Improving condenser hotwell monitoring with advanced cation conductivity instrumentation

Dr. Lena Johansson
Axpo Power AG, Switzerland
lena.johansson@axpo.com

Dr. Irene Mailand
Axpo Power AG, Switzerland

Manuel Sigrist
Julia Gath
SWAN Analytische Instrumente AG, Switzerland

Dr. Patrick Franz
Axpo Power AG, Switzerland

Abstract

Beznau Nuclear Power Plant comprises two identical 380 MWe PWR units with two loops each, commissioned in 1969 and 1971, respectively. Westinghouse built the primary part of the plant and BBC/ABB the secondary circuit. Since Beznau NPP is an old plant, it has undergone an extensive modernization program in the course of the past 25 years, with cumulative investments summing up to 1.5 billion Swiss Francs.

Important modernization measures were the replacements of the steam generators with tubes made of Inconel 690 TT, which were realized on unit 1 in 1993 and on unit 2 in 1999. Copper has been completely banished from the secondary system and replaced by stainless and chromium steel. Moreover, the condensers have been fitted with titanium tubes. As a result of these changes, it was possible to consider changes in the secondary water chemistry regime which was gradually adjusted from low-AVT with a pH of about 9.3 to high-AVT with a pH of 9.8 to 9.9.

The modernization at Beznau NPP is an ongoing process, involving not only large components but also smaller equipment and auxiliaries. This paper will focus on the modernization of the online water chemistry instrumentation in the secondary circuit. Conductivity measurement after a cation exchanger (CACE) is still the most commonly used online analytical method in power plants with steam generators. However, the passive cation exchanger resins require tedious periodic replacement. In nuclear power plants, operating at high pH, the replacement of the cation exchanger resin, as well as the processing of used resin, is a time consuming and costly activity for the plant chemists and operators.

Beznau NPP has extensively tested a new conductivity measurement device using electro deionization (EDI) as a substitution to the conventional passive cation exchanger resin. After a test phase of several months, the new technology was first installed in the condenser hotwell monitoring station. The new set-up has two main benefits:
First, the comfort and safety of operation of these remote subsystems is, with the reduction of routine maintenance work related to resin replacement, greatly improved.
Second, the response time of the measurement is significantly faster than with the traditional arrangement, due to the much smaller amount of resin used in the EDI instrument.

This paper describes the measurement method used, as well as the physical and hydraulic set-up of the new local condenser hotwell sampling and monitoring. Operating experience and data comparing of traditional and new cation conductivity measurements in condenser hotwell applications is shown.

Improving condenser hotwell monitoring with advanced cation conductivity instrumentation

Introduction

Beznau is a nuclear power plant with now almost 50 years of experience. Over the past 25 years Beznau has undergone many modernization measures, e.g. reducing the copper content of large components or improvement of the water chemistry of the secondary circuit. The modernization at Beznau NPP is an ongoing process, but also involving smaller equipment and auxiliaries. This paper will focus on the moderization of the online conductivity monitoring of the condenser hotwell in the secondary circuit.

Conductivity is the most common summary parameter for the monitoring of ionic contaminations in water/steam cycles. As volatile alkalizing agents such as ammonia used to achieve alkali conditions in the cycle dissociate into cations, these substances contribute significantly to the base conductivity of the water, masking the contribution of unwanted contaminants. In this paper, two methods to achieve the cation exchange prior to the conductivity sensor and their impact on the CACE measurement are compared: conventional cation exchange resins and electro deionization (EDI) with several examples of operating experience, showing the advantages of the EDI technology.

Modernization measures in Beznau NPP

In the late 1960's when Beznau NPP was built, many copper alloys were used in the secondary circuit. The condenser, low pressure pre-heater tubes and moisture separator pre-heaters were all made of brass (copper/zink alloy) and the original steam generators tubes were made of Inconel 600 MA. The Inconel 600 MA was found to be unstable regarding primary stress corrosion cracking (PWSCC) and were replaced in both units. Besides the replacement of the steam generators, numerous other components have been replaced using more corrosion resistant materials, which are summarized in Table 1.

Table 1:
Original and current materials used for main components of the secondary circuit

Equipment	Original material (tubes)	Current material (tubes)	Replacement date	
			Unit 1	Unit 2
Steam generator	Inconel 600 MA	Inconel 690 TT	1993	1999
Condenser	70Cu29Zn1Sn(As)	Titanium	1992/1993	1998/1999
Low pressure pre-heater 1 and 2	70Cu29Zn1Sn(As)	Stainless steel X10CrNiTi18.9	1973/1974 1990/1991	1973/1974 1990/1991
Low pressure pre-heater 3	70Cu29Zn1Sn(As)	Stainless steel X10CrNiTi18.9	1992	1993
High pressure pre-heater	St15Mo3	Stainless steel X10CrNiTi18.9	1996	1996
Moisture separator reheaters	90Cu/10 Ni	Stainless steel X2CrNi18.9	1977/1993	
	St15Mo3	Stainless steel X2CrNi18.9		2007
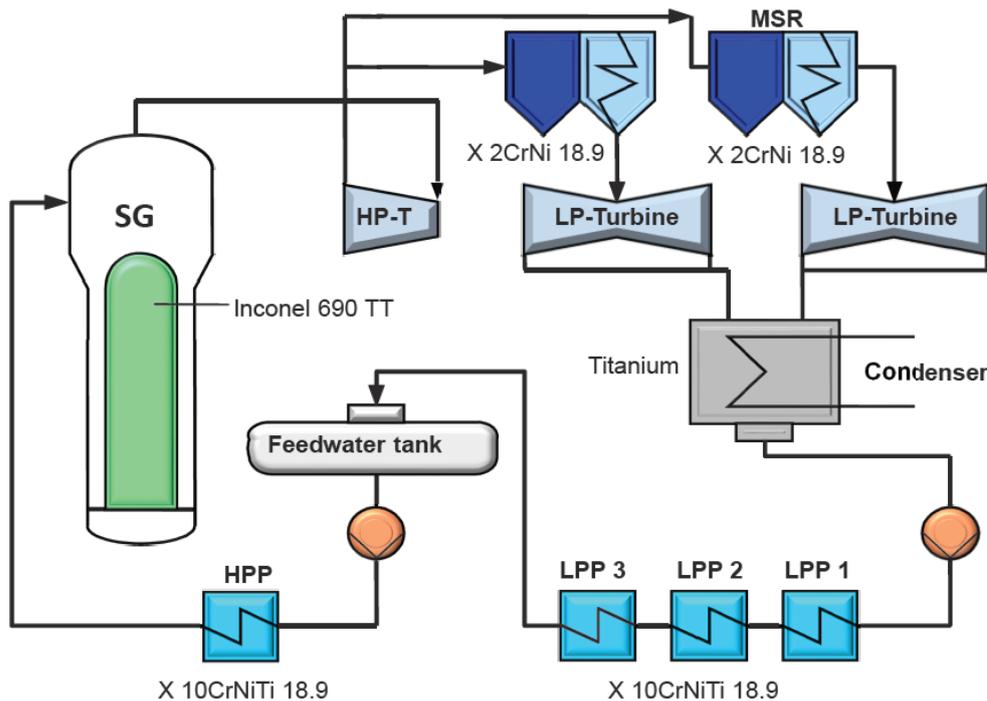
Figure 1: Current material concept of the secondary circuit at Beznau NPP [1]

SG   steam generator
MSR   moisture separator reheater
HPT   high pressure turbine
LPT   low pressure turbine
LPP 1, 2, 3   low pressure pre-heater 1, 2, 3
HPP   high pressure pre-heater

Furthermore, a large number of pipes and tubes made of carbon steel have been replaced by stainless steel, in order to prevent flow accelerated corrosion.

Improvements of water chemistry

The early design of the secondary circuit with mixed iron and copper-based alloys was problematic in two aspects. The presence of copper materials requires a lower alkaline pH than what is necessary for the protection of ferrous materials. At higher pH values copper oxides are produced. These may become a source of intergranular stress corrosion cracking of the steam generator tube material.

After copper was completely banished from the secondary system and replaced by stainless and chromium steel, it was possible to consider changes in the secondary water chemistry regime. Gradually the chemistry was adjusted from low-AVT (All Volatile Treatment) with a pH of about 9.3 to high-AVT with a pH of about 9.8 to 9.9 [1].

During normal operation, the following values are typical for high-AVT chemistry in Beznau NPP:

- pH value in the condensate between 9.8 and 9.9,
- oxygen concentration from 2 to 3 ppb,
- cation conductivity of the steam generator blow down water between 0.11 and 0.15 µS/cm.

Improving condenser hotwell monitoring with advanced cation conductivity instrumentation

To obtain low oxygen concentrations it is important to continuously evacuate the condenser and to degas the water in the feedwater tank. The alkaline pH and the reducing conditions are regulated by adding hydrazine after the high pressure turbine. Beznau NPP does not utilize condensate polishing, therefore it is possible to add the hydrazine before the condenser. The advantage is that already in the condensor alkaline and reducing conditions are achieved.

Hotwell monitoring

In a closed water steam cycle, the condenser has the function of evacuating the unusable heat energy of low pressure steam. The steam condenses to water which is fed back to the feedwater tank and into the water steam cycle. The cooling water used in the condensers in Beznau NPP is taken from a nearby river. The cooling water circulates through tube bundles running horizontally through the condenser. Condensate forms on the outside surface of the tubes and drops to the bottom of the condenser into the hotwell.
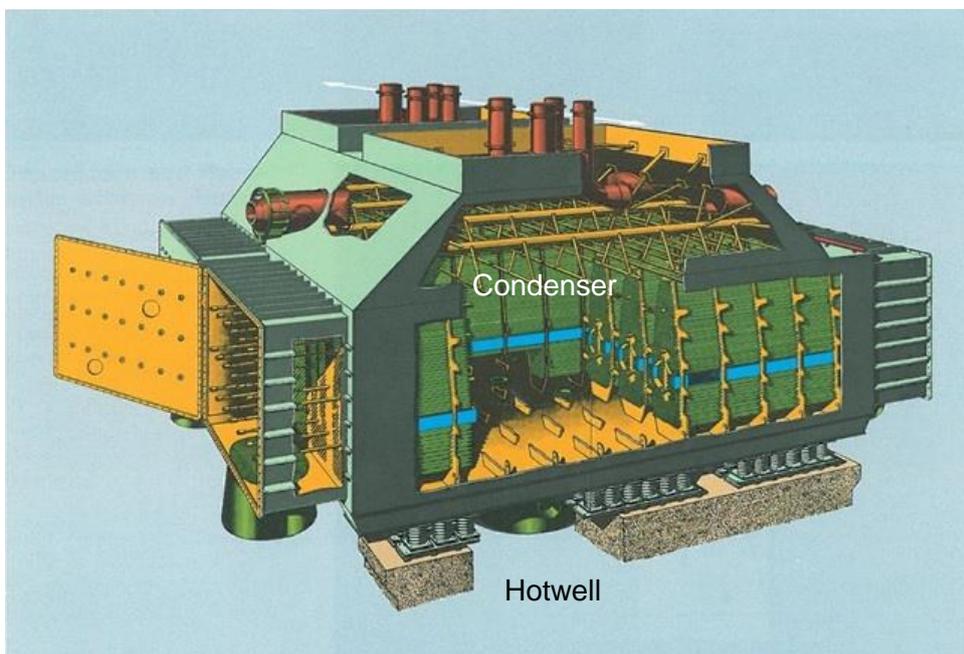
Figure 2: Schematic drawing of the Condenser and Hotwell at Beznau NPP

A vapor pressure inside the condenser at about 70 mbar absolute pressure (vacuum conditions) brings down the steam condensation temperature in the range of the cooling water temperature (25 – 50 °C). However, the vacuum in the condensers also sucks in contaminants from the outside. These contaminants can come from:

- Cooling water leaks at either the interface water box/tube bundles or leaks in damaged tubes.
- Air leaks through low pressure turbine seals and outlet flanges. This air will have two effects:
  o Oxygen will dissolve in the condensate and will need to be removed at later stage in the feedwater.
  o Carbon dioxide (CO_2) will dissolve in the condensate and will increase water conductivity.

As the condenser is an important potential entry point for contaminants into the water/steam cycle, it is essential to closely monitor the quality of the condensate downstream of the condenser. [2]

Improving condenser hotwell monitoring with advanced cation conductivity instrumentation

Hydraulics of hotwell sampling

Hotwell condensate at about 70 mbar pressure is always water at boiling point. The slightest pressure drop will immediately generate steam bubbles in the water. If such a sample is to be extracted from the hotwell, the extraction pump must be located far enough below the condenser water level to allow for a sufficient water head on the pump suction side. In Beznau NPP the conductivity measurement is located approximately 4 m below the condensate surface. It is also crucial to minimize pressure losses and avoid air traps from extraction point to pump. The arrangement in the sketch below shows a simplified P&ID of one of the condenser hotwell monitoring stations in Beznau NPP.
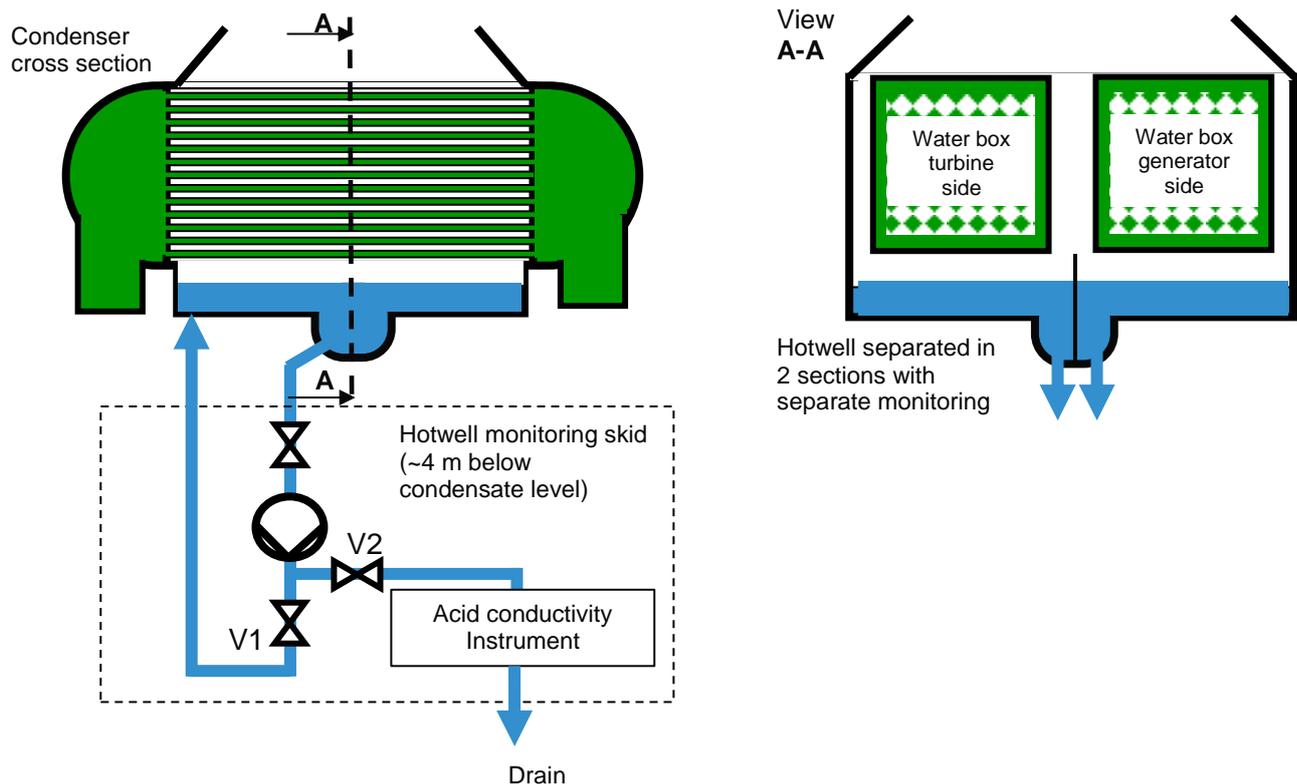
Figure 3: Simplified P&ID of one of the condenser hotwell monitoring stations in Beznau NPP

The sample is extracted from the hotwell using a circulation pump. This pump builds up some pressure against throttle valve V1 from which the sample returns to the condenser. The remainder of the sample flows through valve V2 to the acid conductivity instrument. The flow through the conventional conductivity instrument in Beznau NPP is about 8 – 10 l/h.

Conventional resin cation exchangers

The added hydrazine to the secondary circuit decompose at higher temperatures to ammonia, which significantly contributes to the base conductivity of the secondary water cycle, masking the contribution of unwanted contaminants (e.g. salts or acids). The condensate in Beznau NPP contains around 5 ppm ammonia and about 100 ppb hydrazine at a pH of 9.8 to 9.9.

In order to detect the unwanted contaminants, the conductivity is measured downstream of a passive cation exchanger resin. This is a standard procedure to determine conductivity after cation exchanger (CACE). It uses standard conductivity sensors and transmitters, but conditions the sample with a cation exchange

5

cartridge ahead of the sensor to remove ammonia which allows more sensitive detection of contaminants such as chlorides. The moment even a small amount of salt for example NaCl is added, conductivity shoots up drastically. The typical reaction on the cation column will be:

1) $Na^+ + Cl^- \rightarrow H^+$ ions $\rightarrow HCl + Na^+$
2) $NH_4^+OH^- \rightarrow H^+$ ions $\rightarrow H_2O + NH_4^+$
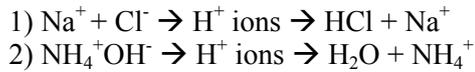
The cation exchange resins are charged with H^+ ions. These ions replace the positive ions of any salt or dissolved impurity, as it dissociates in water. In case 1), the cations replace Na ions and the outcome is HCl, i.e. the corresponding acid, with a 3 to 4 times higher contribution to conductivity. In case 2), the cations replace NH_4 ions and the outcome is water.

Due to the high ammonia concentration, the conventional cation exchange resins require periodic replacement. The frequency of replacements depends on several factors, such as type, quality and volume of the resin, as well as pH, temperature, flow of the sample, see Figure 4.

In Beznau NPP about 2 liter resin per instrument is used and the flow of the sample is around 8 l/h with a pH of 9.8 to 9.9, as mentioned earlier. This means that the resin in the hotwell monitoring stations has to be exchanged more or less every 8 weeks.
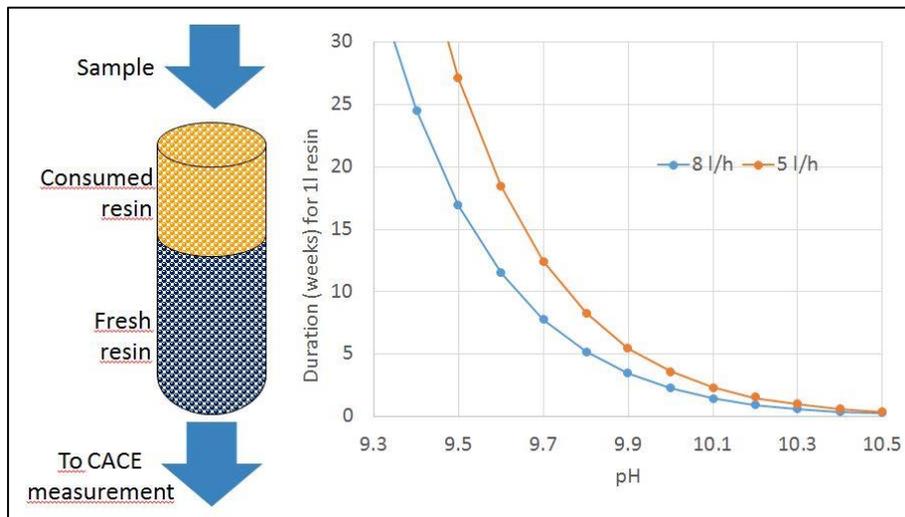
Figure 4: Cationic exchanger passive resin (volume 1 liter) – duration vs. flow and pH [3]

Another draw-back of conventional cationic exchanger resins is the bias they introduce to the cationic conductivity measurement, for instance leaching of fresh resin. After replacement of exhausted resin, the CACE values are biased to high levels due to leaching products until the new resin is sufficiently rinsed by the sample. In Beznau NPP the fresh resin is pre-rinsed to a conductivity of less than 0.1 μS/cm before replacement. However, there may still be some resin leaching to be seen after replacement.

In Figure 5 a hotwell monitoring station, with circulation pumps, conventional cationic exchanger resins and conductivity measurements for the turbine as well as the generator side of the hotwell, is depicted.

Figure 5: Hotwell monitoring station in Beznau NPP with conventional cationic exchanger resins, to the left turbine side of the hotwell and to the right the generator side.

Electro deionization

To address the issue of limited capacity of the conventional cation exchanger resin, an instrument combining cation exchanger resin and electro deionization (EDI) technology was developed. In recent years, water deionization using EDI has become more and more reliable and is wide spread in water desalination plants. The cation exchange of the sample takes place in a small compartment filled with cation exchanger resin and therefore maintaining the same working principle than conventional cation exchangers upstream of CACE measurements.

The advantage of the EDI lies in the continuous regeneration of the cation exchanger resin: the patented design features a resin bed housed between the anode and the cathode of an EDI module with ion-selective membranes separating the resin from the electrode chambers [3]. A schematic drawing of the EDI CACE instrument is shown in Figure 6.
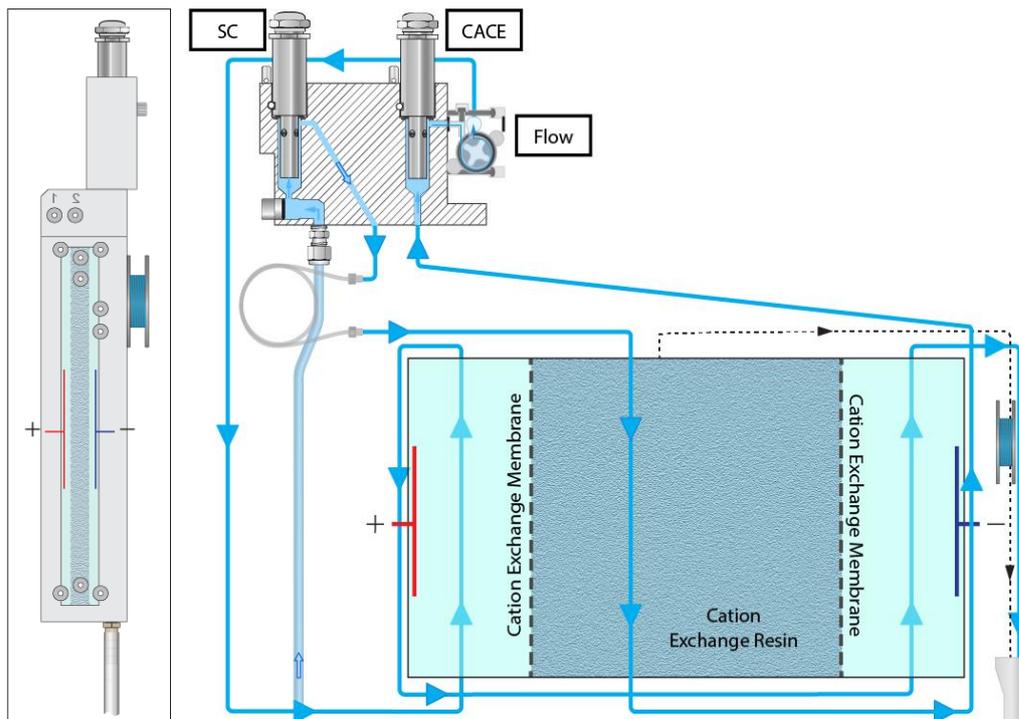
Figure 6: Schematic drawing of the EDI CACE instrument [3]

SC   Specific Conductivity
CACE   Conductivity After Cation Exchanger

In Figure 6 to the left, the EDI CACE instrument is shown from the side. To the right, the instrument is shown from in front. The sample first flows to the SC sensor (ca. 15 µS/cm), then it passes the chamber with the cation exchange resin. Cations from the alkalizing agent (mainly NH_4^+) are here separated from the sample by the cation exchange resin in the same way as in the conventional cationic exchange resins. The sample then passes the CACE sensor (ca. 0.1 µS/cm) before going to the drain. After the conductivity measurements, the sample continuous through the anode chamber to the left, where protons are generated by water electrolysis, and then it flows further through the cathode chamber on the right, where hydroxide is generated. The protons and hydroxide ions needed for regeneration are continuously generated by the water electrolysis, eliminating the use of regeneration chemicals [4].

Comparison between conventional CACE and EDI CACE

The new EDI technology was tested online and parallel to the conventional CACE for several months before the first instrument was installed in the condenser hotwell monitoring station at Benzau NPP. Figure 7 shows photos of the conventional set-up on the turbine side of one of the condenser hotwell (to the left) and next to it is the new EDI CACE instrument on the generator side of the hotwell. The photo to the right in Figure 7 shows a close-up of the new EDI instrument:

1) SC and the CACE conductivity measurements and the flow indicator
2) EDI module
3) Pressure control unit keeping a stable pressure at 0.5 bar

Figure 7: Installed conductivity instruments in the condenser hotwell in Beznau NPP

In Figure 8 the conductivity in µS/cm in the generator side (blue line) and the turbine side (black line) of the condenser hotwell is shown. This is at the time of installation of the new EDI instrument. The figure shows a duration of 10 days in total. The mechanical and electrical installation was completed in about 4 days (seen in pink). The recovery in conductivity after installation of the EDI instrument was fast, within less than one day and shows from day one just as low conductivity as the conventional instrument.
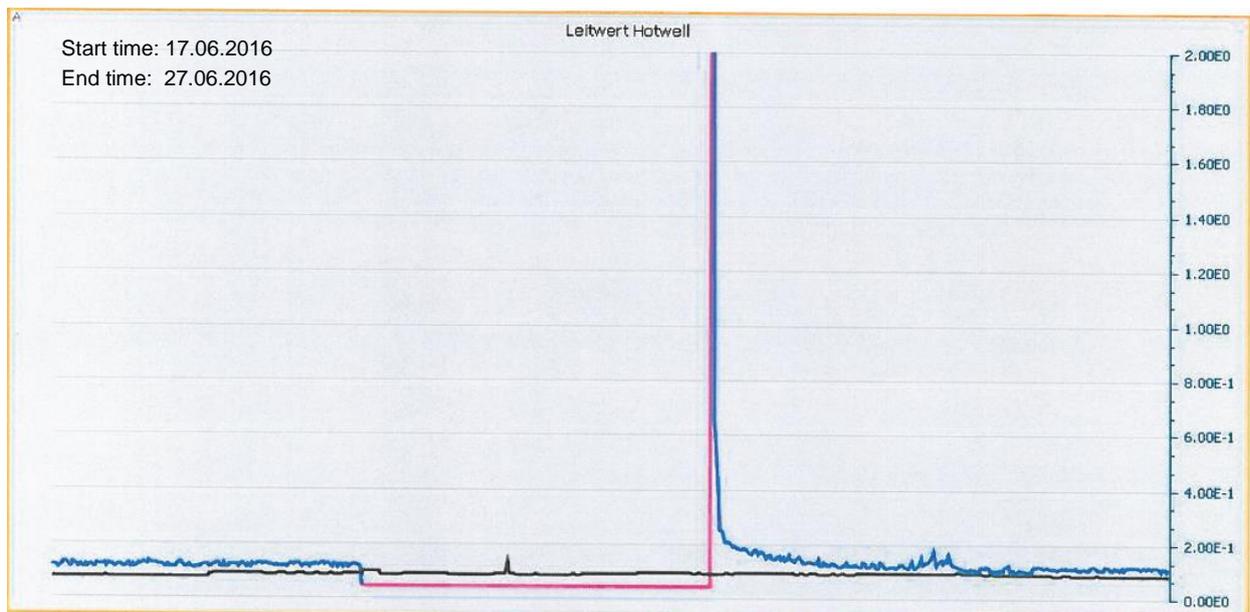
Figure 8: Online measurement of conductivity in the condenser hotwell (turbine and generator side)

In Figure 9 two different examples of operating experience of the new EDI CACE compared to the conventional cation exchange resin CACE measurements are shown. The conductivity in both examples is measured in µS/cm. The conductivity of the condenser hotwell on the turbine side is shown in black (conventional set-up) and the conductivity of the generator side of the hotwell is shown in blue (EDI CACE).
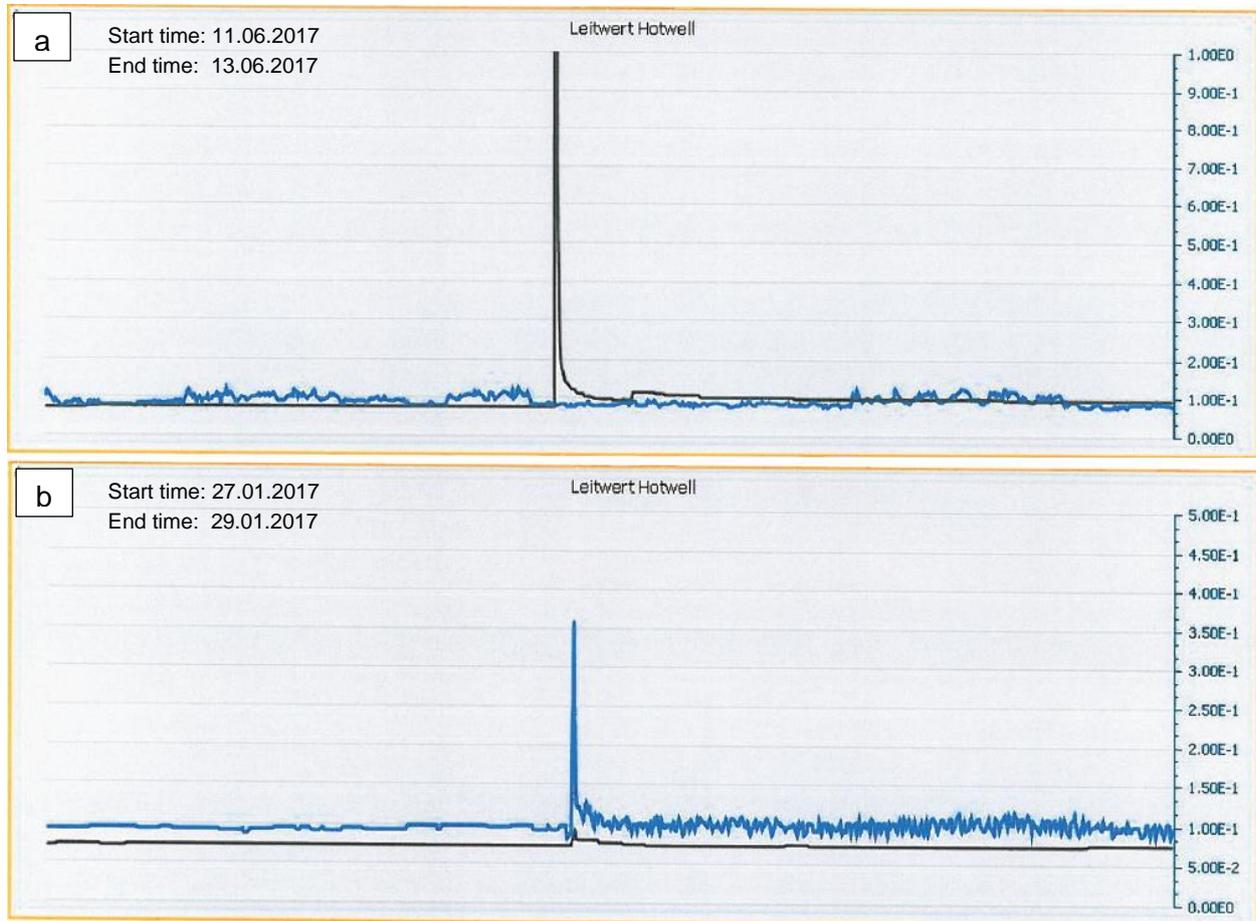
Figure 9:   a) Online conductivity measurement during resin exchange of the conventional CACE
              b) Online conductivity measurement during switch of condensate pumps

a) The periodic replacement of cation exchanger resin of the conventional CACE is accompanied by a large peak in the online conductivity measurement and it takes several hours to a day before the conductivity reaches the level of before resin replacement. This phenomenon is reduced to practically zero with the new EDI CACE technology.

b) The periodic switch of the condensate pumps in a normal operation in the Beznau NPP. With the conventional CACE measurement it is hardly noticeable, but with the much shorter response time of the new EDI CACE measurement the switch is quite noticeable. The different behaviour of the pumps can also be seen. The conductivity measurement before the switch in this example (blue line) moves within a small range of conductivity with time compared to after the switch, where the measured conductivity fluctuates in a wider range, indicating a slightly higher levels of contamination when the second condensate pump is operating.

Conclusions

The installed EDI CACE instrument in Beznau NPP has several benefits. The continuous regeneration of the small amount of exchange resin contained in the EDI CACE instrument results in a major reduction in maintenance work related to replacement of exhausted cation exchange resin compared to the conventional set-up.

The operational experience shows an uncomplicated installation phase, where the recovery in conductivity was notably fast and exhibits an excellent match between conductivities measured after the conventional cation exchanger and the EDI CACE. Also the sensitivity of the new EDI CACE measurement is significantly higher than compared to the conventional CACE, where even the modes of operation of the different condenser pumps is clearly visible.

At present time, all the hotwell monitoring stations in Beznau NPP have been replaced with EDI CACE instruments, in total 8 instruments, 4 in unit 1 and 4 in unit 2.
In Figure 10 the hotwell monitoring station seen in Figures 5 and 7 above is shown, with the 2 new EDI CACE instruments.
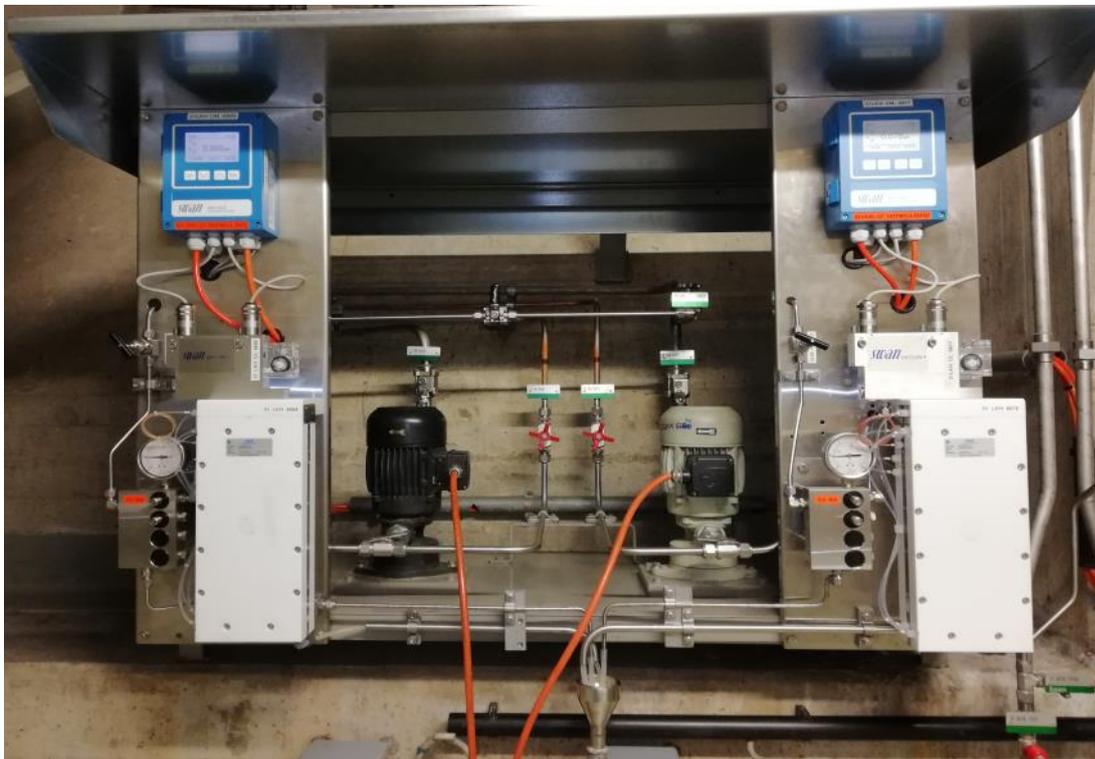
Figure 10: Hotwell monitoring station with new EDI instruments on both turbine and generator side

The new EDI CACE instruments run to the fullest satisfaction and in the near future all the conductivity monitoring instruments using conventional cation exchange resins will be replaced with EDI CACE instruments throughout the secondary circuits of Beznau NPP unit 1 and 2.

References

[1]   I. Mailand, P. Franz and H. Venz, "Corrosion Product Measurements to ensure integrity of the Steam Generators in Beznau NPP." Paper No. 217-O16, NPC 2012, Paris, France (2012).

[2]   M. Rzhia, Dr. P. Wuhrmann, "Cation conductivity monitioring during start-up", Power Plant Chemistry, 2007, 9(11)

[3]   M. Sigrist, "Conventional resin cation exchangers versus EDI for CACE measurement in power plants – Feasibility and practical field results." VGB Powertech Vol. 87, Issue 3, p. 66 – 68 (2017).

[4]   J. Gath, "Conductivity after cation exchange measured after EDI." PowerPoint presentation at BIAPWS symposium, Coventry, U.K. (2017).