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Single-rotor protection

for double-induction and variable speeds

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PROTECTION & CONTROL RENEWABLES
STORAGE WIND

Variable-speed double-fed induction machines now have a rotor-dedicated protection relay. Called P348, it is the first of its kind. Built from scratch, it overcomes issues of very low frequencies and offers fast protection thanks to a patented protection system incorporating a new algorithm.

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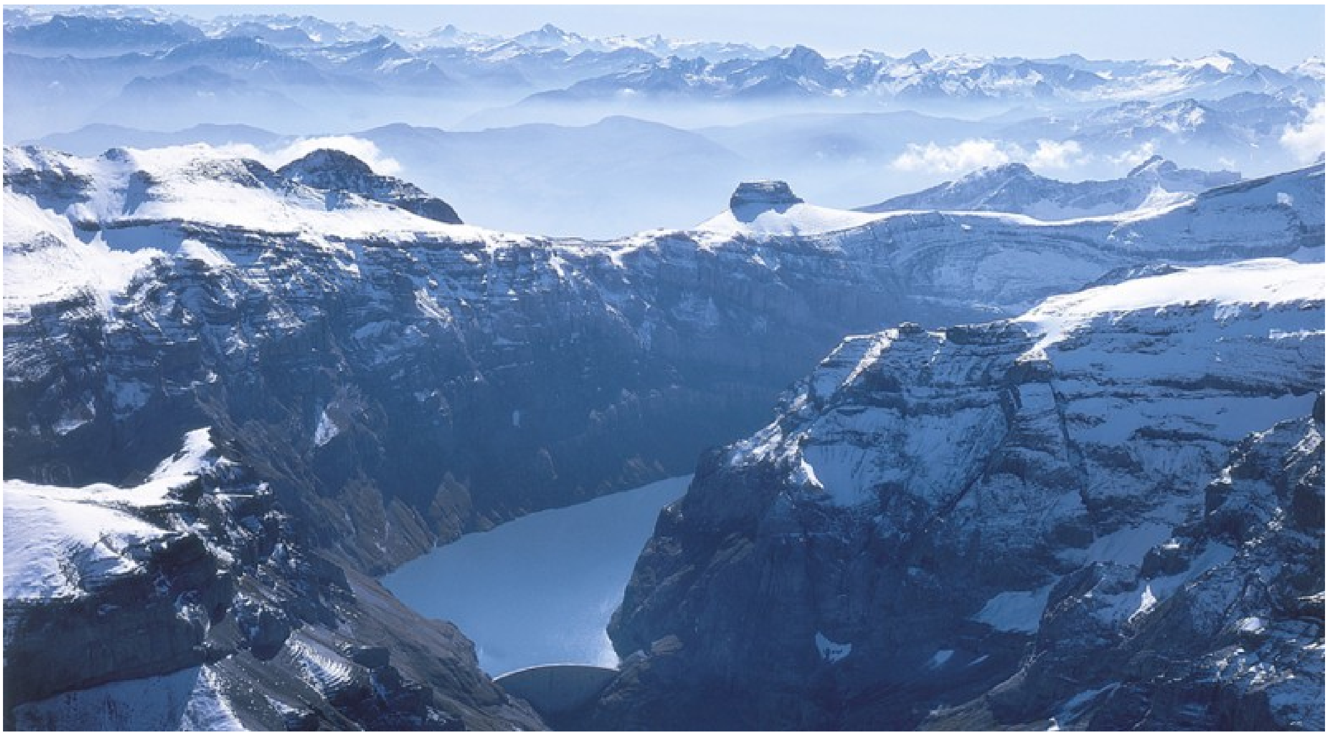


Variable speed pumped storage hydro power plant – Limmernsee

1__Fast protection at low frequencies

Although double-fed induction machines (DFIMs) have been around for some time, it was the rise of wind power for electricity generation that brought them into widespread use. Double-fed induction is also the design of the variable-speed motor-generators used in pumped storage, which is the most efficient way to store renewable power on a large scale rather than use it or lose it.

"Variable-speed DFIMs come with a number of advantages," explains Alexander Schwery, Director R&D Electrical at Alstom Renewable Power. "They operate as fast-response generators and as motors, pumping water back into the elevated reservoir (which acts in effect like a battery).” Indeed, their twin motor/generator capability makes them valuable load balancing tools. And their power electronics are small in size and low in cost and power loss compared with a fully converter-fed synchronous machine.

But, believes Schwery, the advantage of a large-scale variable-speed DFIM is its flexibility and dynamic power adjustability – much greater than anything a standard synchronous machine can offer. Whether it is acting as a motor or generator, its operating point can be changed.

“With DFIMs you can change the operating point when they’re pumping,” he explains. “You adjust the amount of power the machine absorbs to pump the water. On standard machines the speed is fixed so they only take a fixed amount of energy. You can’t really follow the changes in the pattern of wind generation on the system. But with DFIMs you can.”

P348 rotor protection relay

2__Rotors unprotected

So far, so good.

However, Alstom Renewable Power voiced concern over rotor protection in its new DFIM. The machines had standard protection for the stator winding, not for the rotor. And they relied on the power electronics' system to detect overcurrent and overvoltage faults. What Alstom Renewable Power wanted was a rotor-specific, independent protection relay.

It was the start of a project that would involve mapping unchartered territory. "We had the very basic relay hardware," explains
Graeme Lloyd, Protection Group Leader at Alstom Grid in the UK, "and we leveraged our experience from other projects with digital instrument transformers."
The project, which brought together several countries and Alstom sites, would eventually yield the now commercially available – and patented – P348 protection relay.

3__Challenge #1: low frequencies

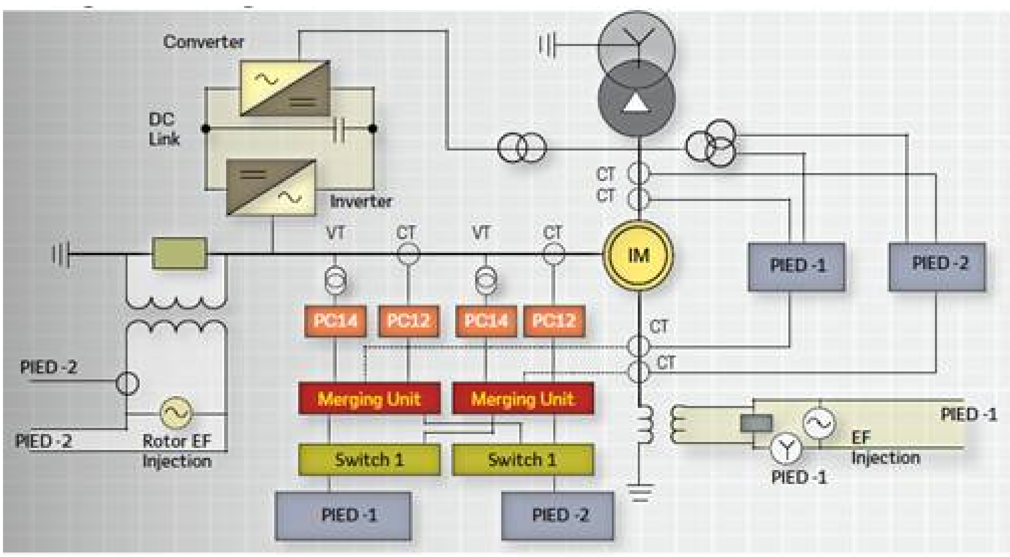
Lloyd and his team had to address 2 major issues: how to measure low frequencies and deliver fast protection.

The rotor speed of the variable-speed DFIMs depends on the frequency of the currents fed by the power electronics converter from the
AC system. During normal operation, current and voltage frequencies range between 0.1 and 6 Hz, and at start-up and braking they range between zero and rated grid frequency. "The

operating slip frequency – the difference between the rotor's rotating speed and the stator's synchronous 50 Hz – is very low," explains Lloyd.

Such low frequencies were clearly beyond the reach of conventional electromagnetic current and voltage transformers (CTs and VTs), which are typically designed to operate only on 50/60 Hz signals on the network and cannot detect DC fault currents. Or they would have to be unfeasibly huge – even bigger than they already are for low frequency measurements.

Conventional protection did not fit the bill. What then of digital instrument transformers (DITs)? That again was a challenge because protection relays, too, are designed to work at 50/60 Hz with mostly 1 A/5 A secondary-rated CTs and 110 V secondary for VTs.



Single line diagram of variable speed machine protection

4 __New sensors

However, round about the time the project began, new kinds of sensors were becoming available – optical and Rogowski sensors that could measure DC and work at low frequencies.

The project team first explored the potential of optical instrument sensors which, rather than providing a 1-Amp or 5-Amp analogue current output, say, would output a data stream of sampled values of the primary current from these non-conventional types of CTs. They effortlessly measure low frequencies, but were too expensive and so were not selected for this application. That left the Rogowski CTs. “We were unsure of the Rogowski CTs”, says Lloyd, “because of the phase shifts they produce and attenuation at low frequencies.” However, testing at the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland would dispel those misgivings. “To measure voltage at low frequencies, we went for resistive voltage dividers.”

5__Challenge #2: ensuring fast protection

The second major issue was to ensure fast protection. Protection relays that used standard Fourier-based algorithms were not designed to protect at low frequencies because the protection algorithms typically need at least one cycle of data before they trip. To extract the fundamental component, Fourier algorithms are used where the sampling rate is tuned to tracking the fundamental frequency. “Tripping speed slows right down when the tracked rotor frequency is low. At a frequency of just 1 Hz, that’s one second per cycle – enough for the machine to be in danger of being damaged," says Lloyd. "You need to be operating within the 10 ms to 20 ms range."

The development team had to develop new algorithms from scratch. To achieve fast protection they designed peak protection algorithms that used a fixed sampling rate and used directly sampled overcurrent and overvoltage values. Plus rms (root mean square) measurements for overcurrent and over-voltage protection. Although rms is not as fast as peak, it does offer the advantage of a steadier measurement.

6__Testing times

In early 2014, the new protection relay was first tried out at the EFPL in Switzerland in the Electrical Machines Group directed by Dr Basile Kawkabani. Rogowski CTs and voltage resistive divider sensors were integrated with a merging unit and primary converters, and faults were applied on the rotor circuit and the stator. "The Alstom Research Centre in Villeurbanne had designed converters that created a data stream from the low voltage output from the sensors," adds Lloyd. "They had also adapted the filters to measure low frequencies. The connected merging unit produced a digital output of sampled values in a format compliant with the recent standard IEC 61850-9-2 LE, which defines the protocol for connection to the P348 relay."

Results were encouraging, while simulator testing back in the UK demonstrated that the innovative peak and rms protection delivered fast, accurate protection. Factory acceptance tests are under way and the Systems team at Alstom Grid in the UK is currently completing the cubicles. The first commissioning is slated for the summer of next year.

Testing at EPFL

The Electrical Machines Group, headed by Dr Basile Kawkabani at the École Polytechnique Fédérale in Lausanne, Switzerland, was the venue for testing the new protection relay on a small 3.3 kVA DFIM.

Three-phase Rogowski current sensors were connected to the rotor and stator, while voltage dividers were connected to the rotor terminals. All the sensors were connected to an IEC 61850-9-2 LE protection relay input through primary converter and merging units. The faults applied to test protection were: three phase, phase phase, and phase to ground. The currents supplied to the relay for the tests were increased by winding 320 primary turns on the Rogowski CTs to represent the larger currents that would be present on a large machine.

Testing with NCITs at EPFL

The peak and rms rotor and stator overcurrent protection was set to 120% of rated current.

The rotor and stator peak and rms overcurrent stages began operating soon after the fault kicked in. The peak protection picked up faster than the rms as expected and the protection stages tripped in the expected time in order to ensure correct peak time delayed protection operation.

The peak three-phase fault current on the real machine at EPFL was 49 kA on the rotor and 6.8 kA on the stator as shown. The three-phase fault current at 5 Hz is many times the overcurrent protection setting so that the overcurrent protection can easily detect these faults and trip quickly.

Machine parameters	Representative test bench DFIM	Large hydropower DFIM
Rated apparent power	3.3 kVA	300 MVA
Stator line voltage	400 V	18 kV
Rotor current	20 A	6 kA
Rotor line voltage	0 to 60 V	0 to 5 kV

Pole pairs	2	6
Rated speed	1500 rpm	500 rpm
Slip range	±10%	±10%

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Alexander Schwery
Director R&D Electrical

Dr Basile Kawkabani
Senior Scientist

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