Proper testing of high-speed DC circuit-breakers in a railway environment

Whitepaper by STEVO Electric

Introduction
High-speed DC circuit-breakers, in this paper referred to as circuit-breakers, are present in all sorts of rail infrastructure. National or urban railways, tramways or metro's, they all rely on circuit-breakers to protect them from disastrous situations. The circuit-breakers can be installed either on board of the trains or on the trackside, in traction power substations. Needless to say that the circuit-breakers are a critical part of the rail infrastructure. In the best case a faulty unit can cause the trains to stand still, in the worst case it can blow up parts of the infrastructure and cause casualties. The life-cycle of circuit-breakers is long, some of the units still in operation are more than 50 years old. Proper testing of circuit-breakers is a hot topic these days as a result of a number of incidents on various LRT and Tramway systems. This whitepaper describes some issues with testing and how to resolve them.

Circuit-breakers, the basics
The role of a circuit-breaker is quite simple: it should switch-off, often referred to as "trip", when an irregularity is detected in the current. An irregularity could be a short circuit leading to an instantaneous peak in the current, or an overload situation in which demand is simply higher than supply. In both cases, the circuit-breaker should do its job and disconnect the devices from the grid.

Circuit-breakers "trip" when the current "I" exceeds a certain value depending on the type of breaker and the value set for that breaker. However, the circuit-breaker will also trip when the change in current is high, this is referred to as di/dt, the change in current per time unit. A graph of the latter is depicted in figure 1. The graph shows the time it takes to trip "t" in milliseconds, often referred to as "opening time", in function of di/dt for 2 types of Secheron circuit-breakers. The larger the di/dt, the faster the circuit-breaker trips. From the chart we can conclude that it takes the UR26 approximately 4,3 ms to trip at a di/dt of $3.10^6$ A/s.

The breaker will also trip when the demand for current rises above the threshold value, hereafter named $I_{ds}$.
I.e. a circuit-breaker set for 4.000 A should trip when the requested current exceeds that value. High Speed circuit-breakers typically trip in 10 ms or less.

Circuit-breakers are manufactured with great care according to specific standards. On the other hand, these devices are operational in the field for decades under various conditions and consist of mechanical parts. Can you expect the circuit-breaker to behave according to its initial manufacturing settings after 40 years?

Needless to say that regular testing of circuit-breakers as part of documented maintenance procedures is mandatory. The question then is: how do we do proper testing? Testing according to figure 1 is impossible as it would require simulating short circuits. There are no test units on the market today that can do that. Testing of the threshold current $I_{ds}$ and the opening time $t_l$ however is perfectly possible with today’s transportable test set. These test sets inject a current and measure the current at which the circuit-breaker trips as well as the opening time $t_l$.

### Testing according to IEC standards

In order to standardize the testing of circuit breakers, specifications were drafted by the IEC (International Electrotechnical Commission) and finalized in documents IEC 60772-2 and 61992-2. It is specified that a circuit-breaker whose operation is affected by the rate of rise of the current, which is the case for High Speed DC Circuit Breakers, 200A/s shall not be exceeded in the vicinity of the breaker’s settings. It is practically impossible and inefficient to test a breaker with a slope of 200A/s starting from zero. It would take a circuit-breaker of 4000 A 20 sec to trip thereby consuming an enormous amount of energy. This energy comes from batteries and electronics which would make the test unit very expensive and no longer transportable. A far more clever way to do this is by first measuring the trip current approximately ("quick and dirty" test) with a steep slope of the injected current and, after determining this threshold current, carry out a detailed test according to the specifications. This is depicted in Figure 2. $I_{ref}$ is the threshold current measured in a prior "quick and dirty" test with a steep slope. The accurate test is performed by first injecting a current with a steep slope till e.g. 5% below $I_{ref}$, then increase the current injection by 200A/s (between $t_1$ and $t_3$). $I_{ds}$ is the correct trip current measured according to the standard. Note that the energy consumption is limited. $T_1$ is typically reached in less than 1 second, $t_3-t_1$ is less than 3 seconds.

A similar procedure should be followed for measuring the opening time $t_l$. First injecting a current with a steep slope, then keeping a constant current level slightly below $I_{ds}$ for 40 msec. Then
injecting a high enough current $I_{ref}$ to trip the circuit breaker. The opening time is $t_2-t_1$.

The "quick and dirty" test is not sufficient on its own as it can lead to misleading results. For example because of a (too) steep slope the circuit breaker can trip too "early", i.e. prior to reaching $I_{ds}$. In this case the $\text{di/dt}$, the change in current, triggers the breaker to trip. During the accurate standardized measurement with a 200A/s slope, the circuit-breaker will turn out not to break and additional iterative testing will be required to determine the correct $I_{ds}$.

**Conclusion**

High-speed DC circuit breakers are critical elements in the railway operator's infrastructure. They will ensure that the damage is limited to an absolute minimum when things go wrong. These vital components are also vulnerable despite the fact that they are build to the highest standards. It is therefore mandatory that their performance is tested on a regular basis according to standard maintenance procedures.