Double earth fault in a PSP during back to back launching sequence

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Pump Storage Scheme, back to back launching

Electricité de France Hydro Department operates monitors and maintains a fleet of more than 1000 machines totaling 20 000 MW+ Among these, 5000MW are pump storage schemes commissioned in the 1980s to help balancing nuclear power. In recent years, these units, thanks to their flexibility, are being operated with very high duty and high cycling, some being started 6 times per day.

The motor generators being used in these PSP are of synchronous type and are no longer started with direct switching to the grid since this very brutal sequence led to quick rotor ageing. Hence, EDF went for softer launching sequences, either using poney motor, static frequency converter or back to back.

The scheme involved in this case study uses back to back launching mode. The PSP is equipped with generators driven by Pelton turbine that are used as driving units and with motor generator connected to a pump turbine which are the driven units. Each of these units is rated 170MVA with stator voltage being 15.5kV.

The back to back launching sequence includes the following steps:

- Both stator windings of driving and driven units are connected together through an IPB and breaker
- Both field windings are energized
- The driving unit is then ramped up to speed with its turbine
- The driven unit rotor follows the same speed ramp up
- The driven unit is synchronized to the grid (speed controlled by driving unit and voltage controlled by its AVR)
- The driven unit beaker is closed to grid
- The driving unit is disconnected from driven unit

Insulation failures during launching sequence

During back to back sequence, the protection scheme has to be elaborated so as to protect both units from electrical faults. The units are equipped with stator earth fault, differential, overvoltage, overcurrent tripping relays. Since both stators are connected, the circuit is protected against earth fault with the driven unit relay; the driving unit star point is open.

As a matter of fact, a fault occurred during this launching sequence and the following protection were activated:

09:48:29.640	Driving U	Stator earth fault
09:48:00.600	Driving U	Rotor earth fault
09:47:58.960	Driving U	Generator CO2 emission
09:47:58.920	Driving U	Field breaker open
09:47:58.800	Driving U	Grid breaker open

09:47:58.640	Driving U	Différential protection
09:47:58.520	Driving U	Excitation thyristor fuse melt
09:47:58.480	Driven U	Stator earth fault

The inspection undertaken after the fault showed several damages on the driving unit stator and rotor, but no damage on the driven unit at all, even though the insulation resistance of the driven unit circuit was almost zero.

On the driving unit both stator and rotor were severely damaged.

On the stator, a partial melt down of one stator bar was found and the adjacent core clamping finger had also partially melted.

The stator core showed several hits on the lamination

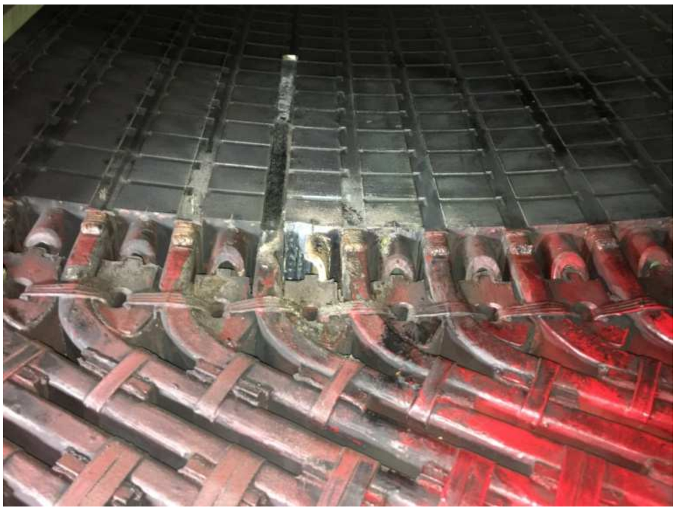
Two rotor poles were damaged, showing zero insulation resistance and interturn faults.

The rotor earthing brush had melted. Melted iron was also found on upper bracket gland seal bearing cover.

On the driven unit side, the stator winding was meggered on its own and showed high insulation resistance values; whereas the IPB duct meggering showed poor values. These IPB ducts being in a humid ambient, with some water dripping, the insulators had surface contamination.

Cleaning the insulators and blowing dry air in the IPB ducts and gallery were undertaken, eventually the insulation resistance of IPB was restored and the unit could be put back on line in a matter of days.

The set of pictures below show the damages suffered by the driving unit:



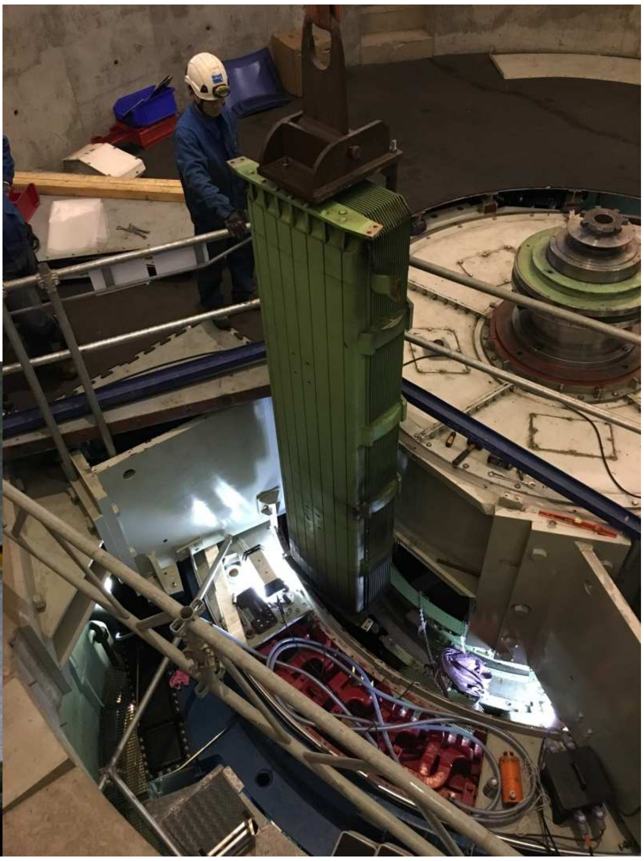
Damaged stator

Melted stator bar and finger

Melted finger and melted lamination

Impact on stator winding

One of the many impacts on core



Faulty pole being removed

Pole 1 with arcing evidence between winding and body

Pole 2 with interturn fault

Most likely failure scenario

Among the various scenario that were built to explain the fault sequence, the most probable one involves a double earth fault, one in each generator (the driving and the driven one).

The fault was very likely triggered in the driving unit where a forgotten foreign object must have impacted the stator winding. A screw driver end was later found in the bottom of the generator end windings.

Simultaneously, the driven unit IPB had a very poor insulation resistance because of heavy moisture in the IPB gallery. The IPB insulation was found to be almost zero after the fault and resumed to several megohms after 2 day drying.

Hence, as the first earth fault resulted in a voltage potential increase of the neutral side and a potential increase to phase to phase voltage of the phases, the latent IPB fault broke down resulting in a double earth fault on two different phase of the electrical circuit.

Whereas the single earth faults currents are limited thanks to neutral impedance, a double earth fault (identical to a phase to phase fault) is only limited by the fault path resistance which is rather low and leads to very high current and important damages. Let’s note that the damages were not as severe as a phase to phase fault with the generators connected to the grid since the short circuit power was in this case moderate.

The almost instantaneous variation of stator current induced a very important voltage on the rotor side, which led to arcing between the 2 poles (input and output poles) and rotor body. The voltage surge was strong enough to damage inter turn insulation on one pole.

Repairs

The repairs that were required on the driving unit we rather extensive and removing was a relevant question but it would lead to a very long outage as the thrust bearing is above the rotor (5 to 6 weeks for mechanical works alone). Hence after checking in details the feasibility, repairs have been performed with the rotor in the stator.

3 poles were removed to give access to the stator and provide working space for the winders.

Spare Roebel bars were available at the plant, therefore the melted stator bar was replaced with a spare one.

Repairing he melted core clamping finger and part of the lamination was more of a challenge. The shape had to be “rebuilt” with glass fiber and epoxy bonding. And the pressure function and the proper lamination insulation had also to be secured. This was achieved using conic wedges inserted in between lamination. As an extra safety against hot spot, a thermocouple was placed in the repaired area to check the core operating temperature. A specific heat run test was carried out for this purpose.

clamping finger repair

The core impacts were ground and checked with El Cid for any stray current.

The two faulty rotor poles were removed. One coil had to be replaced with the spare coil, the second one was cleaned from arcing dust and recovered perfect insulation resistance including interturn insulation.

On the driven unit side, no extensive work was required. Only, the IPB ducts had to be cleaned and dryed to recover an acceptable insulation resistance.

Eventually, 5 weeks after the fault, repair was complete and the driving unit resumed service.

The commissioning tests included: rotor insulation resistance (500Vdc), stator insulation resistance (5kVdc), stator high pot (30kVdc), voltage ramp up, heat run of core, back to back start.

Lessons learnt:

The units described above failed due to the conjunction of several causes that taken individually would not have harmed the equipment so much.

It may be noted that the triggering fact, which could have been avoided, is the presence of a foreign object left in the generator. Such an event shows how important it is to check and double check the tool box completion, the generator cleanliness and to work with empty pockets.

The second factor is linked to heavy moisture in the IPB gallery. It shows the importance of housekeeping and drying in the electrical galleries, rooms and shafts. Water droplets have to be kept away from electrical components, sheds or drainage pipes have to be implemented to prevent insulation loss.

Ultimately, this event showed the importance of an adequate protection scheme to disconnect power during any operating sequence.