Proceedings of the JRC Joint Rail Conference

April 18-21, 2018, Pittsburgh, PA , USA

JRC2018-6237

PROPER TESTING OF DC HIGH SPEED CIRCUIT-BREAKERS AND PROTECTION RELAYS IN A RAILWAY ENVIRONMENT

Wim D'Hooghe
STEVO Electric
Heppen, Belgium

ABSTRACT

DC High Speed circuit-breakers (DC-HSCB's) and Protective Relays (PR's) are present in all sorts of rail infrastructure. National or urban railways, tramways or metro's, they all rely on this equipment 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. Protection Relays are, in most cases, part of the fixed installation. Needless to say that the DC-HSCB and PR are critical parts 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. The first digital protective relays were introduced in the eighties. Proper testing of DC-HSCB and PR is a hot topic these days as a result of a number of incidents on various LRT and tramway systems (STEVO Electric, 2015). This paper describes some issues with testing and how to resolve them.

INTRODUCTION

In modern traction substations, the protection system consists of DC-HSCB's and PR's. The DC-HSCB trips on a command of the PR, called "indirect release", or can trip on itself, called "direct release". The current flowing through the breaker is measured by a shunt. The shunt generates a voltage equivalent to the current going through it, and passes this voltage level to the PR (see fig. 1). In this way the PR knows exactly the current flowing through the system, and will trip the breaker when a fault is detected. A PR can trip the breaker on various fault conditions. This can be a maximum current I_{max}, a rate of current rise di/dt, a thermal overload (I_{th}), etc.

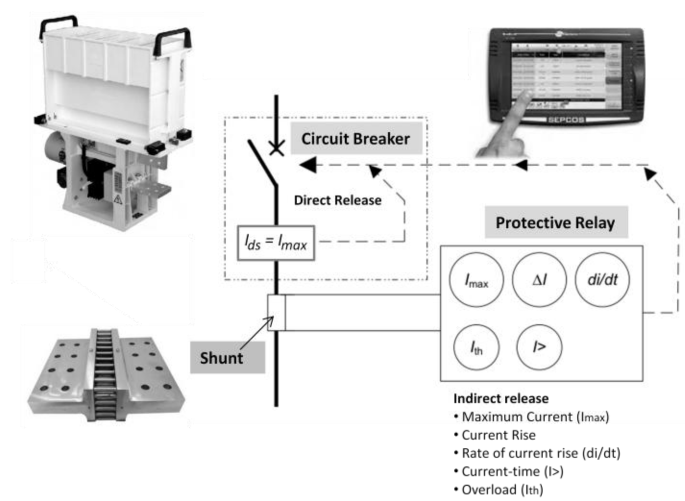

Figure 1

The I_{ds} of the breaker is the current level at which the breaker will trip autonomously (direct release), i.e. without a command of the PR. The I_{ds} of the breaker is always set higher, e.g. 10%, than the I_{max} set on the PR. The direct release operates instantaneously.

It is important to know that PR's of different manufacturers may operate in a different way. Some PR's will generate a trip as soon as I_{max} is reached. Others will use a more sophisticated algorithm. For example, Secheron's SEPCOS I_{max} + (Sécheron, 2008) includes a certain time delay before triggering the breaker (see Figure 2).

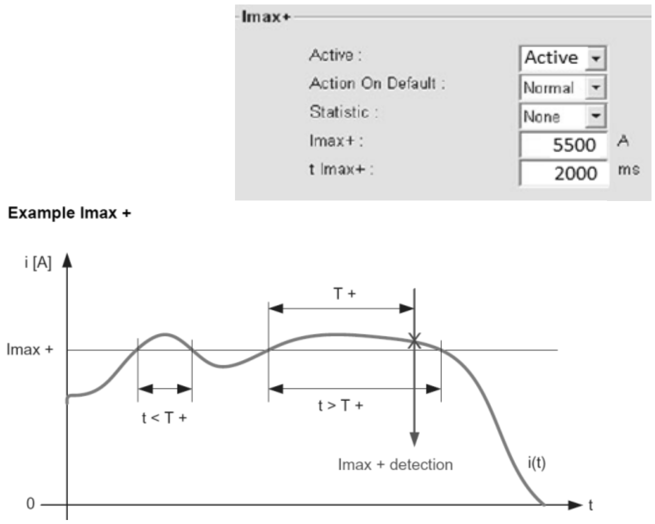

Figure 2

In figure 2, I_{max}+ is set at 5500A but the PR will trip the breaker only when the current remains higher than 5500A for at least 2000ms as t I_{max}+ is set to 2000ms.

TESTING OF THE DC-HSCB

The I_{ds} of a DC-HSCB is in most cases set at the factory at a certain level. In the past, the manufacturer recommended the end-user not to modify the setting because it was difficult to predict the outcome. Nowadays, with sophisticated test & measurement equipment available on the market, adjusting the I_{ds} has become child's play. Changing the I_{ds} of a DC-HSCB is often done by turning a nut on a particular scale as depicted in figure 3. However, it is impossible to make an accurate setting based on such a scale. One needs to actually measure the current.

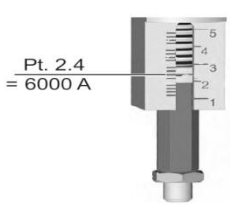

Figure 3

The I_{ds} of the breaker, i.e. the direct release, should be checked/adjusted :

- prior to putting the DC-HSCB in service
- as part of the breaker maintenance program
- after refurbishing
- when adjustments are necessary for an upgrade of the line

In order to measure the I_{ds} , a Primary Injection Test Set (PITS) is required. There are test sets on the market that can generate a DC current as high as 40.000A. The units are modular in design and easily transportable to the breaker's location.

It is important to verify that the PITS can generate a current with a slope of as low as 200A/s. This is required in the standard IEC 61992-2 (Railway applications - Fixed installations - DC switchgear -Part 2 : DC circuit-breakers). The manufacturers of DC-HSCB's also use this standard to set the I_{ds} at the factory. A PITS is usually equipped with batteries and ultra-capacitors and is plugged into a standard power socket during operation. As the amount of energy is limited, the PITS will generate a current rising very fast to a value a bit below the I_{ds} (k_1 value in figure 4). As soon as that value is reached, the current will rise at 200A/s, causing the breaker to trip and returning an accurate I_{ds} level. For a typical current pattern, refer to figure 4.

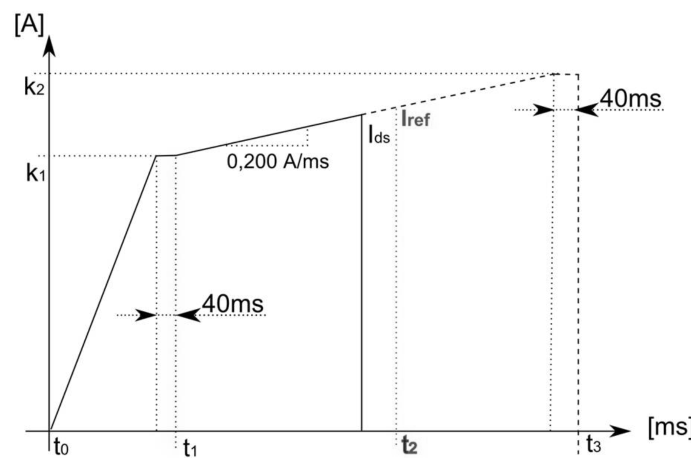

Figure 4

Modern breakers trip quite consistently. The standards EN 50123-2 or IEC 61992-2 state that the trip-accuracy of circuit breakers is plus minus 10%. However, with modern breakers, all trips should be registered in the in the range AVERAGE(I_{ds}) ± 3%. The results of a sample test of such a breaker set at various I_{ds} levels with an increment of 1000A is depicted in Table 1 (STEVO Electric, 2016). The highest accuracy was obtained at 6000A, the lowest at 2000A.

	2000A	3000A	4000A	5000A	6000A	7000A	8000A
Average (AV)	1 966	2 936	3 996	5 014	5 809	7 002	7 974
Standard Deviation	24	30	23	17	15	28	61
Highest	2 022	3 021	4 048	5 052	5 845	7 069	8 089
Lowest	1 905	2 887	3 949	4 955	5 780	6 929	7 850
Delta High-Low (DHL)	117	134	99	97	65	140	239
DHL/AV (%)	6,0%	4,6%	2,5%	1,9%	1,1%	2,0%	3,0%
Median	1 967	2 930	3 993	5 015	5 809	7 007	7 978

Table 1

Besides verifying the I_{ds}, it is important to check the breaker's opening time. This is the time that elapses between the current through the breaker reaching the I_{ds} level, and the breaker actually opening its contacts. Depending on the manufacturer and the breaker model, the opening time can vary between 5 and 30 ms.

Note that during a short circuit, the current will continue to rise as long as the contacts are closed. Assuming a short circuit of 50 kA/s, an I_{ds} of 5 kA and an opening time of 30 ms, the level at which the current will get cut off will be : 5.000 + 50.000*0,03 = 6.500A, which is 30% higher than the I_{ds}. It is also for this reason that the I_{ds} measurement should be conducted at 200A/s. The fault made at such a gentle slope is negligible.

The way a PITS will measure the opening time is depicted in fig. 5. It will raise the current level to Ids-10% and perform an instantaneous ramp up to Ids+10%. The time measured between the ramp up and the current being cut off is an accurate value for the opening time.

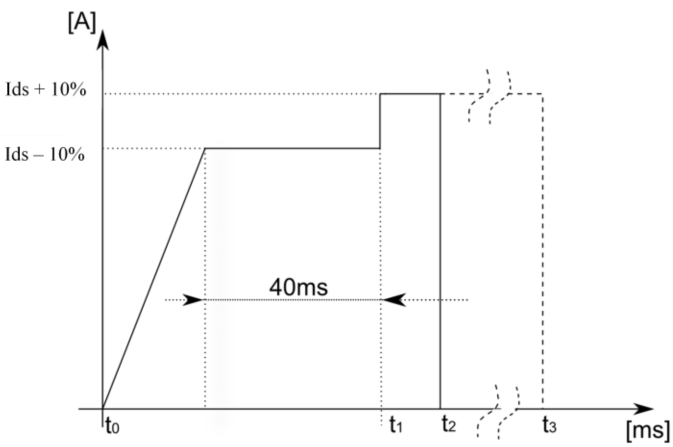

Figure 5

Opening of the breaker on command of the PR uses a completely different mechanism. It is important to measure the response time of this circuit. This can easily be done by combining the PITS with an external device, called the BCD (Breaker Control Drive). While the PITS is injecting a current in the breaker, the BCD generates a trip signal. The time between the trip and the current cut-off is registered on the PITS. This value should be approximately 5 ms.

Finally, the resistance of the breaker contacts should be measured. The manufacturer determines the current that should be used for this measurement, typically 1000 or 2000A. The resistance is typically 15-35 μΩ. "Resistance measurement" or "Voltage drop measurement" is a standard feature of a PITS.

TESTING OF THE PR

Modern digital Protective Relays provide a multitude of functions. The PR can trip the breaker on high current, di/dt, and several timings. An example of such a function is Secheron's "DDL + Delta I" function depicted in Figure 6 (Sécheron, 2008).

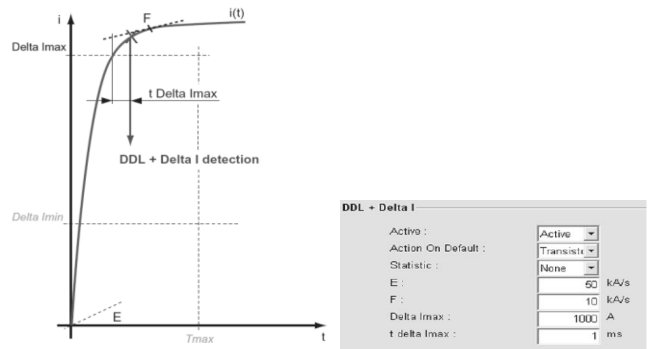

Figure 6

E is the di/dt value at which the PR notices a possible fault and starts measuring. E occurs at time T_0 and current I_{T0}. Delta I_{max} is the delta current on top of I_{T0} at which the timer "t delta I_{max}" is started. If the di/dt value is still higher than F after "t delta I_{max}", the PR will trip the breaker. In our example : if the di/dt is still higher than 10kA/s, 1 ms after the injected current has reached 1000A + I_{T0}, the PR will trip the breaker.

In order to test a PR, a Secondary Injection Test Set (SITS) is used. The SITS emulates the voltage that appears over the shunt in the system. The user is given a toolkit to generate any type of curve : linear, exponential, based on the Tau (τ = time constant of the overhead line), etc. and a combination thereof. In most cases, the possibility is offered to use output files from the PR itself in the SITS. The file format is usually CSV.

The SITS output is connected to the PR identical to the shunt, the trip command output of the PR is fed back into the SITS. In this way all trip functions activated in the PR can be tested. Preprogrammed current curves for each function can be used in order to speed things up.

Secondary injection testing of the PR should be done before the system goes live. As many parameters need to be entered into the PR, human mistakes are possible and should be avoided. It is also recommended to perform the tests after changes to the system have been made and on a regular basis, e.g. once per year. After all, a PR is built up of various PCB's (Printed Circuit Boards) and is often located in harsh environments. Moreover, the last bug in the software is the one that hasn't been found yet...

PUTTING IT ALL TOGETHER

In order to be 100% sure that the protection system will work fine, a test with all the parts in the loop should be conducted. In this way, also all cabling and contacts are checked. This all encompassing test is depicted in Figure 7.

Unfortunately, this test is difficult to do on most of the existing installations. Very often the shunt is affixed on the current busses and is automatically disconnected when one removes the DC HSCB out of its cabinet.

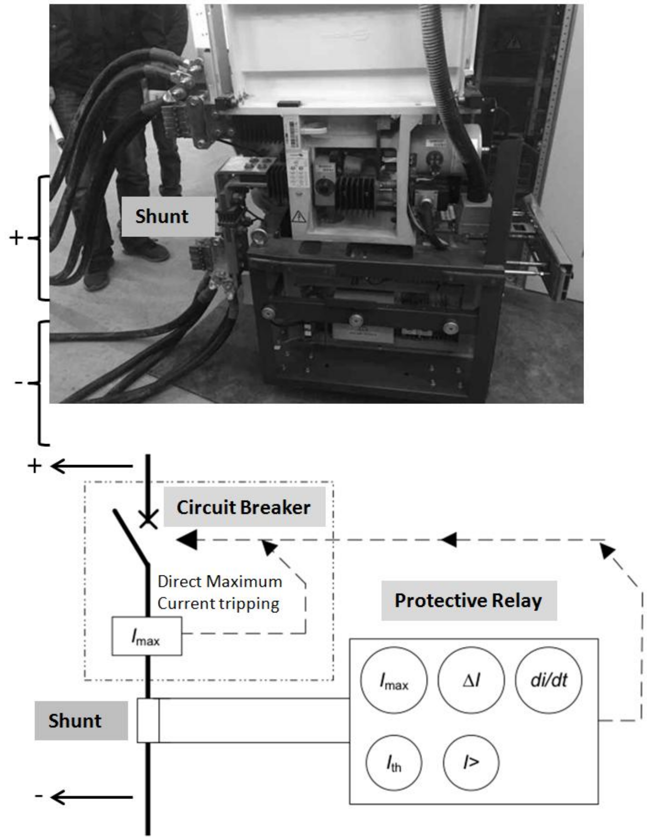

Figure 7

The simplest test to do is to have the PITS generate a current with an extremely high di/dt, e.g. 100 kA/s, enough to trigger the di/dt function on the PR immediately but with a maximum current level below the I_{ds} of the DC-HSCB in order to avoid activation of the breaker's direct release.

The PITS will register the current cut-off and report the reaction time of the complete system after the injection. It proves that the connections are fine between the shunt and the PR, and between the PR and the DC-HSCB.

CONCLUSION

Up to know, the testing of DC HSCB's and PR's installed in the field was very limited if not zero. Transit operators have pushed the industry to come up with a solution. With the introduction of powerful primary and secondary test sets, bulletproof testing of the different parts as well as the complete system has become easy, fast and accurate. This way of testing was prescribed in Germany in 2015 (VDV, 2015). The tests will improve the safety of the passengers and personnel as well as protect the transit agencies assets.

Refer to figure 8 for a modular PITS of 20.000A with full SITS capabilities.

Figure 8

REFERENCES

Sécheron. (2008). *SEPCOS-NG - User Guide.* Geneva - Switzerland.
STEVO Electric. (2016). *Demistifying the accuracy of High Speed DC Circuit Breakers (Part 1).* Heppen - Belgium.
STEVO Electric. (2015). *Primary injection testing : necessity or luxury.* Heppen - Belgium.
VDV. (2015). *Protection in case of Overload Current and Short-Circuit Current from Traction Power Supply Systems for Urban DC Rail Systems.* Cologne - Germany.