

## High Frequency Modulation in France and in TRIMET Saint-Jean de Maurienne for F and G Lines

Olivier Granacher<sup>1</sup>, Quentin Denoyelle<sup>2</sup>, Frédéric Charvoz<sup>3</sup>, Alexandre Riot<sup>4</sup>  
and Matthieu Dhenaut<sup>5</sup>

1. Process Project Engineer, TRIMET France, Saint-Jean-de-Maurienne, France
  2. Process Graduate Engineer, PHELMA Engineering School and TRIMET France, Saint-Jean-de-Maurienne, France
  3. Deputy Engineering Manager, TRIMET France, Saint-Jean-de-Maurienne, France
  4. Process Technician, TRIMET France, Saint-Jean-de-Maurienne, France
  5. Reduction and Gas Treatment Centers Manager  
TRIMET France, Saint-Jean-de-Maurienne, France
- Corresponding author: matthieu.dhenaut@trimet.fr

### Abstract

The unplanned shutdown of several nuclear reactors in France at the beginning of the winter 2016 - 2017 led to the possibility of electricity supply disruption in the country. The TRIMET Saint-Jean-de-Maurienne smelter located in the French Alps is one of the main electricity users in France and has implemented high frequency modulation on its potlines to stabilize the frequency of the electricity grid. This article explains the need for such a service in the winter 2016 - 2017 and describes the technical challenges faced by the plant in designing, installing and validating the power modulation equipment. It also describes the effect of high frequency amperage variations on the pot control system and the mechanisms leading to extra anode effects.

**Keywords:** High frequency grid electricity modulation, Saint-Jean-de-Maurienne smelter, power modulation equipment, high frequency amperage variations, pot control system.

### 1. Description and Examples of the High Frequency Modulation in France

As many electricity grids in Europe, the French one had to face a new challenge with the growing importance of renewable energy such as Solar and Wind.

Electricity cannot be stored cheaply on large scale so at any moment, electricity demand and supply must be equal. If there is too much electricity through the grid, equipment could fail, if there is too little, there is a risk of a black out.

The system frequency is a measure of the balance between energy generated and consumed, as it is linked with the rotation speed of the synchronized electricity generators (Figure 1). It is a constantly shifting number that must be managed and controlled all the time.

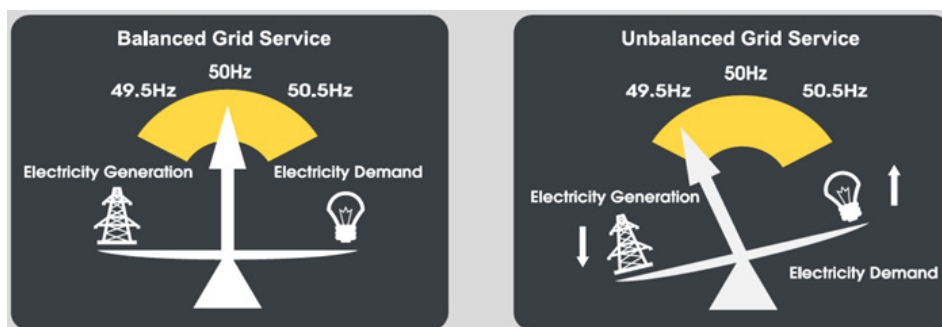
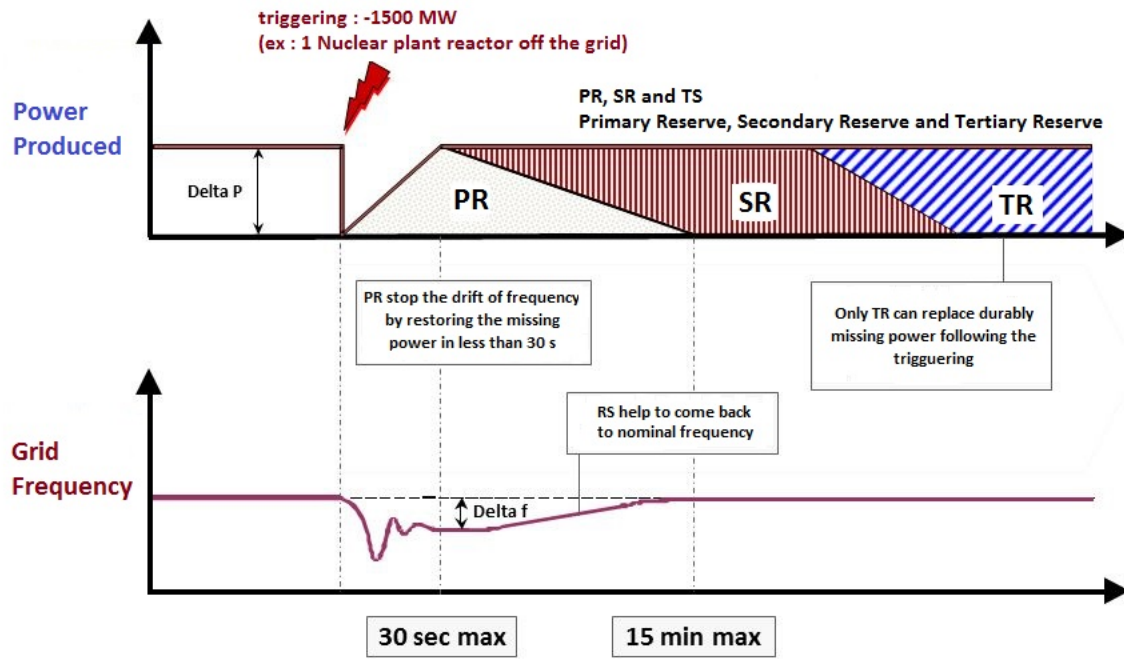


Figure 1. Principle of grid frequency modulation [1].

The control of the grid is “simply” to maintain the balance, in other words, the frequency at 50 Hz. Since 2014, RTE (Réseau de transport d’électricité - Electricity Distribution Network) has developed

with several companies known as “Pool” some new contracts to help maintaining the grid. This contract can be classified in 3 groups depending on the speed of their activation (Figure 2):

- Primary Reserve (PR): Stop the drift of the frequency, activated in less than 30s,
- Secondary Reserve (SR): Restore the frequency, activated in less than 15 min,
- Tertiary Reserve (TR): Manually activated by RTE to help the restoration of the frequency or Reserve replacement.



**Figure 2. Frequency adjustment mechanism.**

TRIMET France in its Saint-Jean de Maurienne plant has been doing Primary Reserve since September 2014 with 20 MW, which rose to 30 MW in mid-March 2015. Saint-Jean reacts in Primary Reserve with a coefficient  $K = 150 \text{ MW/Hz}$  ( $K$  is the factor of primary setting) from 49.80 to 50.20 Hz with a “dead zone” of no response between 49.99 to 50.01 Hz.

To reduce the impact of power variation on the pots, we have shared power modulation between the 2 potlines: the F potline (AP18 at 200kA, 60 pots) and the G potline (AP30 at 340 kA, 120 pots). Most of the time the power modulation stays within  $\pm 5 \text{ MW}$ :  $\pm 2 \text{ kA}$  on F potline and  $\pm 4 \text{ kA}$  of G potline. A lot of the frequency variation occurs also from 16:00 to 05:00 and at the top of the clock. During these peaks, power modulation can go over 20 MW and can generate some time process incident such as anode effects depending on the state of the pot.

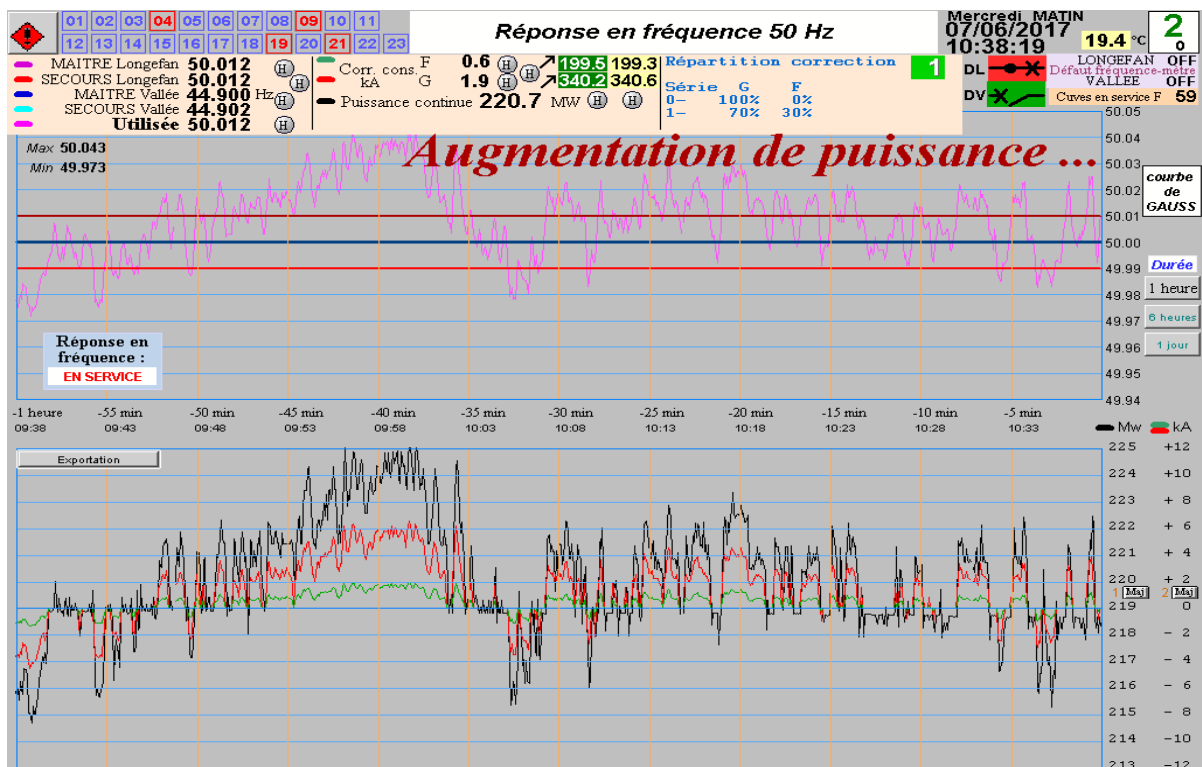


Figure 3. Frequency adjustment supervisory screen (1 hour view).

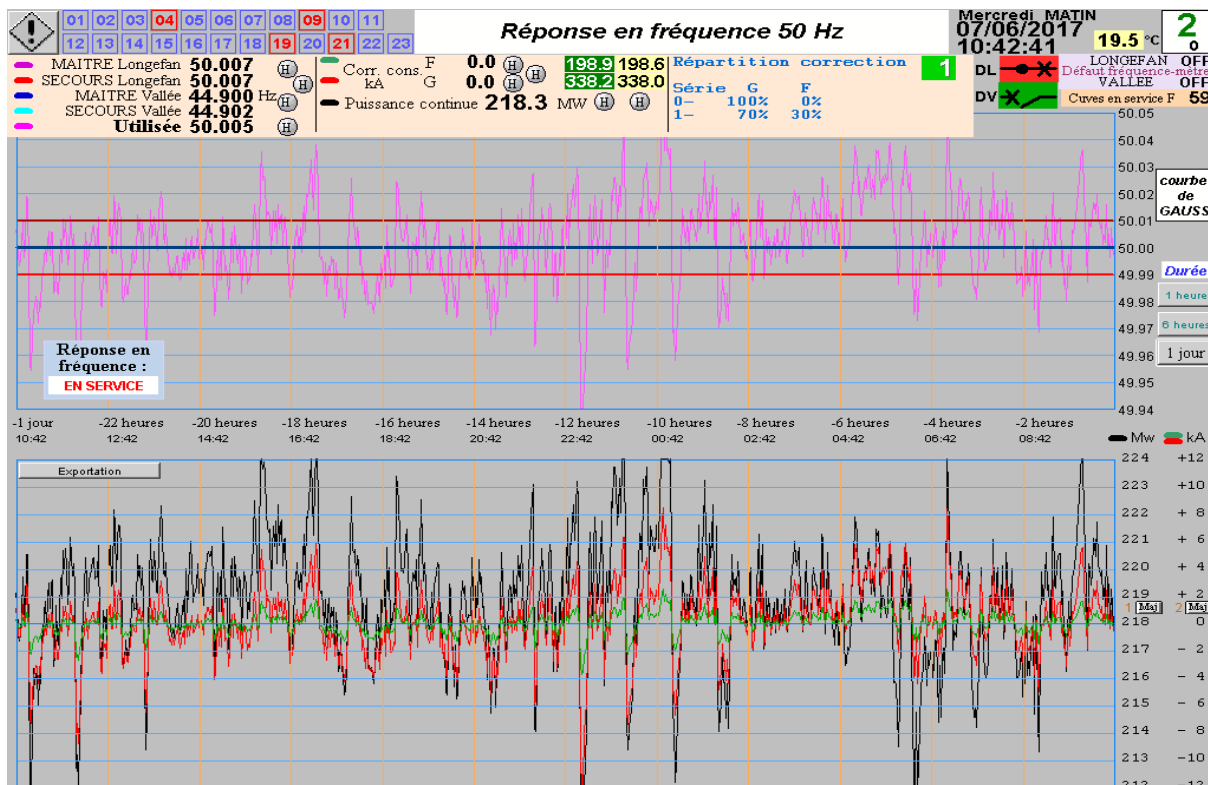
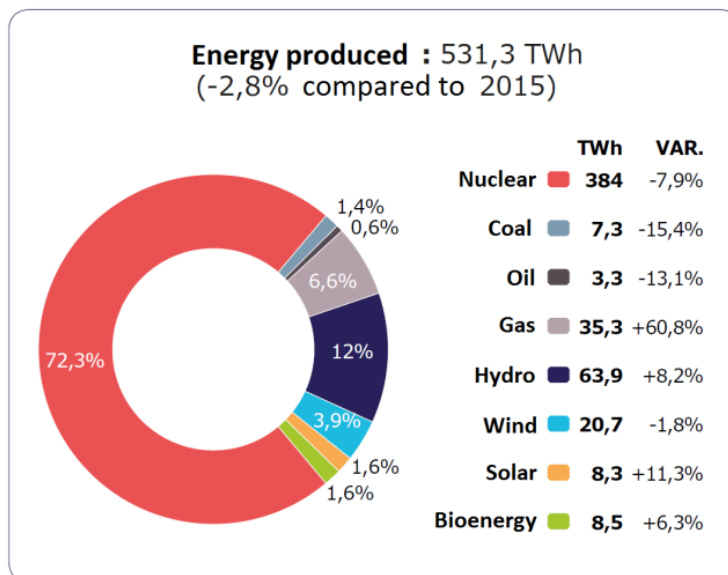


Figure 4. Frequency adjustment Supervisory Screen (24 hour view).

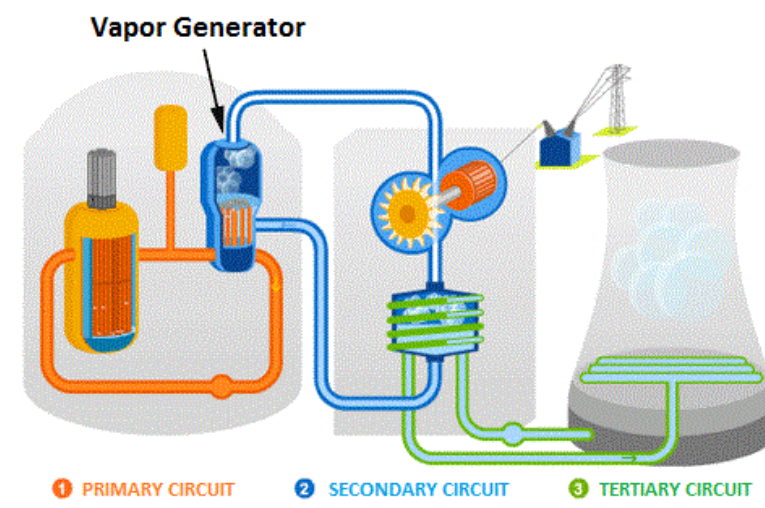
## 2. Crisis in France Due to Nuclear Power Shutdown for Additional Maintenance in Winter 2016 - 2017

Nearly  $\frac{3}{4}$  of the electricity in France is produced by nuclear plants with 58 reactors spread in 19 power plants. Electricity production in France is therefore very dependent on the health of those reactors.



**Figure 5. RTE French Electricity production distribution for 2016.**

After the Fukushima disaster in Japan in March 2011, the safety and maintenance procedures are being strongly reinforced over the world. Early in June 2016, the A.S.N. (Nuclear Safety Authority of France) showed that some quality test made par Electricité de France (E.D.F). (Electricity of France - the biggest electricity supplier of France and owner of the nuclear plants) revealed than at least 18 nuclear reactors could be affected by an anomaly on the vapor generators. The vapor generator is the heat exchanger between the water of the primary circuit and the secondary circuit. It transforms the water of the secondary circuit in vapor that will be used for electricity generation.



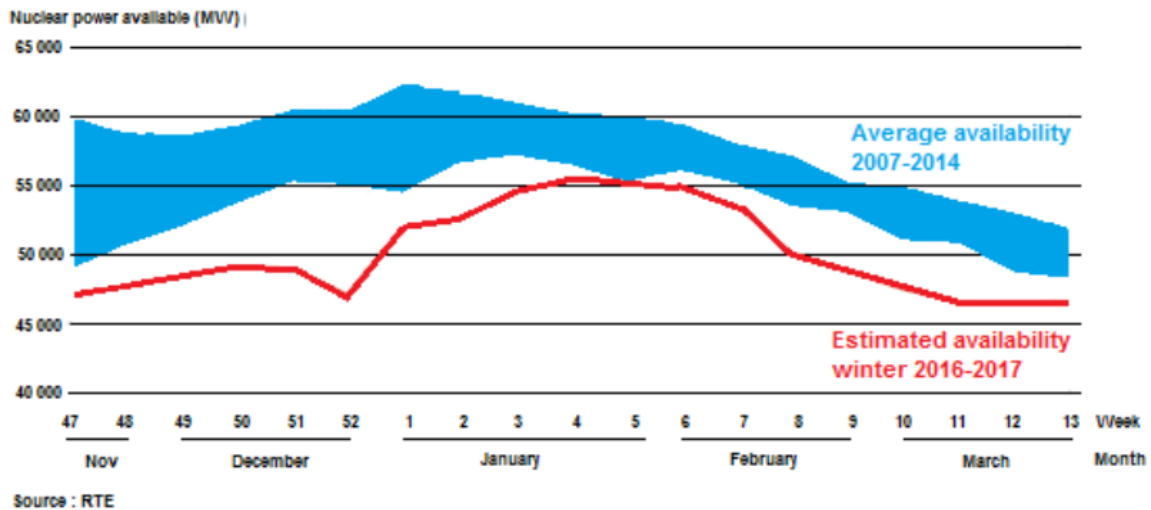
**Figure 6. Vapor generator into a nuclear plant.**

At the beginning of the winter 2016 to 2017, 21 nuclear reactors from a total of 58, were still down for maintenance or control of this anomaly of the vapor generators. In mid October 2016, because of this situation, warnings from RTE were made for the winter season. In case of cold weather, the French

electricity network could have outages. RTE could use different tools to ensure the balance of electric grid such as:

- Imports from countries neighboring France (Import capacity raised up to 30 % compared to the previous winter),
- Mechanism of power reduction for industries during peaks of consumption,
- Mechanism of power reduction for private consumers during peaks of consumption.

### Availability of nuclear reactors during winter



**Figure 7. Nuclear electricity production forecast for winter 2016/2017.**

The network and transport company RTE announced also that each degree Celsius below the average temperature of the season creates an extra consumption of 2400 MW in France. Regarding this situation TRIMET France plant of Saint-Jean de Maurienne decided to anticipate some power reduction.

The price sensitivity of the main contract that would be activated was at an offered price validated for the “Fast Reserve”. In case of electricity price over this level, the risk to be activated was higher. So we created some indicators to check electricity spot price 24 h forecast (price, time of peak of consumption, number of neighboring countries available for import at a lower price) versus some electrolysis process indicators such as bath height and bath temperature. For example in Figure 8 that shows the situation in November 2016, we spotted out that during 3 days, the price of energy at the peak of consumption in the evening was over 800 €/MWh. But at the same time at least 6 neighboring countries were able to deliver the necessary power at a price below the plant contract.

Later in the winter, more and more nuclear reactors were verified, and the ASN delivered for each the authorization to re-start and to be back online.

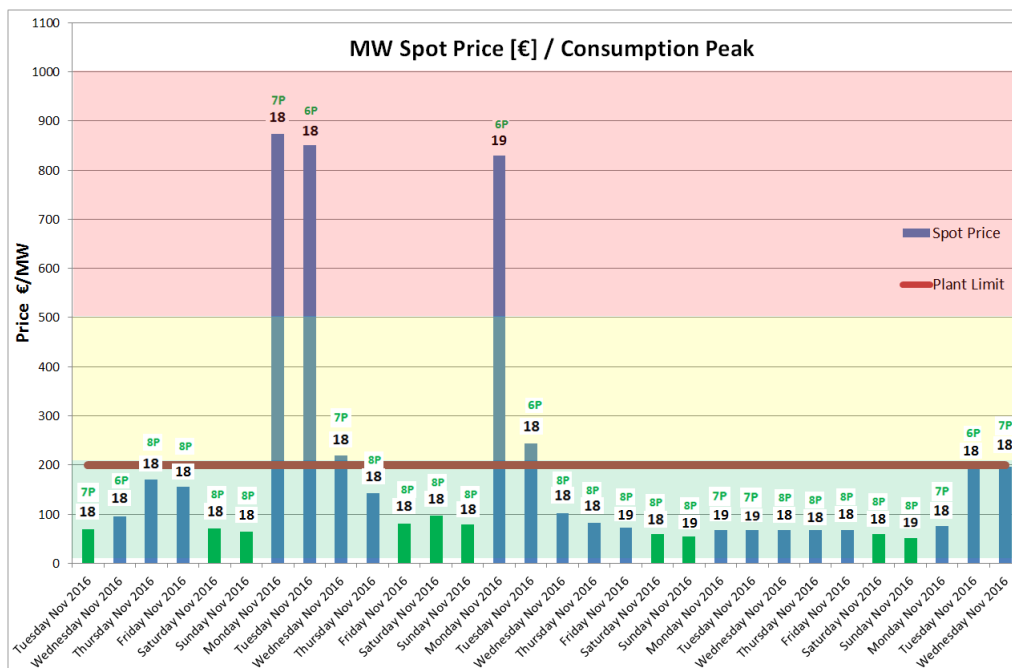


Figure 8. TRIMET France energy indicators, November 2016.

The temperature during this winter was considered as normal until mid-January 2017. During weeks 3 and 4, the average temperature fell to an average of 4 degrees below normal temperature for this season, temperature in Saint-Jean de Maurienne was around - 10°C. During these 2 weeks, voluntary power reductions were requested by RTE and the Saint-Jean de Maurienne plant reduced power by 20 MW over 8 days, and the plant activated “Fast Reserve” on Wednesday, 25 January 2017 at 95 MW from 11:30 to 13:30 h. (The Fast Reserve can be activated in 9 minutes by RTE if requested).

The rest of the winter, with temperature close to normal seasonal temperature and with only 6 nuclear reactors stopped for maintenance in February, was considered as the end of the Crisis. This episode showed the importance of the power exchange in Europe, which prevented several times power reduction at the Saint-Jean de Maurienne plant.

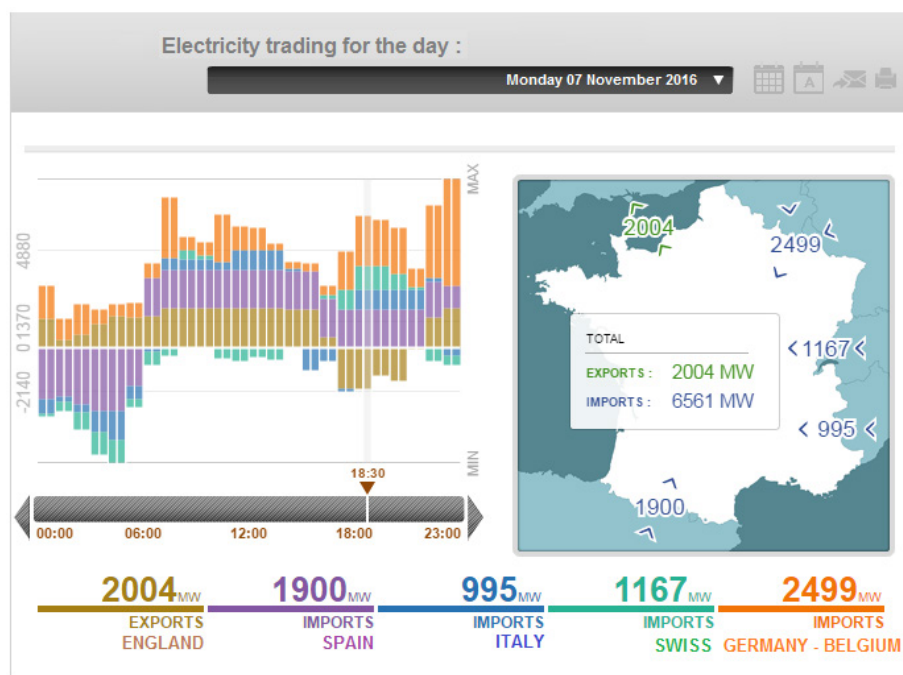
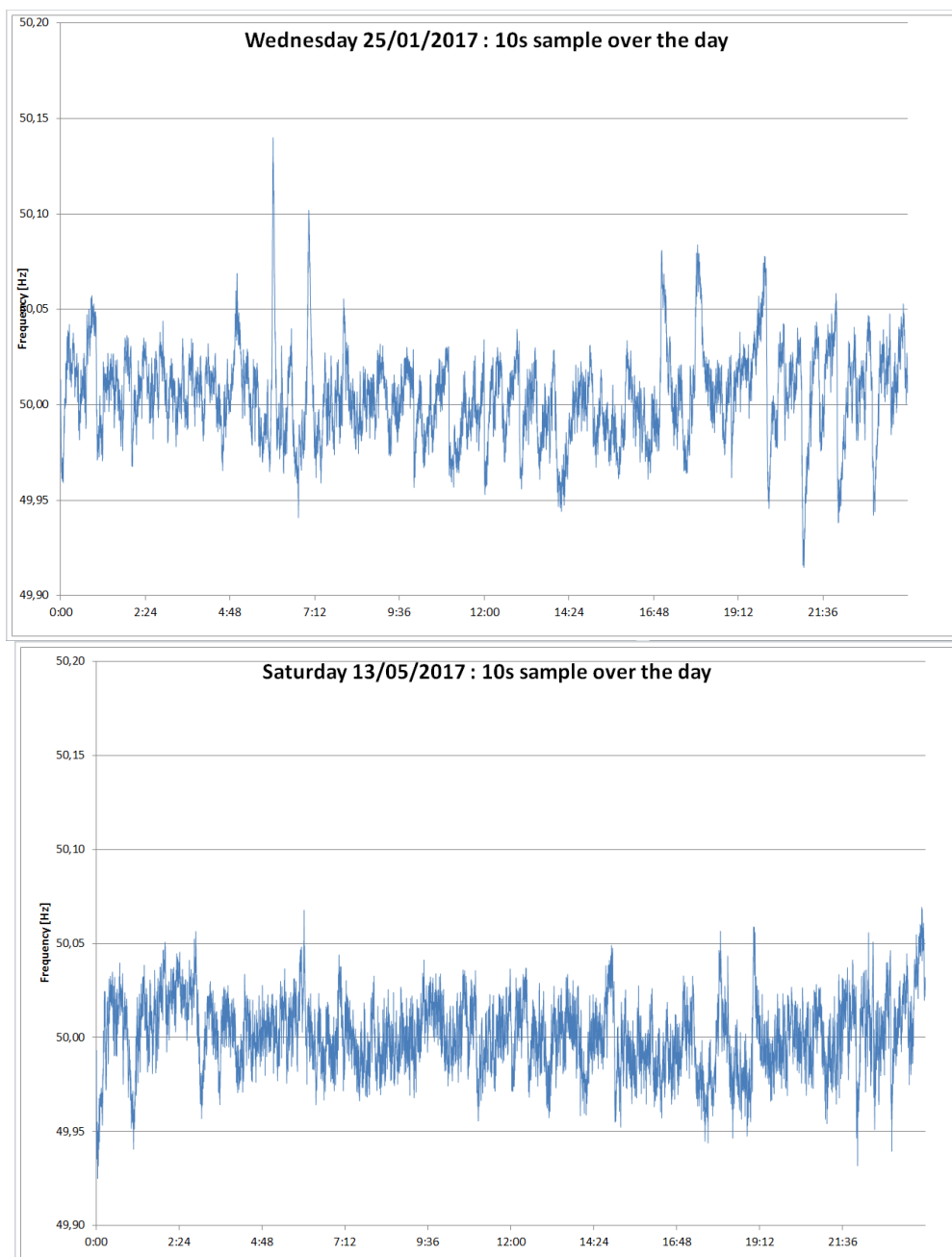


Figure 9. Import / Export during the most critical day.

Figure 10 shows the grid frequency comparison between 2 days, Wednesday 25/01/2017 when the Saint-Jean de Maurienne plant was activated in Fast Reserve, and Saturday 13/05/2017 with no stress on the grid. We have much more variations on the 25/01/2017 (e.g., in the morning around 6:00 and 7:00 am, two peak above 50.10 Hz) than on 13/05/2017 where we see that the frequency is much more contained.

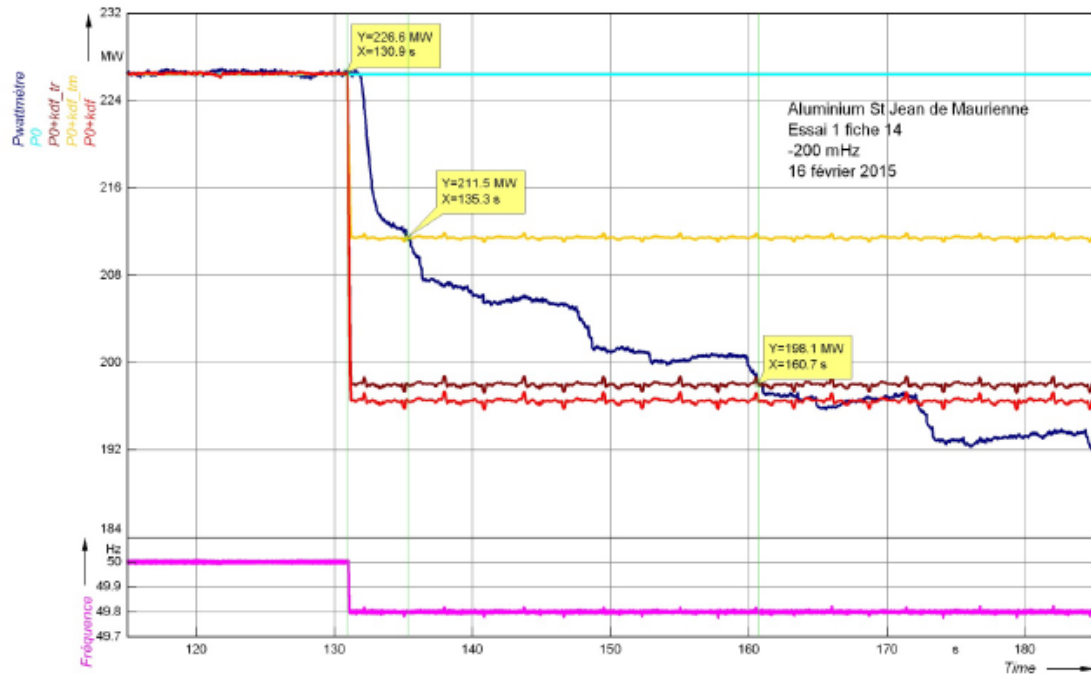


**Figure 10. Frequency data comparison.**

### 3. Homologation of High Frequency Modulation

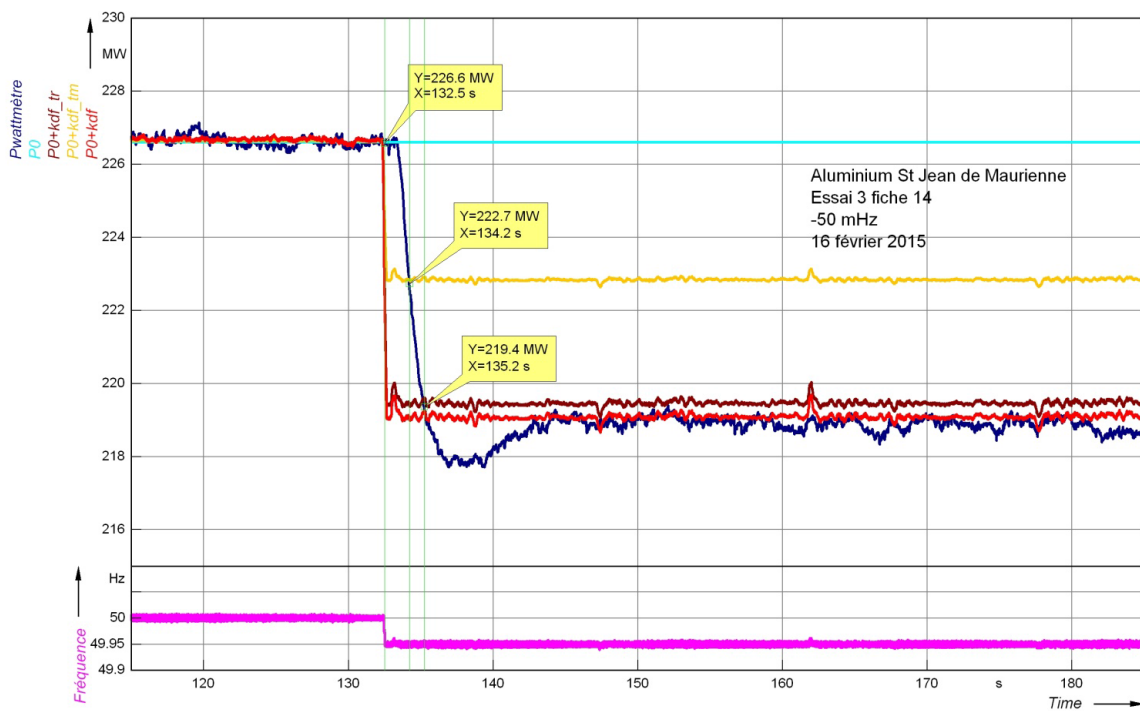
The homologation of frequency modulation is composed with several trials which can be described as:

- Injection of artificial frequency variation of +/- 200 mHz during 15 minutes the result must be:
  - Reach 95 % of the 30 MW (+/- 5 %) less than 30 s
  - Reach 50 % of the 30 MW (+/- 5 %) less than 15 s
  - Maintain the power during 15 minutes.



**Figure 11. Example of decrease of 30 MW with -200 mHz.**

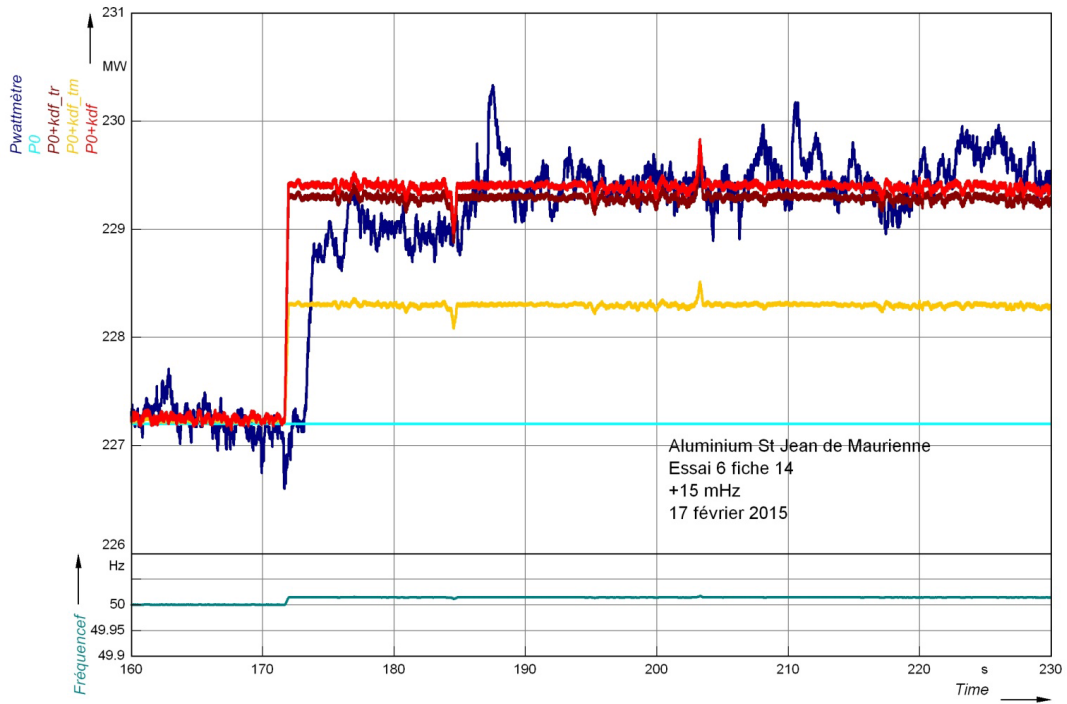
- Injection of artificial frequency variation of +/- 50 mHz during 15 minutes, the result must be:
  - Reach the power of 7.5 MW ( $\pm 5\%$ ) less than 30 s,
  - Reach 50% of the 7.5 MW ( $\pm 5\%$ ) less than 15 s,
  - Maintain the new power during 15 minutes.



**Figure 12. Example of decrease of 7.5 MW with -50 mHz.**

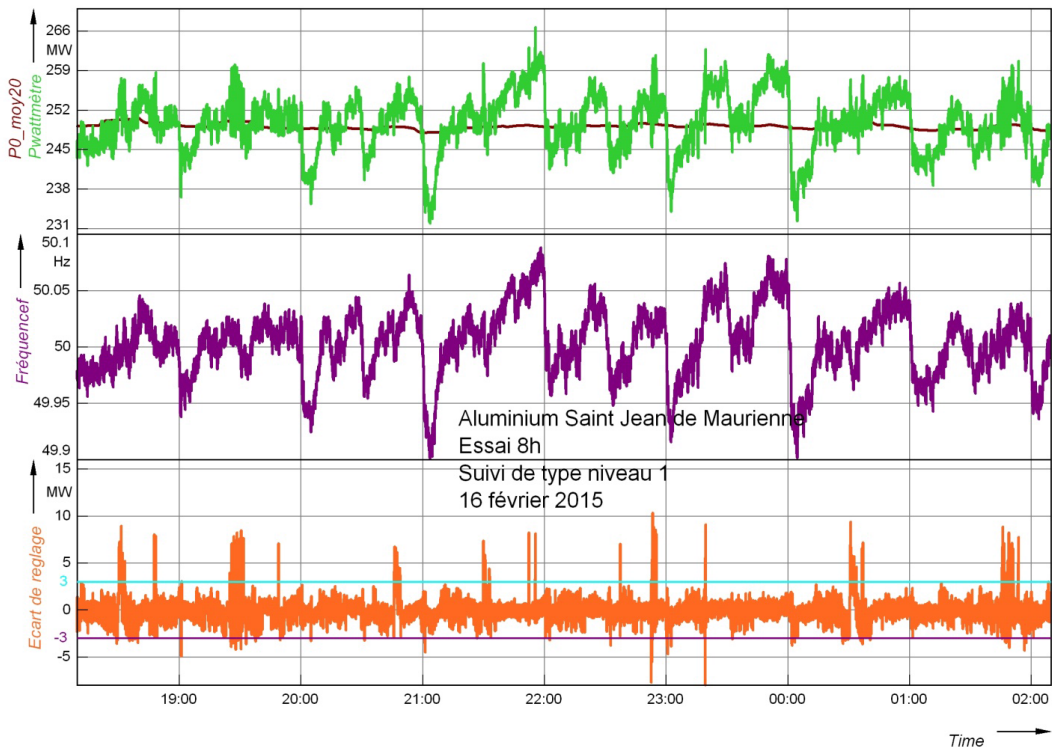
- Injection of artificial frequency variation of  $\pm 15$  mHz during 15 minutes, the result must be:

- The power variation must be superior to  $0.005 \times K$
- Maintain the new power during 15 minutes.



**Figure 13. Example of +15 mHz.**

- Follow up the power variation during 8 h, the result must be: Power variation follows the frequency variation, the maximum deviation must be  $\pm 3\text{MW}$ .



**Figure 14. Example of following of the frequency variation with maximum deviation of  $\pm 3\text{MW}$ .**

#### 4. Way of Programming the High Frequency Modulation with Fully Automated Controllers

The network frequency is measured continuously; the value is connected to a PLC, which calculates the value of kA to correct with the relation  $\Delta P = k \times \Delta f$ . The operation can choose to apply the frequency response either on both potline F+G or only on G potline.

#### 5. How to Deal with Several Potlines F and G

The Saint-Jean de Maurienne smelter currently operates 2 potlines - G and F - running respectively at 340 kA with 120 pots and 200 kA with 60 pots. High frequency modulation was firstly implemented on G potline and F potline was added later on to soften its impact of high frequency modulation on G potline.

The monitoring system of the electrical substation manages without stopping the Fast Reserve and the Primary Reserve activation, the split between the 2 lines: a frequency of the grid outside the dead zone needs to trigger a change in the power of both potlines which involved an amperage change in both potlines. However, G potline runs as an extension of F potline so an amperage change on F potline means the same change on G potline. The monitoring system takes the following steps to set the new amperage targets:

- Calculation of the total amperage variation based on the power change needed for F potline: see Figure 15 – This calculation uses a measured coefficient based on previous tests. Calculation of the G potline adjusted amperage target based on the number of pots in operation taking into consideration F potline amperage change

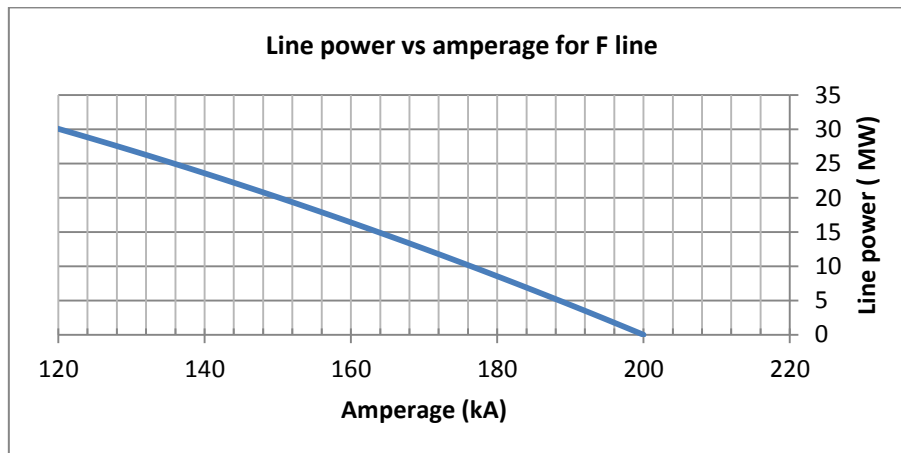


Figure 15. Relation between potline power and potline amperage.

#### 6. Link between kA variations during high frequency modulation and anode effects

##### 6.1. Effect of amperage variations on anode effect rate

In G potline the anode effect rate showed a significant increase after the start of the power modulation in 2014: see Figure 16.

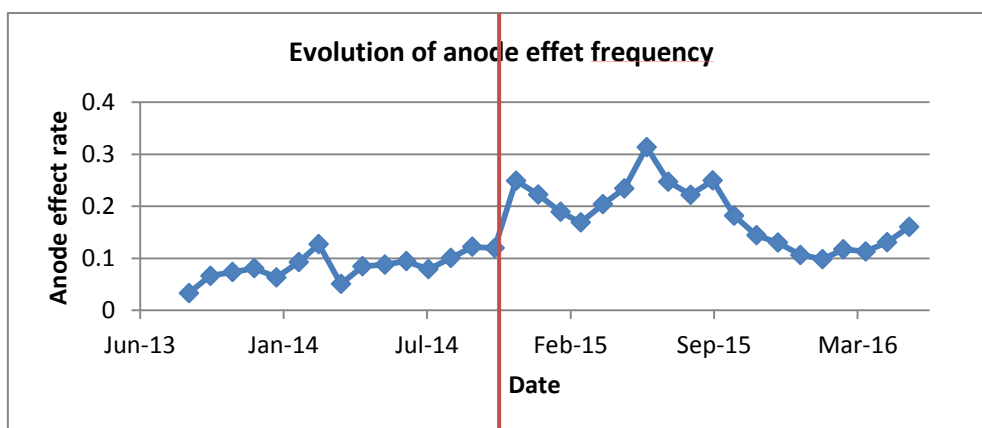


Figure 16. Monthly anode effect rate in G potline before and after the start of power modulation.

In order to investigate the link between the amperage variations and the anode effect rate, we created an amperage variability indicator and correlated this indicator to the anode effect rate in the same period. Figure 17 shows the result: a significant correlation between amperage variability and anode effect rate. This result led to the investigation of the possible causes of this correlation.

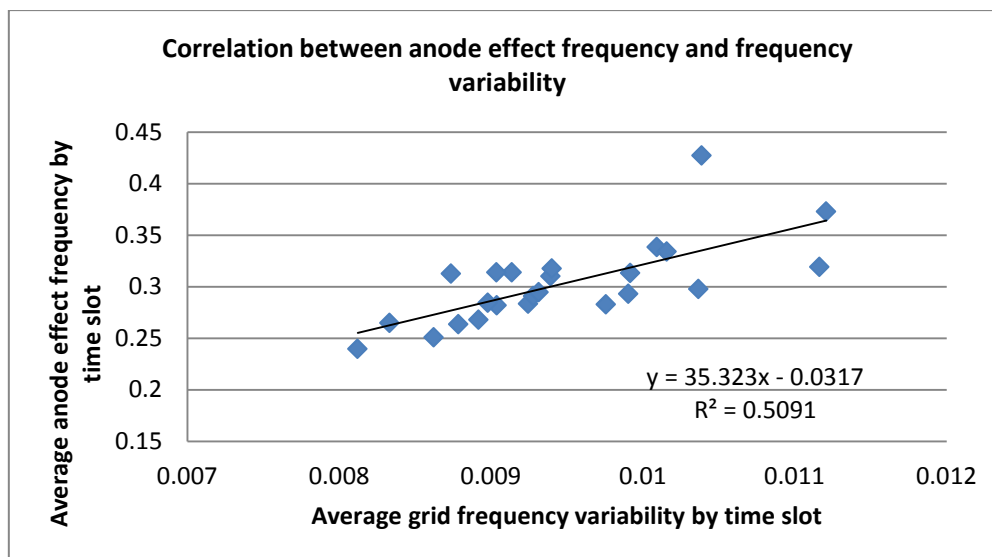


Figure 17. Correlation between amperage variability and anode effect rate.

## 6.2 Effect of Amperage Variations on Pot Resistance Calculation

1 second data from the pot control system showed that large amperage variations were linked to resistance changes: see Figure 18.

The amperage increase shown happens within 2 min and the pot resistance shows a simultaneous drop. The main reason for this resistance drop appears to be the set value of extrapolated voltage. (E which is not exactly the one experienced by the pot. For the pot in Figure 18, the extrapolated voltage appears to be too small. The extrapolated voltage can be estimated by the linear (straight line) correlation between pot voltage and amperage as shown in Figure 19. The extrapolated voltage is zero current intercept of the correlation straight line with the vertical (voltage) axis and is given by the constant term in the liner curve fit equation

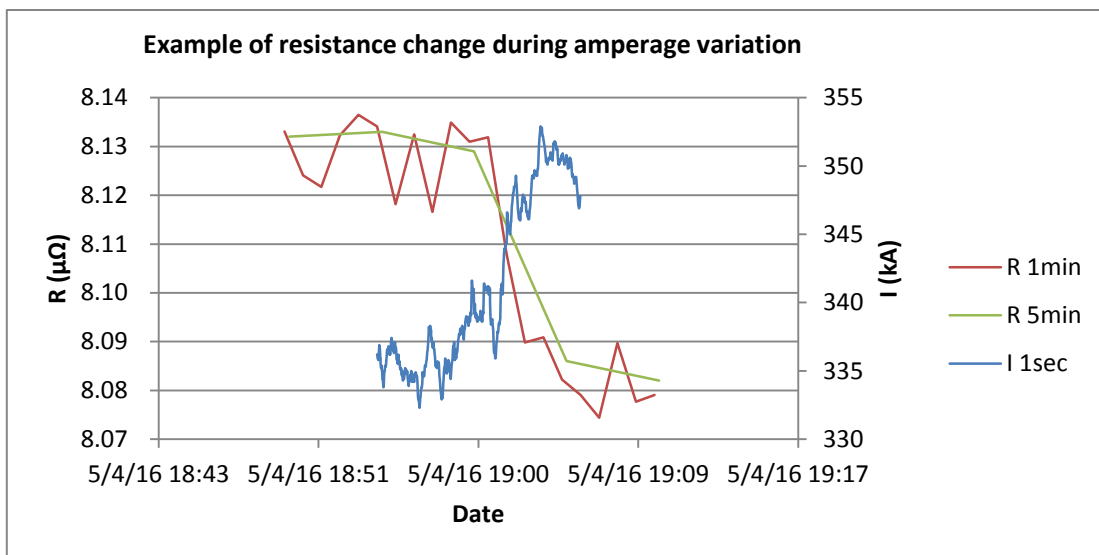


Figure 18. Example of pot resistance change during amperage variations.

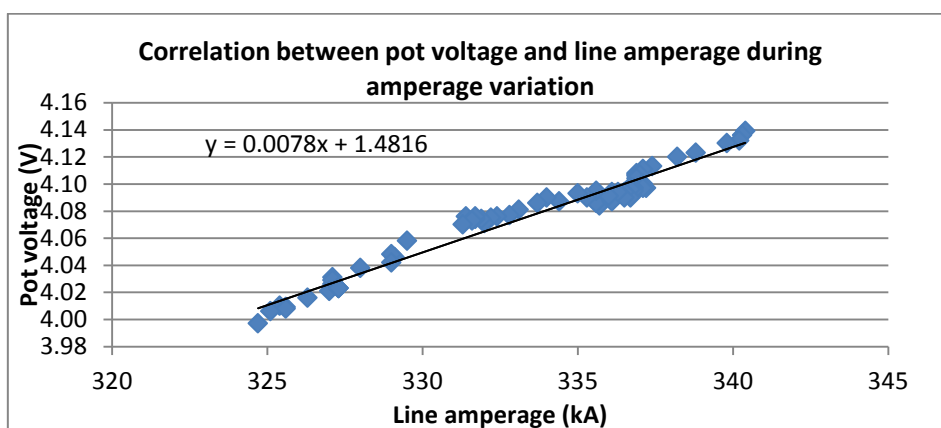


Figure 19. Correlation between pot voltage and potline amperage during amperage variations.

Experimental data show that the actual value of E calculated from linear correlation between pot voltage and pot amperage, using 1 second values during amperage variations, is often different from the value in the control system which is set at 1.65 V, see Figure 20; 1.65 V should represent all pots in the potline. The average of the E values shown in Figure 20 is 1.634 V, which is just slightly smaller than the value used in the control program. E = 1.4816V for the pot in Figure 19.

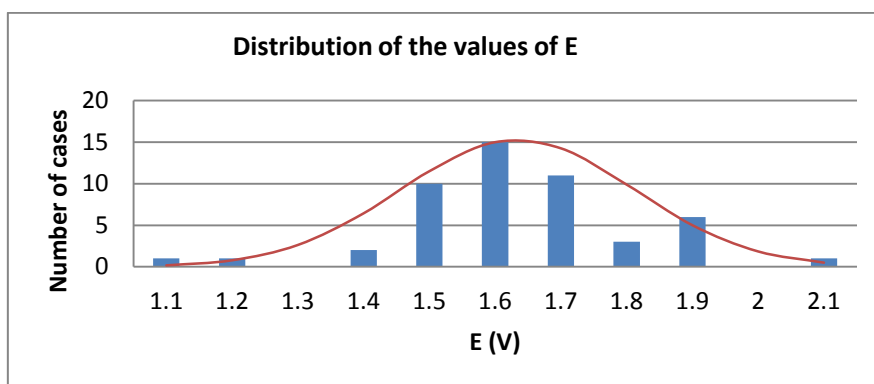
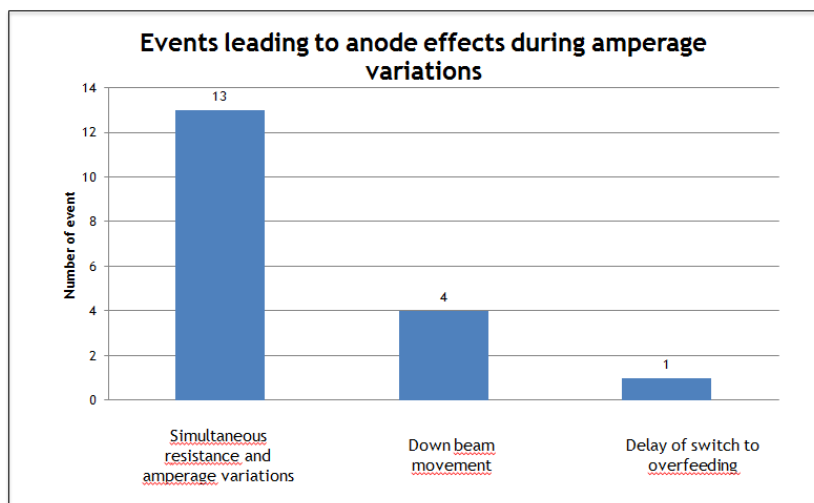


Figure 20. Calculated values of E during large amperage variations.

In a study of 393 anode effects in G potline, were found 18 anode effects directly linked to the large amperage variation at the same time as frequency modulation. Figure 21 gives the events leading to the anode effects during amperage variation. 13 out of the 18 anode effects are linked to resistance

variation during frequency modulation. This analysis proved that the anode effect increase shown in Figure 16 was not linked to the start of the frequency modulation in the potlines.



**Figure 21. Events leading to anode effects during amperage variations linked to frequency modulation.**

## 7. Conclusion

In response to new constraints on the electricity grid in France, the TRIMET smelter in Saint-Jean de Maurienne has managed to design, test and implement high frequency power modulation. This has helped in stabilizing the grid frequency during the cold spells of the winter 2016/2017 where the power production capacities were reduced by unplanned maintenance. The management of the amperage variations in both potlines has allowed stable operation and frequency modulation was shown to have limited impact in anode effect frequency.

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