Aspects about Supply Systems in Railway Electric Traction

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Abstract—The paper presents aspects of electricity supply systems used in railway transport. There are also presented the protective devices which are found in the electrical system from the railway traction systems. Finally are show a case study from an electric traction system were it was monitored some electrical parameters (voltage, current) at different loads.

Keywords—electric traction system; protection; protective devices; electrical parameters monitoring.

I. INTRODUCTION

Rail transport is achieved, in most cases, using electric traction with the help of electric power systems. These electric traction systems are used all around the country and their popularity keeps rising. The electric railway traction means all plants where electricity is converted, transmitted and consumed. Electric railway traction systems differ from one another by the type of currents, voltages and the frequency used of the contact line. Scientific research and technical achievements in the field of electric traction current continue to develop. Consequently, rail companies are very interested and obliged to raise the standards of performance, safety and reliability of electric traction.

II. ELECTRIC SYSTEMS USED IN RAILWAY TRACTION

Over time various electrical power supply systems were used in railway traction system. Following in the paper are presented, in chronological order, some electric power supply systems of the railway traction, [1], [2], and [3].

A. The three-phase system in alternating currents with 25 Hz frequency and 1.5 kV, 3 kV or 6 kV voltages

The three-phase system in alternating currents with 25 Hz frequency and 1.5 kV, 3 kV or 6 kV voltages was used in the first electrified railway lines in Switzerland and northern Italy, around 1900. Overhead lines for the transmission of power energy had operated with alternating current high voltages, namely 60-110 kV. Electric traction substations of this system were equipped with basic three-phase step-down voltage transformers which are built very simple. Used electric locomotives were equipped with three-phase motors. Due to the contact line that have a high level of complexity to the crossings and to substations, this system has long been abandoned.

B. The direct current system

The direct current system had a great development until the 1960 years, being the most commonly used electrical system. This system was the only one which allowed the building electric locomotives with series excitation direct current motor, which are powerful, simple and also present ideal characteristics for railway traction. These locomotives are built to be used and operated in the heavy conditions imposed by railway operations and can be equipped with electric rheostat and regenerative braking.

C. The mono-phased current system with 16 ⅔ Hz low frequency

The mono-phased current system with 16 ⅔ Hz low frequency arose from the need to combine the good results of the contact line at high voltage (15 kV) with the proprieties of electric locomotives equipped with asynchronous alternative current motors with collector. Since at the motors with collector could not provide a satisfactory switching at 50 Hz, the line was supplied with a lower frequency of 16 ⅔ Hz.

The mono-phased current system was developed in two variants:
- in the first variant, the power supply is made from the transport general network using three-phased current with 50 Hz frequency;
- in the second variant, the power supply is made from by its own traction power network using mono-phased current with low frequency (16 2/3 Hz in Europe and 25 Hz in the United States).

D. The mono-phased current system with 50 Hz frequency

The mono-phased current system with 50 Hz frequency and 25 kV voltages in contact line is the most widely used system today and it is considered the most convenient and modern electric traction system. This electric traction system consists of power feeders, return feeders, electric traction substations, overhead contact lines, section and subsection substations etc. This system has a less complex construction and the 25 kV voltage leads to achieve on a simple and easy catenary suspensions.
Electric traction substations are directly connected to the national electricity system through 110 kV lines. These downstep substations have the role to convert the 110 kV voltages to 25 kV, used in the supply of electric locomotives and electric frames. The return of the traction current in electric traction substations is made through the running rails of the railway and the return feeders. The development and expansion of this system was greatly delayed, because it could not build simple and reliable electric locomotives.

III. PROTECTIVE DEVICES IN ELECTRIC TRACTION ELECTRIC SYSTEM

A. Generalities

In an electric circuit the protective devices represent the circuits which have the role to protect the electrical equipment from an electric traction substation, supply feeders, return feeders and respectively contact line against abnormal operating regimes, [4] and [5].

In the case of the electric traction system there are two operating regimes, namely:
- normal operation regime, characterized by maintaining the voltage and currents of the overhead lines within the nominal values;
- failure regime, characterized by a sudden decrease of voltage and a sudden increase of current in the overhead line.

The failure regime in an electric traction system is caused when a short circuit occurred on the overhead line, on section and subsection substations, on electric traction substations or on consumers (locomotives and electric frames).

The sudden increase of the current in the case of short-circuits from overhead lines or consumers have serious consequences on both the electrical equipment of the electric traction substations and on the other nearby plants.

The protective devices used in our country focuses on protecting of power transformers, respectively power supply circuits (supply feeders, overhead line, return feeders etc.).

B. Transformer protection

When using power transformers the following faults may occur: short-circuit across the primary terminals, internal short-circuits, windings short-circuits, grounding etc.

Power transformers used in electric traction substations are equipped with basic and backup protection systems. The basic protection mounted on power transformers are:
- gas protection (Bucholtz and RS 1000);
- protection against grounding (Chevalier).

The backup protection which are mounted on power transformers are:
- differential protection;
- over-currents protection;
- over-voltages protection;
- distance protection

C. Gas protection

Gas protection needs to act quickly to faults within the power transformer because all these defects are accompanied by gas releases. Gases can be an indication of the type of fault in the transformer, by their color and flammability. If the gases are non-flammable, odorless and colorless it means that the transformer removes the air remaining inside, after filling the tank with oil. A yellowish, non-inflammable gas indicates damage to the wooden pieces. A gray or black, slightly flammable gas shows a breakdown in the oil tank or an overheating, followed by the oil decomposition. The relay responsible for detecting the gas formation or the oil flow is a Bucholtz type relay which is mounted on the connecting pipe between the tank and the conservative.

D. Protection against internal faults

Protection against internal faults by grounding (called tank protection or Chevalier) is shown in Fig. 1 and operates at the occurrence of internal faults with grounding considering that 25 kV overhead contact line operates with the neutral connected to the rail (power transformer is mounted completely isolated from earth). Internal faults, even short circuits between windings are accompanied by destruction of the insulation to the ground (tank or core of the transformer), [1].

Fast saturation current transformer (CT) is mounted on the connection between power transformer tank, which is isolated from the rail, and earth connection.

The speed and safety of the protection against short circuits with grounding is dependent on the solving the following problems: transformer tank insulation to the earth, choosing both a fast saturation current transformer (CT) and a current relay (I).

E. Differential current protection

Differential current protection is used against internal short circuits and to the short-circuit of terminals of the power transformer, as an addition protection to the gas protection and it is mounted on all power transformers with power ratings greater than 5.6 MVA, [1].

Fig. 1. Electrical diagram of a power transformer protection against internal faults grounding.
Differential current protection acts on the occurrence of differences between the currents from the two ends of the protected area. From the point of view of the protection elements, the current differential protection can be longitudinal and transversal directions. Longitudinal protection is that on comparing the longitudinal differential currents between two points of the same circuit. The transversal protection makes the differential comparison between two or more currents of circuits or elements.

F. Over current protection

Over current protection acts when the current increase through the power transformer primary in the same time when the voltage decrease on the 25 kV busbar. It is used against dangerous over currents which can occur inside the transformer as a result of some short circuits on the contact line.

The electrical diagram of over current protection is shown in Fig. 2 and is made with an electromagnetic current relay, connected to the current transformer-CT mounted on power supply circuit of the power transformer. The diagram also includes: the electromagnetic time relay-T and the electromagnetic intermediary relay-RI, which command the opening of power circuit breakers on both the 110 kV and 25 kV voltage levels. The electromagnetic intermediate relay-RI performs the position signaling of circuit breakers.

G. Maximum voltage protection

Maximum voltage protection acts when over voltages is higher than a voltage threshold adjusted on voltage relays. The voltage increases on the transformer primary above of 123 kV value on one phase leads to opening the circuit breaker on the 110 kV busbar, [1].

H. Power supply circuit protection

The most commonly used electric traction system in Europe is in mono-phase current with 50 Hz frequency and 25 kV voltage of overhead contact line. Distance between two electric traction substations varies between 50 and 60 km, depending on the route profile and the minimum currents of short-circuit in the contact line which is lower than the maximum currents of the line.

The basic protection devices of supply feeders are the distance protection. When a short circuit occurs, the impedance at the end of the contact line is decreased under the impedance measured in normal circumstances, with a normal load.

The distance protection operation is based on permanent measurement of the contact line impedance and when this impedance is decrease under a $Z_e$ threshold value, and then the protection is activated. The condition for the protection to be activated is:

$$Z < Z_e, \quad (1)$$

where $Z$ is the measured line impedance, [1].

This distance protection is achieved by using complex impedance relays whose role is to command the circuit breakers of the supply feeders on the protected contact lines.

After the occurrence of electronic relays, the old distance protection from electric traction substations was replaced. On the supply feeders of the contact line from the electric traction substations was replace the impedance relays which have a circular characteristic with the electronic protections. The principle of functioning protections is the selecting of the abnormal operation regime with the ones with normal regime by monitoring the waveform of the traction current.

The traction current waveform of normal regime has an approximately trapezoidal shape and having the amplitude equal to around 0.5-0.6 of the amplitude of a sine function whose zero crossing has the same slope as the traction current.

Thus, this protection establish in advance the amplitude of short-circuit current by measuring the slope ($\frac{di}{dt}$) of the crossing through zero.

When the amplitude of traction current exceed over a predetermined value representing 0.75-0.9 of the sine waveform amplitude, then the $\frac{di}{dt}$ protection detects this regime as abnormal operation regime breaking the contact line by opening the circuit breaker.

When the protective devices of the supply feeders are made using relays with circular characteristic, then this are not able to protect the overhead line against short-circuit currents in the immediate area of an electric traction substation. Because of that the impedance protection with circular characteristic is complemented by a current sectioning protection, without time delay.

Fig. 2. Electrical diagram of overcurrent protection.
IV. CASE STUDY

The electric traction system is considered a distortion load and has a low power factor. The existence of the distortion regime leads to a deterioration of the quality parameters to electric energy. Because in electric traction there are no special measures for the distortion regime, these parameters far exceed the permissible values. Also, the presence of a high amount of reactive energy consumptions is common in electric traction systems.

Considering that the electric traction system is monophased, while the national supply network is three-phased, there is the possibility to supply the traction feeders through different phases, with the existence of some neutral zones on the overhead line when switching phase (sectioning substations).

The protective devices used against short-circuit currents of contact line from the electric traction system on the 50 Hz alternative current are: impedance, $di/dt$, and current section. Electric traction substations are equipped with current and voltage measuring relays, used to monitor the values of those parameters from the overhead lines.

In Fig. 3 is presented a schematic diagram of a supply feeder of overhead line in an electric traction substation. A feeder cell is achieved of the following electrical equipment: busbar switching-S with 35 kV and 1200 A; vacuum circuit breaker with 35 kV and 1200 A; current transformer-CT with a ratio of 600/5/5 A; voltage transformer-VT with a ratio of 25/0.1 kV and contact line-CL. In the case study which was performed in a traction substation were monitored the current and voltage waveforms from the transformer secondary using an oscilloscope. The current was acquired using a Hall Effect current probe and the voltage was measured directly from the secondary transformer of feeder cell, [6] and [7].

In Tab. 1 are presented the parameters which were acquired and processed from the electric traction substation that was monitored, namely: voltage, current, $di/dt$, $\phi$ angle, apparent power, active power and reactive power.

In Fig. 4 are shown the current and voltage waveforms for the regime without the load. The parameters measures on contact line have the following values: the current has 6.99 A and the voltage 24.52 kV. From the figure it is observed a phase shift between the voltage and current waveform, on the contact line without the load, resulting that the current is phase shifted before voltage with -36°, meaning that the overhead contact line is operating in a capacitive regime.

Tab. 1. Monitored Parameters from an Electric Traction Substation.

<table>
<thead>
<tr>
<th>V (kV)</th>
<th>I (A)</th>
<th>$di/dt$ (A/ms)</th>
<th>$\phi$ (degree)</th>
<th>S (MVA)</th>
<th>P (MW)</th>
<th>Q (MVAr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.05</td>
<td>2.58</td>
<td>3.225</td>
<td>-46.51</td>
<td>0.062</td>
<td>0.042</td>
<td>0.045</td>
</tr>
<tr>
<td>24.22</td>
<td>10.068</td>
<td>12.42</td>
<td>-83.16</td>
<td>0.243</td>
<td>0.197</td>
<td>0.142</td>
</tr>
<tr>
<td>24.07</td>
<td>20.28</td>
<td>23.45</td>
<td>-55.87</td>
<td>0.488</td>
<td>0.273</td>
<td>0.404</td>
</tr>
<tr>
<td>24.05</td>
<td>36.72</td>
<td>40.80</td>
<td>-60.33</td>
<td>0.883</td>
<td>0.767</td>
<td>0.437</td>
</tr>
<tr>
<td>24.07</td>
<td>111.6</td>
<td>52.8</td>
<td>31.46</td>
<td>2.686</td>
<td>1.996</td>
<td>1.401</td>
</tr>
<tr>
<td>23.95</td>
<td>82.08</td>
<td>84.00</td>
<td>47.44</td>
<td>1.966</td>
<td>1.446</td>
<td>1.331</td>
</tr>
<tr>
<td>23.82</td>
<td>188.4</td>
<td>204</td>
<td>51.2</td>
<td>4.488</td>
<td>3.497</td>
<td>2.812</td>
</tr>
<tr>
<td>23.62</td>
<td>198</td>
<td>300</td>
<td>39.6</td>
<td>4.677</td>
<td>3.603</td>
<td>2.981</td>
</tr>
</tbody>
</table>

In Fig. 5 shows the current and voltage waveforms when a load is present on the overhead contact line. The following values were measured: the current has 111.6 A value and the voltage has a 24.075 kV value.
From the Fig. 5, it can observe that these waveforms differ from the line operating without a load. In the case of current waveform its shape is an approximately trapezoidal, specific to the electric traction system. As it can be seen, the current is phase shifted after voltage with an angle of a 42° value, meaning that the line is operating in an inductive regime. The current slope on the current crossing through zero is approximately 132 A/ms.

In Fig. 6 is presented the oscilloscope screen used for monitoring of the current and voltage waveforms on the contact line from electric traction system which have a load.

By monitoring these parameters are obtained information about supply system in the electric railway traction. In exploitation of the electric traction system, the $\frac{di}{dt}$ protection sometimes trigger even if there is not a short-circuit current on the overhead line. By monitoring the current and voltage parameters of the contact line it can find more factors which cause the unexpected triggering of the $\frac{di}{dt}$ protection. Thus it can take measure for these situations to not occur in the future, for increase the safety in exploitation of the electric traction system.

**V. CONCLUSIONS**

Due to technical and economic advantages (lower operating and maintenance costs, higher ratio power-weight, lower environmental pollution etc.), the electric traction is found in the most countries.

In power supply of electric traction system are used various systems such as:

- the three-phase system in alternating currents with 25 Hz frequency and 1.5 kV, 3 kV or 6 kV voltages;
- the direct current system;
- the mono-phased current system with 16 ⅓ Hz low frequency;
- the mono-phased current system with 50 Hz frequency.

The most used traction system is the 50 Hz, mono-phased with a 25 kV voltage.

Avoiding of abnormal regimes on the overhead contact line is performing by using some protective devices. The main protective devices used it is refers on protecting the power transformers, respectively the power supply circuits (supply feeders, return feeders, contact line etc.). In this sense, the power transformers are provided with basic protection (gas protection, grounding protection) and backup protection (differential protection, over-currents protection etc.) and also for power supply of contact line are used following protections: impedance protection; $\frac{di}{dt}$ protection; sectioning current.

The structure of railway electric traction systems and the protection devices mounted on the overhead lines are very complex. It is necessary to provide a proper exploitation and maintenance to these systems in order to prevent the occurrence of fault regimes which lead to perturbation on railway transports. Thus, it appears the necessity to monitoring of some parameters from power supply of electric traction. By monitoring of these parameters (for example: voltage, current), it can obtain information regarding of operating regimes of the electric traction systems, of unexpected triggering of $\frac{di}{dt}$ protection etc. Thus, it will can increase the safety in exploitation of the electric traction system by taking measures that the faults regimes to be avoided.

**REFERENCES**