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FAULT ANALYSIS AS A BASIC INPUT FOR MAINTENANCE MANAGEMENT TO IMPROVE THE OVERALL RELIABILITY OF THE BELGIAN TRANSMISSION GRID

Patrick De Cuyper
Elia Asset NV
Belgium

Introduction

Due to the deregulation of the electricity market, operating conditions on a power system network have been drastically changed. Some examples are:

- Inter-connectors are becoming heavily loaded due to cross-border power exchanges.
- The load forecast on inter-system connections is no longer stable in time, but can rapidly change due to the existence of short-term delivery contracts between the consumer and the supplier.
- Each outage of an asset can have a direct impact on the benefit margins of the Transmission System Owner as the supply of energy may be interrupted.

From the above it can be seen that the number of outages is one of the most important elements to determine a maintenance policy. Therefore a balance has to be found between a maximum availability and a maximum reliability of the assets, as both are influenced by the number of outages. But a distinction has to be made between scheduled and unscheduled outages. The availability of the network depends strongly on the scheduled outages; therefore less maintenance should be programmed, whereas an improved reliability would require more maintenance. As shown with figure 1.

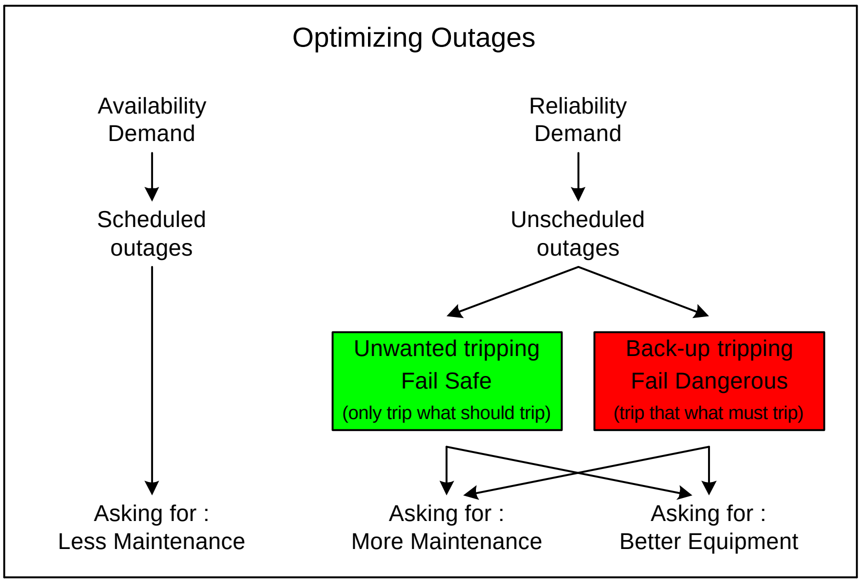

Figure 1: Availability demand versus reliability demand

From the figure it can also be seen that the reliability demand has a security aspect, avoiding unwanted trippings (fail safe mode), and a dependability aspect, having correct and fast fault elimination (fail dangerous mode). Besides asking for more maintenance the reliability demand will also ask for better equipment.

Thus the real challenge for maintenance management is in minimizing the scheduled outages for maintenance work, including replacements of end-of-life assets, without endangering the reliability of the power system. At this point Fault Analysis can be used as a basic input to achieve this goal.

Fault Analysis on the Belgian transmission system

The Belgian grid contains voltage levels from 30 kV up to 380 kV, and can be characterized as an older network, highly meshed with few ongoing developments. As the grid is highly meshed operation drawbacks are smaller but due to his age the need for maintenance and retrofit of existing assets is much higher. The next table gives an overview of the Belgian Grid.

Voltage level	Km lines[1]	Km cable	# Sites[2]	# Substations[3]	# Bays[4]
380 kV	1476	-	26	13	108
220 kV	388	-	19	10	66
150 kV	3724	249	226	78	854
70 kV	3031	228	262	156	1094
30 – 36 kV	4	2100	273	134	1303

Table 1: Overview of the Belgian grid (data 2004)

An in-depth fault analysis of every incident on the Belgian transmission system has been conducted since the beginning of the ’60. Even then and now the definition of an incident did never change: “An incident is every unwanted or unplanned switching of a circuit-breaker”. However the used methodology and postulated goals did change during this period. Nowadays the major part of the information to conduct this fault analysis is coming from digital fault recorders. Table 2 gives an overview of the number of installed DFR’s on the Belgian grid.

Voltage level	# Fault Recorders
380 kV	13
220 kV	10
150 kV	53
70 kV	49
30 – 36 kV	13

Table 2: Overview of installed DFR (data 2004)

[1] Electrical line length is mentioned.
[2] A site is considered when a specific voltage level is present.
[3] A substation is considered when at a site a busbar is present with at least 3 bays connected on it.
[4] Only bays connected to a busbar at a substation are considered

The information coming from those digital fault recorders gives the opportunity to make a better follow-up of the equipment, as well High Voltage primary equipment as Low Voltage secondary equipment. Some examples of this are presented in the next two chapters.

Case 1 (Fault caused by lightning storm)

In this chapter a fault that occurred on the network during lightning storms on August the 20th 2002 will be commented. That day about 60 faults were noticed on the Southern part of the Belgian grid. The total number of faults occurred in a period of 3 hours. The fault that will be commented occurred at 09:27 AM. The next figure 2 shows the situation of a small part of the Southern network at the moment of the fault.

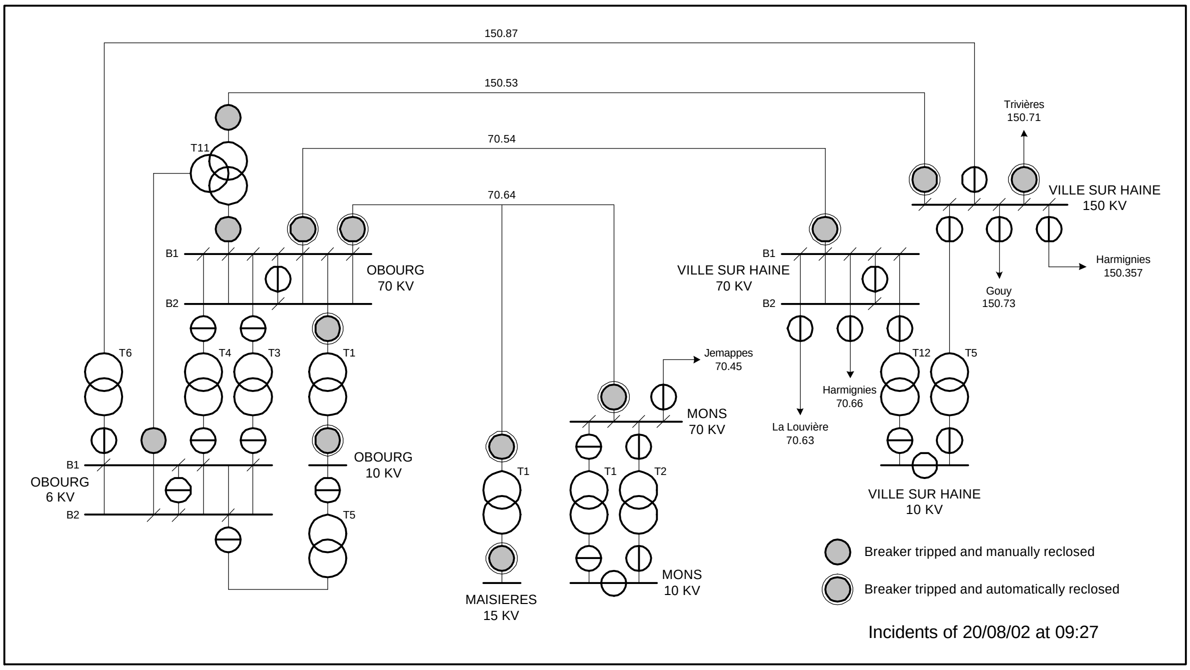

Figure 2: Situation of a part of the Southern network on 20/08/02 at 09:27 AM

From the above figure it can already be seen that all lines, which tripped automatically reclosed. The only action conducted at the Control Centre was the reclosing of transformer T11 150/70/6 kV at the Obourg substation. The tripping and the automatic reclosure of transformer Obourg T1 70/10 kV has to be considered as normal, as the 70 kV substation of Obourg passes at zero voltage and transformer T1 is subsequently tripped by clearing. Once the voltage is present again, transformer T1 automatically recloses. The same situation happens for transformer T1 70/15 kV at Maisières site, due to the tripping of the line 70.64, and, once the voltage is present again on the line 70.64, transformer T1 at Maisières substation automatically recloses. At first sight the only unexplained trip for the Control Centre was the tripping of the circuit breaker of the line Trivières 150.71 at the Ville sur Haine substation. All other trips were linked to a lightning strike that has hit the lines 150.53, 70.54 and 70.64 nearby the Obourg substation. This assumption proved to be right for the Control Centre by an automatic fault location conducted on the line 150.53, which indicated a fault 4-N at 0,95 km from Obourg. So for the Control Centre this part of the Southern network was fully operational after they manually reclosed transformer T11 150/70/6 kV at 09:39 AM. The only comment they made to the Fault Analysis department was, besides mentioning the manual reclosure of transformer T11 at 150 kV side, a request for investigation on the unwanted tripping of the circuit breaker of the line Trivières 150.71 at the Ville sur Haine substation, since they assumed a protection problem.

As already stated an in-depth fault analysis is conducted, on every incident on the Belgian transmission system, so also for this one. This analysis was made on August the 21th. And this analysis shows some remarkable results. The recordings of the DFR's installed at the Obourg substation and the Ville sur Haine substation were used as an input for this analysis.

Looking to the recording from the DFR installed at the Obourg substation for the line 70.54 Obourg – Ville sur Haine the occurrence of a fault 4-8-N is noticed. This fault is cleared at the Obourg station after 87 ms by the three phase tripping of the installed air-insulated circuit breaker, type DCF 80 of EIB. But 15 ms after the opening of pole 8 of this breaker a first restrike on this pole is noticed. The breaker manages to cut the fault current by his further mechanical opening but the isolation is insufficient resulting in a second restrike 33 ms after the first one. As the breaker is at this moment mechanically totally open, he does no longer achieve to cut the fault current. At the end the fault on the line 70.54 is cleared by the back-up opening of the breaker, second zone tripping, on the line 70.64 at the Mons substation.

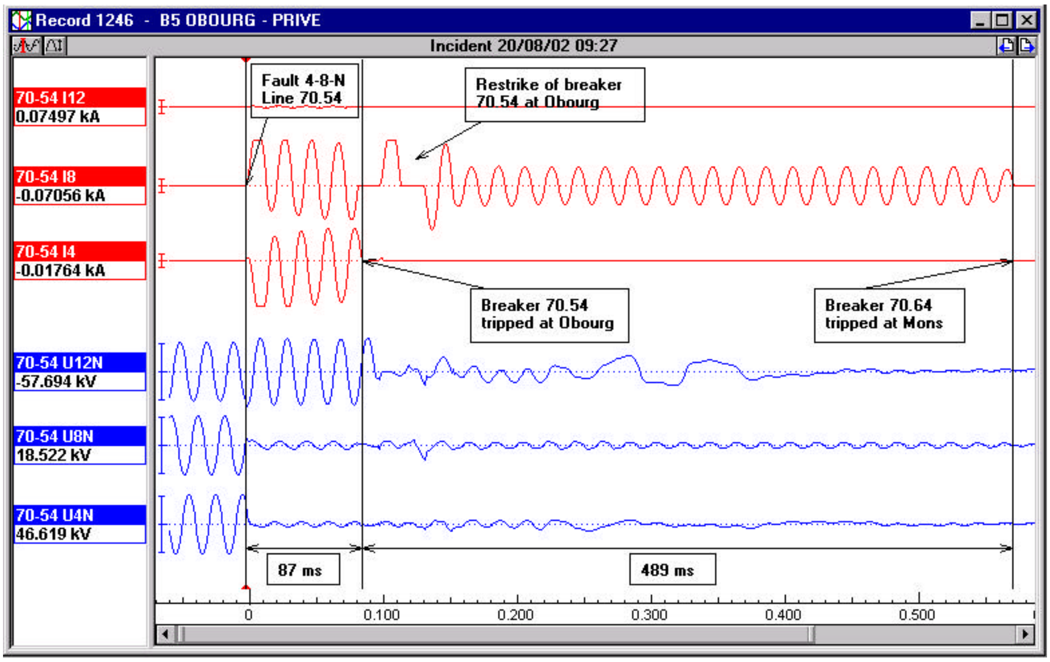

Figure 3: Registration of currents and voltages of line 70.54 at Obourg substation

Once these phenomena were noticed the Fault Analysis department contacted the Control Centre requesting to put breaker 70.54 at the Obourg substation out of service in a safe way. The breaker wouldn't probably even cut any load current or charging current of the line anymore. So it was necessary to isolate the breaker totally. This could be achieved by switching over the line 70.54 on busbar B2 at the Obourg substation. Now the load current could be cut off by the breaker 70.54 at the Ville sur Haine substation and the charging current of the line with the bus coupler at the Obourg substation. All this was done at the beginning of the afternoon on August the 21th. Immediately field crew started their investigations on the suspected circuit breaker. During the disassembly of the pole 8 of the breaker some damage could be clearly noticed, at the mobile and fixed contacts of the breaker.

This damage is showed with the next three photographs of the damaged pole. The first photograph gives an overview of the disassembled pole 8. On the picture can be seen that the mobile and the fixed contacts of both chambers are seriously damaged.

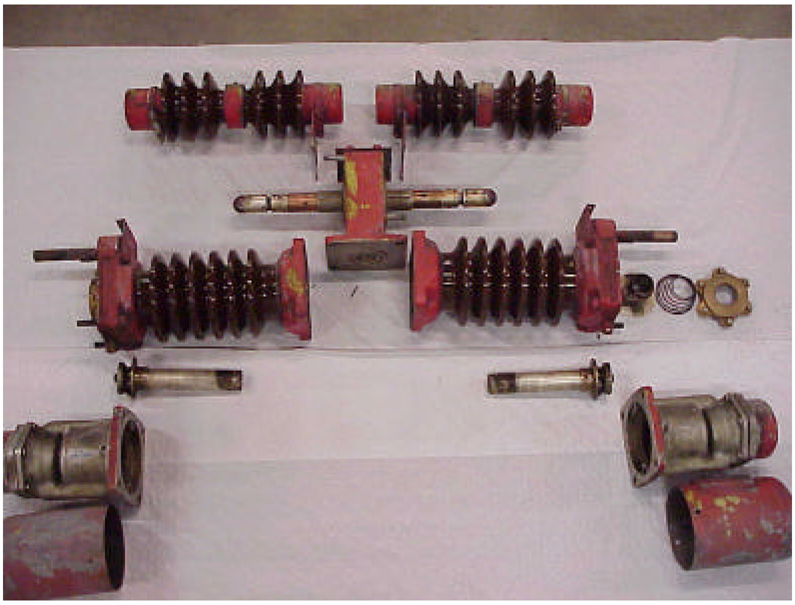

Photo 1: The disassembled pole 8

The next two pictures are showing the burning in due to the internal arcing on the mobile and fixed contact.

Photo 2: The fixed contact

Photo 3: The mobile contact

From the recording of figure 3 can also be seen that there was no fault on the line 70.64. The line tripped in back-up at the Mons substation, due to the non clearance of the fault on the line 70.54. As already stated above, once transformer Obourg T11 150/70/6 kV has tripped, the 70 kV substation of Obourg passes at zero voltage and as for transformer T1 70/10 kV also the breaker Mons 70.64 trips subsequently by clearing.

But what happened with the line 150.53 and why did the breaker of the line Trivières 150.71 at the Ville sur Haine substation trip. For the line 150.53 it was also the fault recording from the DFR installed at the Obourg substation that gave a correct view on what happened. From figure 4, also part of the same record as for the fault on the line 70.54 can be seen that the line 150.53 is only hit 100 ms after the inception of the fault on the line 70.54. This moment coincides with the internal restrike of breaker 70.54 at Obourg substation, but has to be classified as by chance.

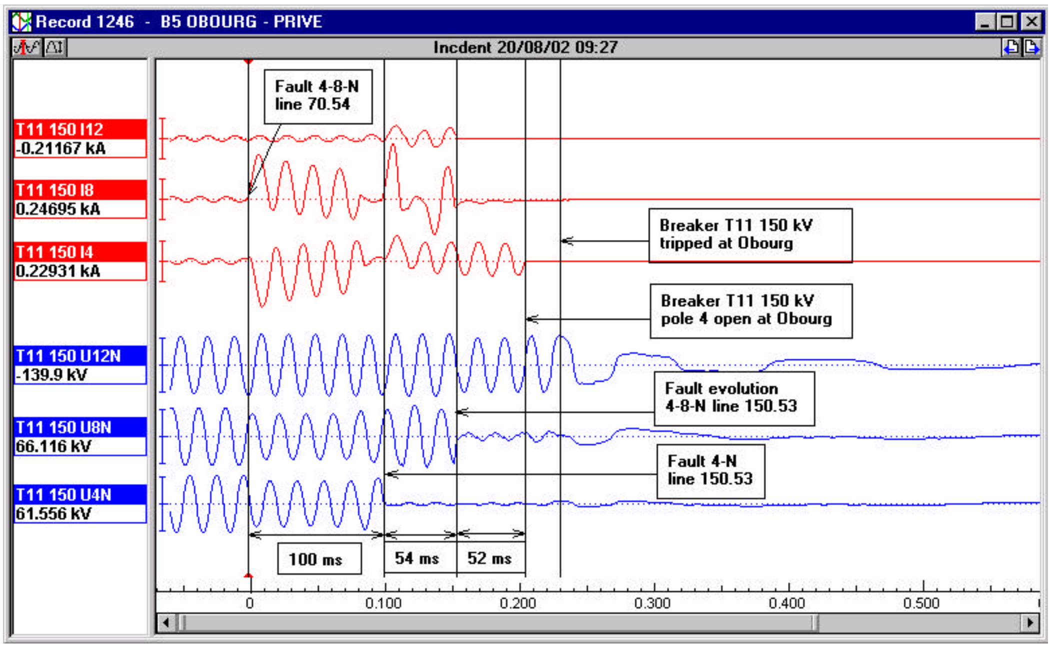

Figure 4: Registration of currents and voltages of line 150.53 at Obourg substation

From the recording can furthermore be seen that 54 ms after the fault 4-N on the line 150.53 the fault is evolving to a 4-8-N fault. This fault evolution has had a small impact on the further cause of the incident. As about 106 ms after the beginning of the fault the 150 kV breaker of transformer T11 performs a single pole opening of phase 4, which is normal, since on 150 kV and above single phase tripping is applied for single-phase faults on lines. But due to the evolving nature of the fault, the differential line protection has converted the single pole order into a three pole order and some 26 ms later the 150 kV breaker of transformer T11 trips the remaining other poles, and blocks the autorecloser. This explains also why the Control Centre had to perform a manual reclosure on this breaker.

So the only problem left was to find out why the breaker of the line Trivières 150.71 tripped at Ville sur Haine substation. Therefore the registration of the DFR located at Ville sur Haine substation was used.

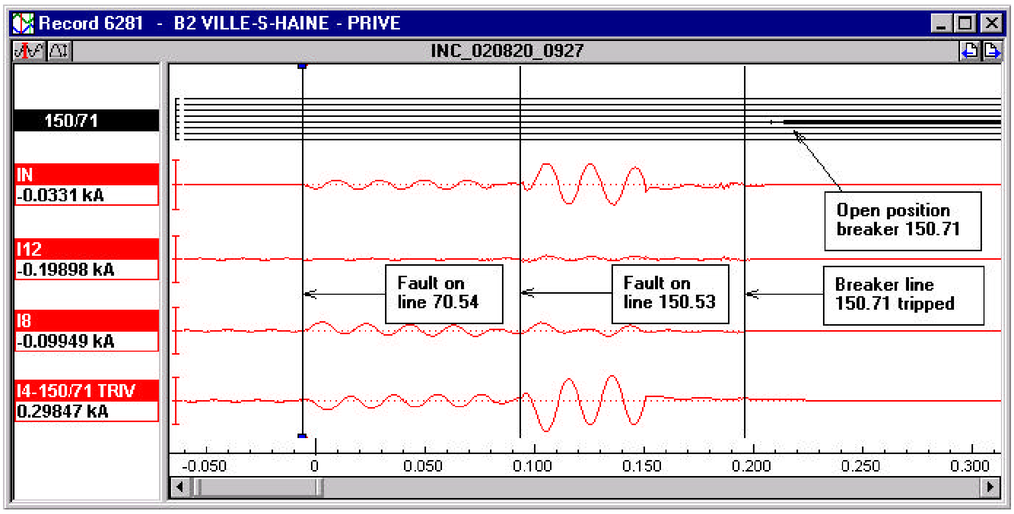

Figure 5: Registration of currents and digitals of line 150.71 at Ville sur Haine substation

From the record, shown in figure 5, can be seen that the breaker tripped about 202 ms after the beginning of the fault on the line 70.54, or 102 ms after the beginning of the fault on the line 150.71. This ascertainment was used to suppose that the tripping of the breaker was ordered during the fault on line 150.53. Furthermore the tripping contact of the distance relay did not show up on the logical channels for the line 150.71, the only logical channel attracted was the open breaker position. So it was assumed that the tripping was ordered by the differential line protection, as the tripping contact is not registered. But some questions remained open: "Why did the differential protection only trip at one side, why not immediately after the beginning of the fault on the line 70.54. Also the older electromechanical differential relay installed, type RN27b of Siemens, had proven reliability statistics, and the last preventive maintenance on the relay panel was carried out some two weeks ago" All of this made that the origin of the problem was probably to be found on the differential relay, installed on the line 150.71 at Trivières substation. All this proved to be right as field technicians found an open circuit on all three phases on one winding of the current transformer.

Investigations carried out on the three current transformers showed that all of the three current transformers didn't suffer a lot of the open circuit, beside of a premature ageing. The non-destruction of the current transformers was averted by the presence of four windings, thus limiting the voltage raise on the open winding, and a rather low load current on the line. But as a precaution all of the three current transformers were replaced.

From the fault described above can clearly be seen that an in-depth fault analysis, making use of records coming from DFR's, together with a well-known protection plan can be a basic input for maintenance and so improve the overall reliability of the network.

<u>Case 2 (Fault caused by a circuit breaker)</u>

Due to a problem with the 150 kV oil-filled cable Drogenbos – Ixelles 150.641, some switching operation had to performed at the Ixelles 150 kV substation. To put the cable 150.641 out of service also transformer T3 150/36 kV at Ixelles substation has to be switched off as shown on the single line diagram presented by figure 6.

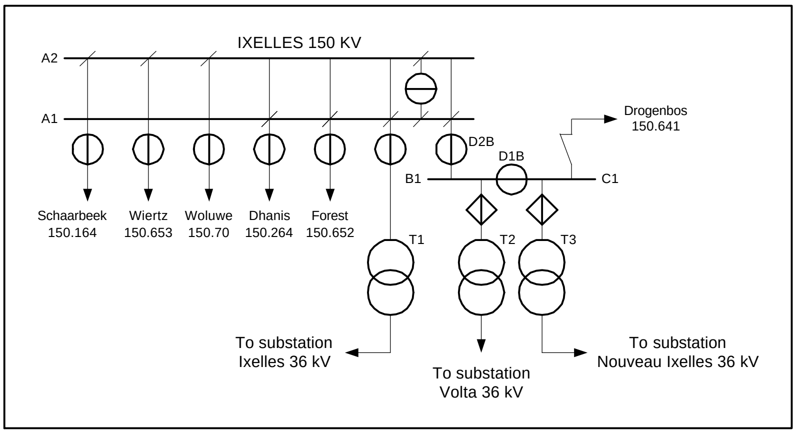

Figure 6: Single line diagram of Ixelles 150 kV substation

The disconnection of the cable 150.641 took place early in the morning of June the 23rd 2003. In normal situation transformers T1, T2 and T3 located at Ixelles substation are feeding the load of the Southern part of Brussels capital. Thus once the cable isolated and grounded, the Control Centre wants to bring back transformer T3 in service, as this is necessary to meet the N-1 criteria. The switching operations on cable 150.641 were finished about 11:00 AM, and immediately after the Control Centre wants to bring transformer T3 back into service, for reasons as described above. This operation is done at 11:09 AM by closing breaker D1B at Ixelles 150 kV substation. At the moment of switching in a fault occurs on a 150 kV bushing of transformer T3.

Investigations showed that the fault was due to a high overvoltage caused by a synchronising delay on one pole of the breaker D1B, type MHM 170 of Magrini. This synchronising delay was found coming from an internal problem in the command box EPM 255 of one phase, being an improperly fitted circlip in one of the electrovalves used for closing all three poles of the breaker. Also a deformation of the circlip was noticed, which caused the circlip to leave its location. This has as a result that the valve is more relaxed and thus the speed of switching in of that pole is slower than the two other poles. The next two photographs are showing the electrovalve and the deformation of the circlip.

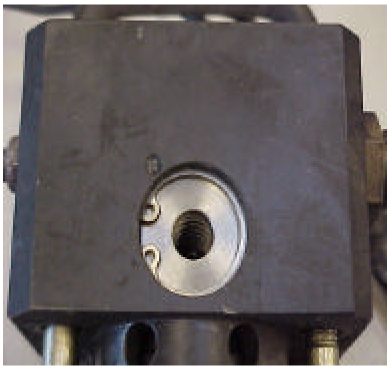

Photo 4: The electrovalve

Photo 5: The electrovalve disassembled

So the origin of the fault was rather quickly found but one question remained unanswered. Was this problem with the circlip in the electrovalve a single problem or could it be that other command boxes EPM 255 would suffer from the same problem? In order to solve this problem rapidly without the need to plan outages, allowing the isolation of the breaker and consequently the check of the electrovalves on site, it was decided to look up where breakers of this type MHM 170 combined with a command box EPM 255 are installed and see if also a DFR is installed at that substation. The aim was then to control the last switching operation of the breaker registered by the DFR, as each DFR is triggered for switching operations. One of the results of this lookup is shown with the next figure 7.

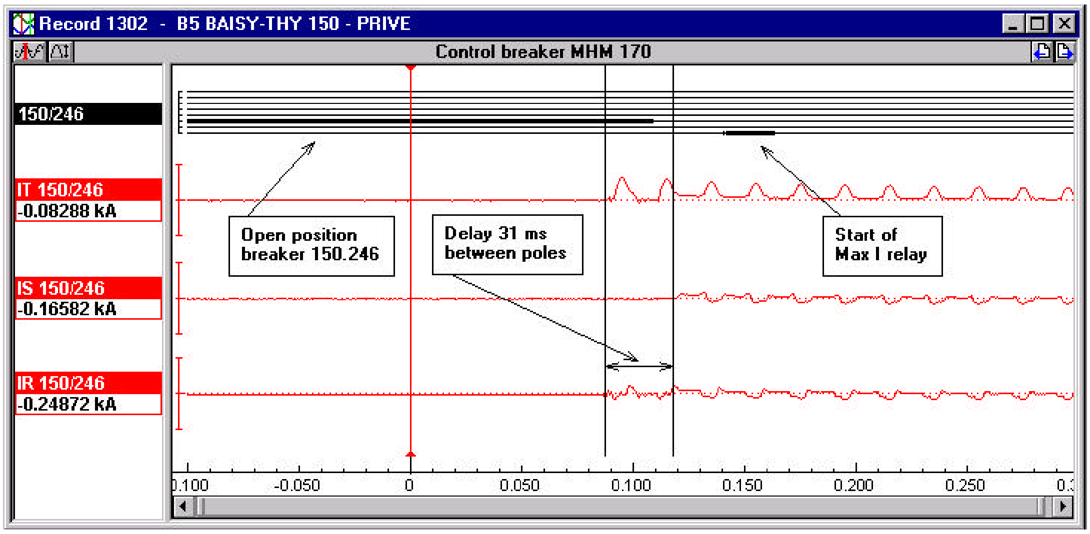

Figure 7: Registration of currents and digitals of line 150.246 at Baisy-Thy substation

Figure 7 shows the switching in of the line 150.246 at Baisy-Thy substation. At the line end a transformer 150/36 kV, without a breaker at 150 kV side, is connected. In the recording of the inrush current of the transformer a delay can clearly be seen between phases R and S, and S and T respectively. This delay was also due to the earlier mentioned problem with the circlip in the electrovalve of the command box EPM 255 for breaker MHM 170 of Magrini. In some other cases almost the same registration could be found, not necessary with a delay as high as showed in figure 7.

As a result of this investigation Elia has decided to replace all circlips of the electrovalves on all command boxes EPM 255 during the next maintenance of the breaker equipped with the specified command box. It is important to mention that by using DFR registrations, which are normally not verified, no reporting of an incident by the Control Centre, a certain amount of outages to schedule have been avoided in this case.

Conclusions

Today more and more other points of interest beside the traditional one, understanding the cause of an incident, can be connected to fault analysis. One of these new points of interest, maintenance management, has been highlighted with the study of two real cases. The first case, an incident due to lighting strike, shows that an in-depth fault analysis can be a basic input for maintenance. What seemed to be a normal incident, origin of the fault well known and almost correct elimination of the fault, showed that there was an immediate need for maintenance on two non suspected assets of the network. The second case, a problem with a command box of a breaker, shows that by the use of normally not verified DFR records a lot of outages to plan could be avoided. Instead of controlling some suspected command boxes on site, use has be made from DFR records to check the switching in of the breaker, thus allowing to determine that the mentioned problem was also present on other command boxes of the same type.

From both examples can be seen that fault analysis can be used as a basic input for maintenance management to improve the overall reliability of the network. In the first case the reliability demand of the network was influenced, just in time maintenance on suspected assets. In the second case the availability demand, by avoiding some scheduled outages.

Authors Biography

Patrick De Cuyper is born in 1964 in Belgium. He graduated in 1987 as Industrial Engineer in Electromechanics at KIH De Nayer (Mechelen, Belgium) and started working in 1988 as protection engineer within the Protection and Fault Analysis Departement of LABORELEC. In 1995 he became Head of the Fault Analysis and Statistics Group within the Protection and Fault Analysis Departement. In the context of the deregulation of the electricity market he joined in 2000 the new created Belgian TSO, Elia System Operator NV and Elia Asset NV, to become Fault Analysis Manager within the Infrastructure Departement of Elia Asset NV. At the begin of 2004 he stepped over to the Grid Services Departement of Elia Asset NV, to become responsible as Service Manager for all Low Voltage secondary equipment for the Service Area North.