanical tension wires. Ii is directly feeding the train via the contacted pantographs. It operates with a voltage **Vs** for example 25kV and 50Hz.

Negative Feeder: The negative feeder operates with voltage **-Vs** via the autotransformers according to the Fig. 1. Most of the current feeding the train will return to the supply station by the negative feeder and not by the tracks.

Return Circuit: The return circuit is the total interconnected system consists of the track, earth-system conductor, earth grid and earth itself.

2 Electric Railway System Protection

The electric railway system consists of positive, negative and return circuit will be protected by distance relays in supply stations.
The trip command is connected to the double phase circuit breaker, which disconnects both of the positive and negative feeders.
The measuring quantities for the distance protection relays installed in each supply station are as follows:

a) Voltage: positive busbar voltage according to the Fig. 1.
b) Current: Sum of the positive and negative feeder currents. The measured current will be summed by secondary connection of the corresponding current transformers. The relay current is as follows:

$$I_{relay} = I_{pos} + I_{neg} \quad \text{(Eq. 1)}$$

An example for an electric railway system with two main tracks (Track 1 and Track 2) and two side tracks

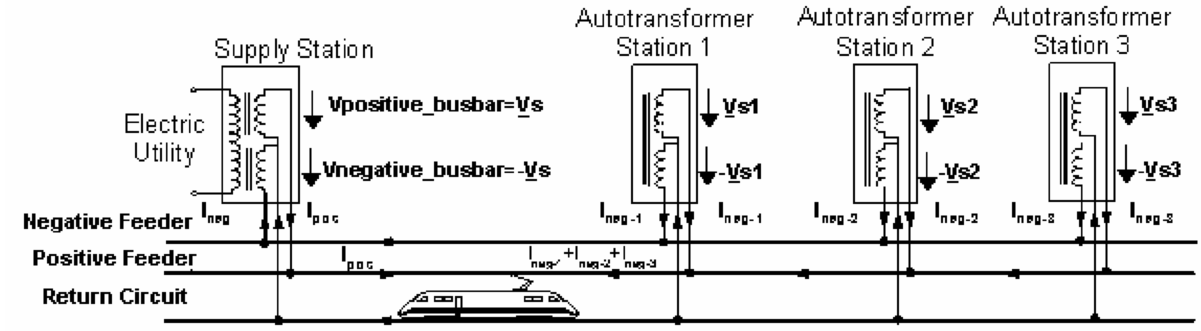

Fig. 1. Simplified Overhead Contact Line system with negative feeder arrangement

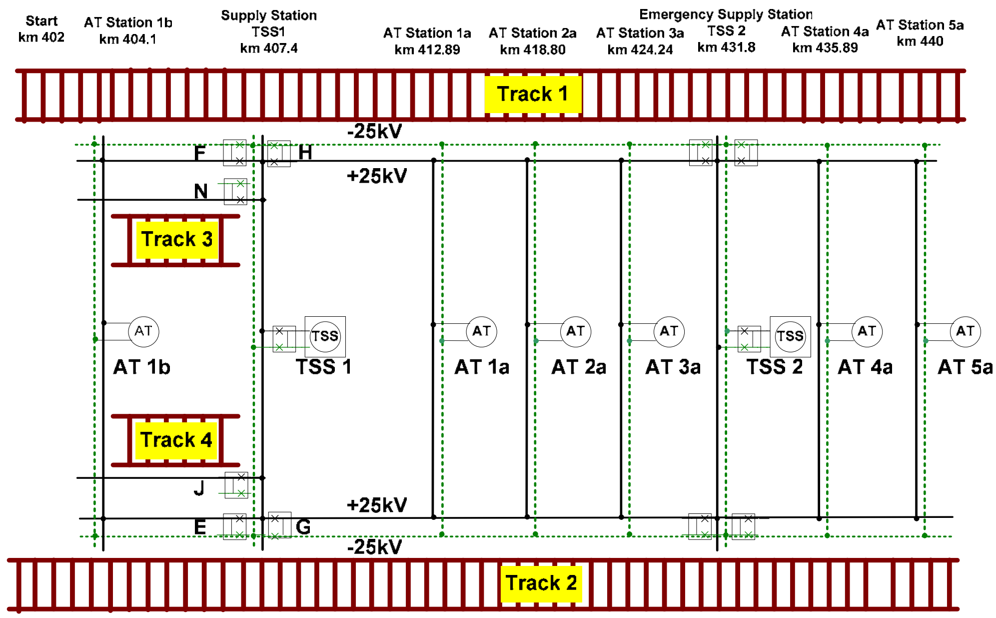

Fig. 2. Two traction supply stations and six autotransformer stations for energizing two railway tracks

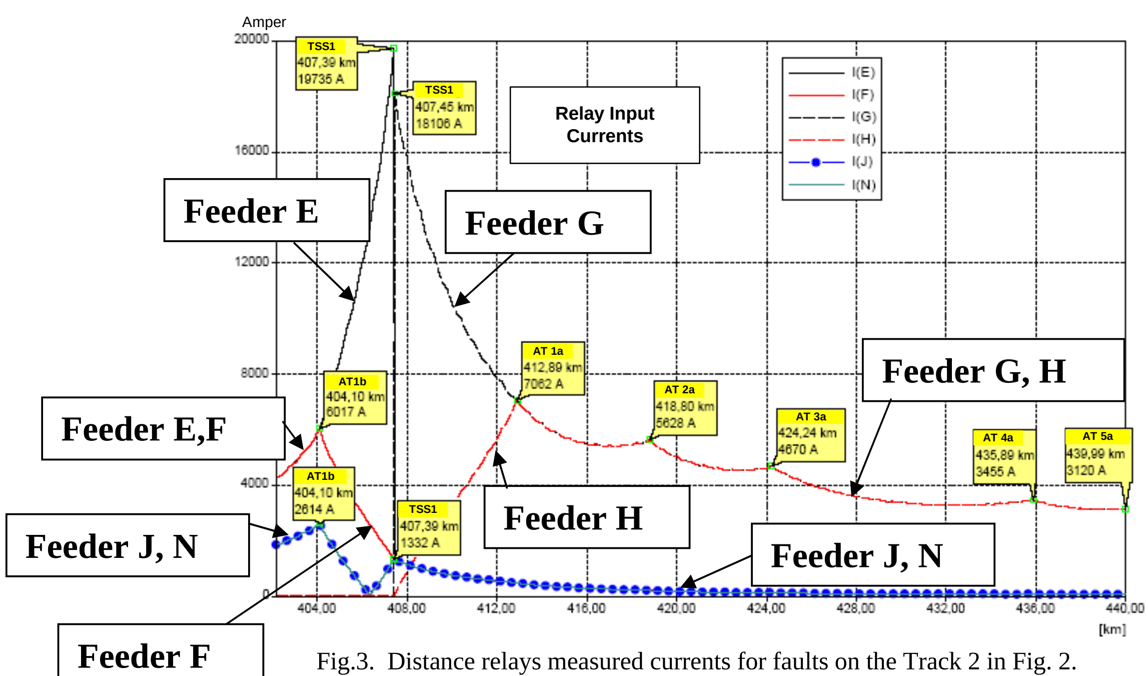

Fig.3. Distance relays measured currents for faults on the Track 2 in Fig. 2.
(The result is generated by SITRAS® SIDYTRAC program.)

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(Track 3 and Track 4) with two supply station (TSS 1 and TSS 2) and six autotransformer station (AT 1a to AT 5a and AT 1b) is shown in Fig. 2.
TSS 1 Feeders G and H supplies the Track 1 and Track 2 toward right side of the TSS 1 station. These feeders are equipped with negative feeders.
TSS 1 Feeders E and F supplies the Track 1 and Track 2 toward left side of the TSS 1 station. These feeders are equipped with negative feeders.
TSS1 Feeders J and N supplies the side tracks Trak 3 and Track 4 toward left side of the TSS 1.
The supply station TSS 1 is normally in operation. The supply station TSS 2 comes into operation for emergency situation alone or in parallel with TSS 1.
During normal operation, if a short-circuit between Track 2 and positive feeder happens then all distance relays at Feeder E, F, G, H, J and N measures abnormal currents as all positive feeders, all negative feeders, along with all autotransformers are in parallel. Fig. 3 shows the measured current of Feeder E, F, G, H, J, N as the short-circuit location moves along the track 2.
The correct setting of distance relay should trip the fault selectively with Zone 1 or Zone 2 of the distance relays at relevant feeders according to the following scheme:

For example for a fault on main track (Track 2) between supply station TSS 1 and TSS 2 the distance relay at Feeder G should trip with Zone 1 or Zone 2. The distance relay at Feeder H should trip with Zone 2. In this way, the TSS 2 and autotransformer stations AT 1a to AT 5a are de-energized. Then undervoltage relay in these stations will disconnect these stations from positive and negative feeders in around 2.0 seconds. Later, the autoreclose function in TSS 1 reenergizes the Feeder G and H. Now feeder G feeds only the Track 2 and feeder H feeds only the Track 1. If the fault still exists on the Track 2 then the Feeder G trips again with Zone 1 or Zone 2 and remains open. In addition all connection between autotransformer stations and Track 2 remains open. The connection between Track 1 and autotransformer stations is closed by system operator so that Track 1 returns to normal operation.
Same scheme should be realized if a fault on a side track (Track 3 or Track 4) between TSS 1 and autotransformer station AT 1b happens.

Realization of this scheme confronted with following difficulties:

As Fig. 3 shows the measured fault current of Feeder E, F, G, H increases when the fault location is near to the autotransformer stations. This leads to decrease in the measured impedance by these relays. (see Fig. 4)

In addition, Fig. 3 shows that the measured fault current of Feeder J and N becomes zero for a fault location on the Track 2. Therefore the relays measures very high impedance and will not pickup to clear the fault.

During normal operation the measured current by the relay is equal to the train load current. And during short-circuit between positive or negative feeder to ground, the relay current is equal to the short-circuit current.
However the relay measured impedance is not directly proportional to the distance-to-fault caused by following facts [3]:

a) The current injection effect and impedance of autotransformers along the tracks.
b) Parallel connection of positive feeders of all parallel tracks.
c) Parallel connection of negative feeders of all parallel tracks.
c) Back-infeed effect of autotransformers located behind the regarded supply station.
d) Additional infeed effect of supply systems behind or front of the regarded supply station.
e) Different impedances per line length for positive and negative feeders.
f) Side tracks with lower priority are not equipped with negative feeders. Therefore, the fault current measured by side track relays becomes zero for specific short-circuits located on the main track.

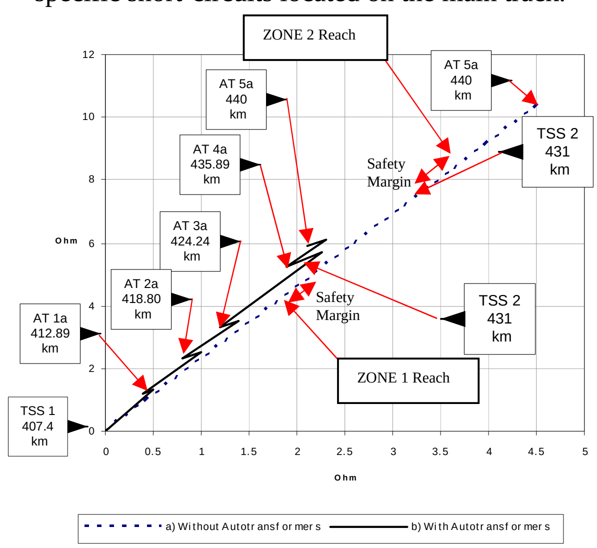

Fig.4. Proper selection of Zone 1 and Zone 2 for distance relays at feeder G in Fig. 2 considering the effect of parallel tracks and autotransformers current injection.

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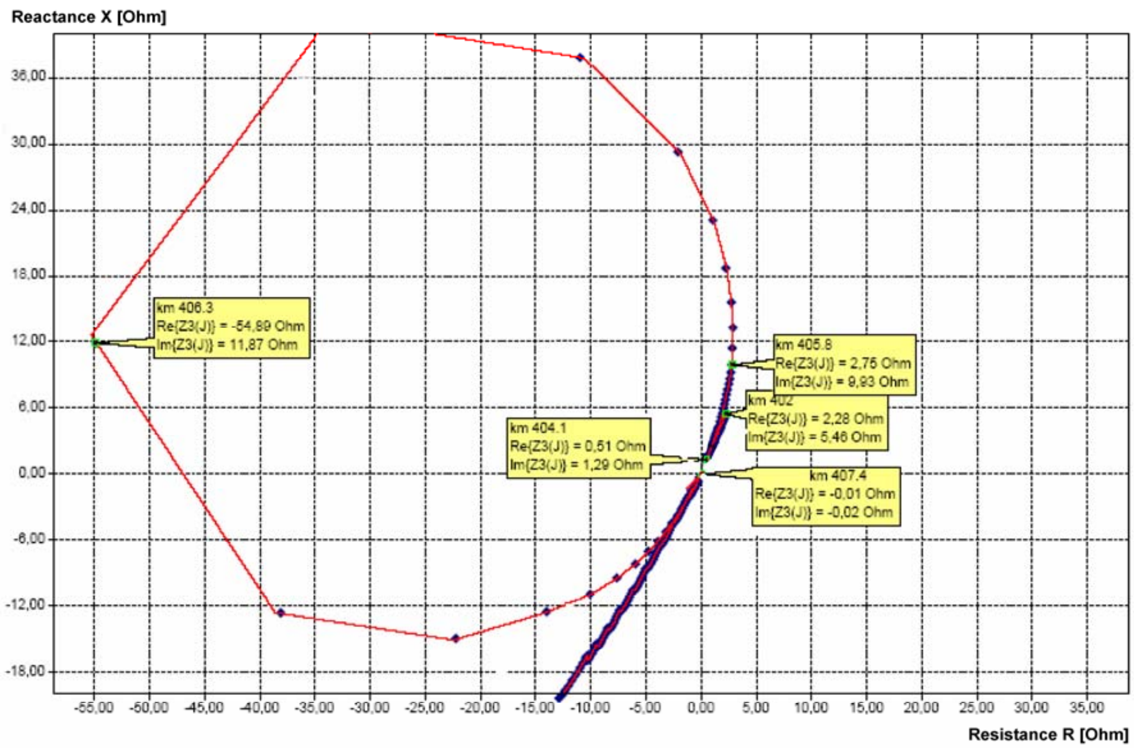

Fig 5. Measured impedance of distance relays at feeder J and N in Fig. 2 considering the absence of negative feeders

3 Distance relays zone 1 settings

In case of fault on main tracks, for example Track 2, in Fig. 2 with fault location between TSS 1 and TSS 2, the fault should be cleared by distance relay Zone 1 of Feeder G. Curve (a) in Fig. 4 shows the Feeder G relay measured impedance when a all autotransformers are disconnected, positive and negative feeders of the Track 1 and Track 2 are not parallel to each other. Curve (b) in Fig. 4 shows the measured impedance in normal operation when the Track 1 and the Track 2 are parallel and autotransformers are in operation.

As shown in Fig. 4, the observed impedance for a given fault location in case (b) is approximately half of the case (a) while the Track 1 and 2 are in parallel. In addition, the current injection at each autotransformer station results a saw-shape drop in the impedance locus.

The measured relay impedance in the R-X plane like Fig. 4, should be created for the following fault scenarios by simulation methods (like SITRAS® SIDYTRAC program or [1]):

- Fault between catenary to running rail
- Fault between negative feeder and running rail
- Fault between catenary and negative feeder
- No fault but maximum load conditions

And also for following operation conditions:

- All autotransformer are disconnected.
- Track 1 and Track are not parallel.
- All autotransformer are connected.
- Supply station TSS1 is in operation
- Supply station TSS2 is in operation

In order to have a selective protection for the distance relay at Feeder G in Fig. 2, its Zone 1 reach should be smaller than the supply station TSS2 impedance reach measured by the relay.

Therefore all of the created R-X planes should be analyzed for finding the minimum impedance reach of the autotransformer station AT 4a after the saw-shape impedance drop as shown in Fig. 4.

A safety margin of 10% to 20% can be applied to have a safe value for Zone 1 reach.

Finding the Zone 1 reach for Feeder G distance relay in Fig. 2, according to the above method, needs vast amount of simulation for creation of R_X phase plane diagram. During these analyses we have found the following rule:

$$Zone-1_{reach} = k \times Z_{TSS-remote} \quad \text{(Eq. 2)}$$

Where:

$Z_{TSS-remote}$: Impedance of one catenary between the two supply stations (For example between TSS1 and TSS2 in Fig. 2).

k : The reduction factor between 70±10%. It considers the autotransformers injection effect and parallel impedances of positive feeders or negative feeders between parallel tracks.

The Zone 1 needs no delay to send the trip command to circuit breakers.
Same rule is valid for adjusting distance relay at Feeder H, E, F, J, N in Fig. 2 when a fault on the main tracks or on the side tracks of the left side of TSS 1 happens.

5 Distance relays zone 2 settings

In order to have a selective protection for the distance relay at Feeder G in Fig. 2, its Zone 2 reach should be higher than the supply station TSS2 impedance reach observed by the relay.
The advanced analysis method mentioned in section four is applicable. However finding the Zone 2 reach, according to the above method, needs vast amount of simulation for creation of R_X phase plane diagram. During these analyses we have found the following simple rule:

$$Zone-2_{reach} = k \times Z_{TSS-remote} \quad \text{(Eq. 3)}$$

Where:

$Z_{TSS-remote}$: Impedance of one catenary between the two supply stations. (For example TSS1 and TSS2 in Fig. 2)

k : A factor between 170±20%

The Zone 2 should send the trip command to circuit breakers with 0.4 to 1.0 second delay.
In practice some side tracks parallel to main track has no negative feeders. Track 3 and 4 in Fig. 2 and 3 are an example of such tracks.
As Fig. 3 shows, for a given fault location on main Track 2, the distance relay on Track 3 observes zero current or infinite impedance. Fig. 5 shows the corresponding impedance locus of the distance relay located at feeder J in Fig. 2.
In such a situation distance relays at feeder J will not pick up. But the distance protection on the main track at Feeder E and F trips with Zone 1 or 2 correctly and then the distance relays at feeder J trips with Zone 1. Therefore the suggested rule in Eq. 3 remains valid.

6 Conclusions

The configuration of electric railway systems, especially if they are supplied with autotransformers between positive and negative feeders, is very complex.
The used and well known protection principle “distance protection” is facing problems which could lead to relay malfunction. The nonlinearity between distance-to-fault and impedance-to-fault is described in the paper. Rules for optimization of distance protection Zone 1 and Zone 2 are proposed.
For future relay settings calculations, these rules will be implemented in an existing expert system for protection coordination.

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