ESP emission reductions with advanced electrode rapping together with novel energising methods

Christer Mauritzson, *Sales Manager, ALSTOM Power Service, Växjö, Sweden*
Martin Kirsten, *Sales Manager, ALSTOM Power Service, Växjö, Sweden*
Hans Jacobsson, *ESP Process Expert, ALSTOM Power Service, Växjö, Sweden*
Anders Karlsson, *ESP Process Expert, ALSTOM Power Service, Växjö, Sweden*

Abstract

To help keep the collecting plates clean, Power Down Rapping (PDR) and Power Off Rapping (POR) have been used for many years.

In this paper it is shown, that the simple TR interaction available with PDR and POR can be made in more elaborate ways, and that this greatly reduces the ESP emission compared to the old strategies. Increased rapping losses that may cause major emission peaks when conventional PDR or POR is used can, in many cases, be managed with the more advanced rapping regimes discussed in this paper.

For the ESP entry fields, excessive dust build-up on the collecting plates may increase the voltage that is required to start the corona. The increased voltage increases the risk for spark-over limitation at a [too] low current.

This and other disturbances have been successfully addressed with more intricate novel rapping strategies combined with new ways of using PDR, what we call Power Control Rapping (PCR).

Compared with ESPs that use conventional rapping the novel methods have in several ESP plants reduced the emission with 30 % for low to medium resistivity dusts. For dusts characterised by a high resistivity this novel method is even more successful, and emission reductions of more than 50 % have been obtained at several plants.

Combining advanced rapping and a more smooth HVDC supply – also referred to as Switched Mode Power Supply (SMPS) technology – even higher emission reductions have been obtained in a number of ESPs, especially when operating with low to medium resistivity dust.

It seems possible that the above mentioned emission reductions can be obtained for all ESPs, provided the dust is, for whatever reason, difficult to dislodge from the collecting plates.

Introduction

Historically, a fat, black emission plume after a coal fired boiler was a desirable sign of prosperity. With tighter and tighter demands for a clean environment, a modern ESP today is usually designed to remove so much of the flyash content, that the emission from the stack is very nearly invisible.

It has been a long way to come – usually imposed by Governments – to today's very low emission levels. A few of the ESP technology development steps should be mentioned – in an approximate time frame:

- 1930 – today: The tougher and tougher governmental emission regulations require larger and larger size for new ESPs to comply.
- 1950 and later: Existing – and later new ESPs - that must yield a reduced emission, use POR (Power Off Rapping), later PDR (Power Down Rapping). Especially common in USA and South Korea
- 1960 and later: Coals with low sulphur content – to abate acid rain - give high resistive ash which is difficult to collect. When high ash resistivity becomes a problem SO3 conditioning (and other conditioning agents) is introduced to reduce the resistivity

- 1980 – today: In Europe and most of Asia the ESPs were built large. Later Semipulse / Intermittent energisation is used as a very powerful means to reduce the emission when the ash resistivity is high
- 1993 – today: New smooth HVDC supplies that use high-frequency power conversion improve the ESP collection efficiency further
- 2000 – today: This paper describes how well designed rapping strategies combined with PCR (Power Control Rapping) is used to keep the collecting plates cleaner. The result is a possible 30 –50 % additional emission reduction for all designs of ESPs and all types of ESP processes. This improvement figure is of course given "on top". Meaning that all the above improvement methods are already in use.

Some "truths" about the rapping of collecting plates

First, please note that we do not at all discuss the rapping of the emission electrodes in this paper. We have not really deviated from the emission electrode rapping settings or strategies as we have always used them. If we have changed any emission electrode timer settings at all, we would have done this in order to make the emission electrode and collecting plate rapping in the same bus section occur at the same time (although the emission electrodes are additionally rapped much more frequently than the collecting plates). This minor change of philosophy is merely a means to simplify the complicated schemes that surround each individual ESP rapping strategy

The main difference is that we have totally changed our approach about how to best rap the collecting plates – always targeting to reach the lowest possible emission after the ESP.

One of the last technical documents that Mr Sigvard Matts wrote before he retired, was a small pamphlet with the humble name:

"What can EPIC II do for your ESP".

In just a few pages Mr Matts describes the effects of corona and back corona, and how we then worked to abate back-corona and thereby could successfully reduce the emission. What Mr Matts **did not** write in this pamphlet were a few clues to follow that he instead verbally gave to us:

"I bet, that in the next decade the best way to improve the ESP collection efficiency will be to seek improved ways to rap the collecting plates – Targeting to improve dust agglomeration and to reduce dust re-entrainment".

"I bet that every particle that has been finally collected on an ESP collecting plate has been collected and lost, collected and lost not only once or twice, but possibly dozens of times. And the smaller the particle size and the higher the resistivity of the particle, the higher the number of collect-and-lost events".

So, was Sigvard right? Honestly speaking, today we do not know with 100% certainty. But some of our sharpest ESP process experts have certainly worked along the rapping - reentrainment trail that Sigvard gave us, and so far the results are – to express it in a modest way – astonishingly good!!

About one "force" that makes the collected dust stay on the collecting plate - which leads us to the use of PCR (Power Control Rapping)

It is a common knowledge that maybe only in the order of 1- 4 % of the negative electrical charges that are generated by the corona on the emission electrode will actually hit and stick to a dust particle.

For our discussion the corona current has an additional function than just only to charge the particles: When a charged particle has reached its destination on the collecting plate it will quickly loose its negative charge to the collecting plate, and then - intuitively – we would conclude that the particle would just come loose and drop down. But it sticks to the collecting plate because

- the particle does not come alone, and
- the corona current has to pass through the [initially very thin] dust layer to reach the collecting plate.

The collected dust layer can be seen as an electrical resistor. The corona current that passes through the dust layer will therefore give rise to a voltage drop across the dust layer - which gives an electro-mechanical holding force. It is mainly this holding force that makes the dust layer stay on the collecting plate and not just reentrain again into the clean gas.

Let us look at the levels of dust resistivity that we see in an ESP, and then draw some important conclusions: If we define low-resistivity dust as 10 up 8 Ohmcm, and high-resistivity dust as 10 up 14 Ohmcm, then the resistivity span between high and low resistivity is actually as high as a factor 1000 000!!

With a constant corona current we can then conclude, that the voltage drop across the collected dust layer would be 1000 000 times higher in the high-resistivity case, and hence the mechanical holding force will be much, much higher in the high-resistivity case. *Here we wish to state, that the relationship between the voltage drop across the dust layer and the generated holding force seems <u>not</u> to be a linear function. We have some indications that the holding force generated is greater than a simple linearity would predict, complicated by the known fact that there is a 4-5 ms non-corona time each 10 or 8,3 ms. This gets further complicated when Semipulse™/Intermittent energisation is used, and even more complicated when ripple-free HVDC supplies are used – which is now an everyday reality with the increased use of higher frequency switched power supply TRs. Instead of going back to basics, we have studied the resulting behaviour and reactions of many existing ESPs, and have empirically found the ESP rapping strategies to use*.

Everyone knows that when rapping collecting plates that are laden with low-resistive dust, it is quite easy to dislodge the dust. The dust may even – augmented by the still remaining voltage drop across the dislodged dust layer – be maintained as "one piece of cake", and can in an ideal case possibly even nicely slide down along the collecting plate surface in that form.

Only when the dust cake hits the hopper sides and bottom will the dust "crack up" into fine particles and give a "boil-up" cloud of particles reentraining into the clean gases. A certain amount of reentrainment will inevitably be created at each collecting plate rapping event, and therefore the reentrainment increases the average ESP emission. A very simple partial conclusion that we have drawn is, that ***to minimise the average emission, the number of collecting plate rapping events should be kept as low as possible***. We believe this is true for all dust resistivities. This statement is given without any further evidence here, but nevertheless, it is one of the foundation pillars for our presented work in this paper.

The shearing forces that are induced by the collecting plate rappers are for most qualities of low-resistive dusts usually sufficient to dislodge the dust from the plates. However, if the dust resistivity is higher, the holding forces created by the voltage drop across the dust layer may already become too high for some ESP rapper designs – and some dust will then stay on the collecting plate. The same thinking can be applied for a dust which in itself is sticky. For such a dust, any additional “help” from an electrical holding force may be the start of an undesirable dust build-up. To improve the cleaning effect it follows as one logical conclusion from the above discussion, that there would then be a few possible paths to follow of which only one is covered in this paper:

- Redesign the rapper system to give increased and sufficient rapping forces, so the dust collected can be well sheared off from the collecting plates. This is how it has hitherto been done in most European ESPs that use the tumbling hammer design
- Install sonic systems with the goal to release the dust following the principles of the walls of Jerico.
- Cut off (POR) the HVDC current completely during the collecting plate rapping event. This removes the dust holding force, and is a simple way that allows the collected dust to come loose.

It was soon found that the use of POR increased the reentrainment greatly during the collecting plate rapping event. The reason for the increased reentrainment is, of course, that the HVDC cut-off during the collecting plate rapping also stops the dust collection in the bus section affected - so the whole ESP dust collection efficiency is reduced. But POR is a way to keep the collecting plates clean, and keeping the collecting plates clean is more important than the relatively short emission peaks (smoke puffs) that POR would create.

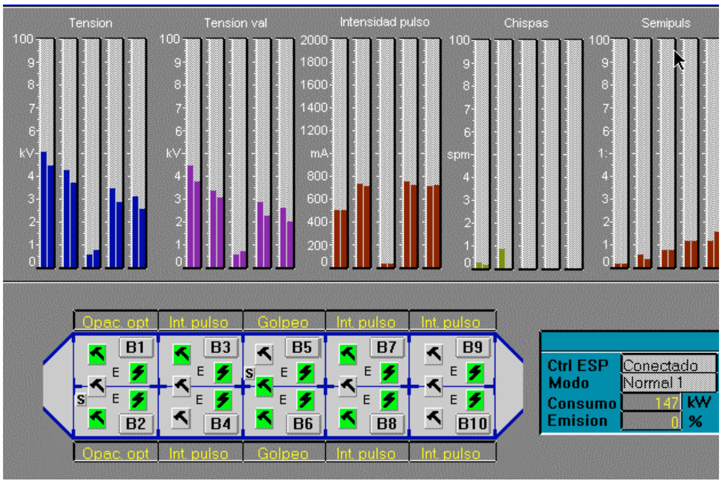

Fig 1. A screenshot view of an ESP with POR ongoing in the C-field. The current (Intensidad pulso) is zero, but there is still a voltage reading, due to collected charged particles incoming from the upstream field. The A-field shows quite low current as limited by sparking.

By using PDR, some HVDC is still applied during the rapping interval. This gives two improvements over POR:

- The bus section retains some collection efficiency
- Some voltage drop remains across the dust cake, and this greatly reduces the reentrainment while the dust cake slides down to the ESP bottom.

The correct PDR current level to use would be the exact point where the "the holding force is just enough reduced so the available rapping force matches the shearing force which is mechanically available from the rapping system". For all PDR currents that are higher than this, the holding force will be too high, which would prevent the ESP rappers to get the collecting plates clean.

Another effect creates major rapping problems with increasing dust resistivity - first PDR will be rendered inefficient and for even higher resistivities also POR becomes inefficient. The effect is the ***dust layer time constant***.

The collecting plate can be regarded as one side of a capacitor and the outer surface of the dust layer can be regarded as the other side of the same capacitor – The ash in the layer itself can be regarded as a resistance connected in parallel with this capacitor.
We can then use the formula:

[CxR] = time, where C = Capacitance, and R = Resistance

For low resistive dusts the time constant can more or less be disregarded as it has no or little impact on the rappers' cleaning effect. But for a high-resistive dust the dust layer time constant may be in the order of 1-1½ minute. If the corona current gives a voltage drop of U across the dust layer and the dust layer time constant is one minute, this formula tells us that if we cut off of the corona current the voltage will after one minute still be as high as U/2!!. Which still gives quite a high dust holding force – and this can create major dust dislodging problems.

The solution that we apply is to cut off the HVDC supply some time before the collecting plate rapping event. To differentiate this from the more common PDR or POR operation we call this PCR (short for Power Control Rapping).

For medium-resistive dusts the dust layer time constant will actually help us to maintain a certain holding force across the dust layer even if we use POR. So, for many medium resistivity dusts we would possibly not use the time shift possibility available in the PCR software, or would perhaps only use quite a small time shift.

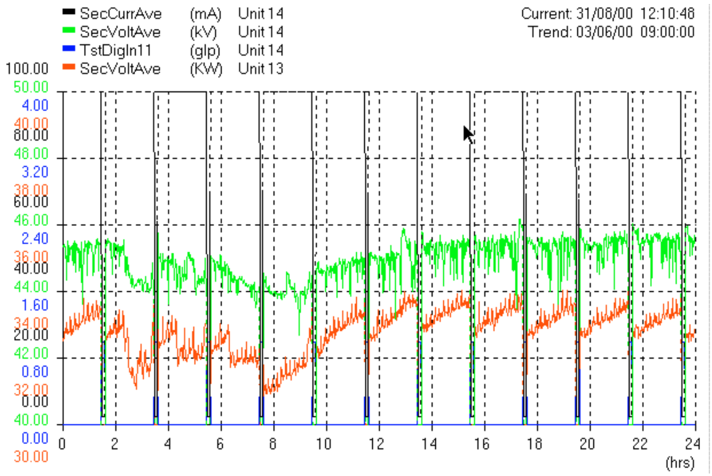

Fig 2. The lower trend illustrates how the voltage varies by time after PCR at a given corona current (250 mA). The upper trend, from a parallel field also operating with PCR is operating at spark over voltage, i.e. no current limitation. The current in this field then showed a saw tooth shape (however not shown in this graph). The current dropped by time after PCR.
The possible operating current before PCR was introduced was lower than 100 mA and after the use of PCR the current almost tripled.

Some news about smooth HVDC and collecting plate rapping

The above discussion that step-by-step logically leads to giving a glimpse about the use of PCR software discusses purely rapping of the collecting plates – and is completely rinsed from the ESP difficulties that arise when back-corona is present. The example where the span of holding forces was mentioned to be a factor 1000 000 times - as created by current and resistivity - would never really materialise, because back- corona would set in long before this.

The abatement of the ill effects of back-corona has been most satisfactorily covered in earlier papers – the first one published about the patented software EPOQ and PCR at the ISESP conference in Budapest in 1996.

Let it only here be mentioned, that with serious back corona present – when not abated with the help of e g EPOQ software in the TR controller – the back-corona itself breaks down the voltage which constitutes the dust layer holding force. The back-corona creates a very large amount of reentrainment and therefore an unnecessarily and highly increased emission. There are, however, some ESPs that are several decades old and have not yet been upgraded with modern controllers. Some of these ESPs are so voluminous, that in spite of a very high back-corona level, an emission below Authorities' requirements may still be met. In these ESPs, the back-corona itself may reduce the holding forces so much that this actually assists the rappers to keep the collecting plates clean!! We know, however, that the remaining dust is even more difficult to dislodge and the dream of a nice sliding dust cake will remain a dream only, because severe back-corona severs the dust layer with crater holes.

In some ESPs – specifically similar to the ESP example that is described in the paper that we published in New Delhi in October 2003 – the resistivity of the dust is quite high. Sometimes the dust behaviour that we see - especially in the first field - is such that spark-overs do occur at an expected kV level, but at very low HVDC current indeed, maybe only at about 10 % of the HVDC supply rated current. This leads to quite low particle charging in the first field – with associated low dust collection – but moreover the whole remaining downstream part of the ESP suffers. By using the smooth HVDC as supplied from a power supply that uses high-frequency power conversion technology, we had a working hypothesis that because of the minimal ripple the current introduced into the ESP could become much higher with the same spark-over voltage limitation.

Our immediate experience was a doubling of the current entered into the ESP, and with the improved particle charging the ESP emission was drastically reduced. However, the increased corona current raised the dust holding force – probably by considerably more than would be indicated by the power increase. Although we already had PCR in use (with time shift) we saw clear indications of dust build-up on the collecting plates (sparking was occurring at gradually reduced current levels). We then applied PCR even more aggressively. And this solved the problem.

What does "aggressive application of PCR" mean? In the case described it means the following:

- Let PCR reduce the applied power during rapping to zero
- Use increased PCR time shift
- Wait much longer than the commonly used 4-6 minutes waiting interval between the collecting plate rapping events in the first field. We rapped the collecting plates in the first field only twice per hour (or a factor 5-6 less frequently than previously).

The aggressive use of PCR with the high-frequency HVDC power supply in the first field slowly restored the current to the initially high current level, and it stayed at that level. And the emission remained low.

Then we applied aggressive PCR in the first field - using conventional TRs - and, to our astonishment, the emission improvement step was very large, although not reaching all the way down to the level we had reached with the high-frequency HVDC supply.

Then we applied aggressive PCR in all the fields (under simultaneous control both by PCR and EPOQ software, of course). And since that day these ESPs run under these new PCR parameterisations, because the emission reduction was so massive.

On the use of PCR also for low-resistive dust

After our very encouraging emission results by using PCR as above described, we have also applied PCR rapping on ESPs that precipitate low-resistive dust. For such ESPs the use of EPOQ software cannot reduce the emission – because there just is no back-corona to abate. But PCR certainly can reduce the emission. Quite often by as much as 30 %!!

The use of aggressive PCR extends the ESP mechanical life

ESP experts, when asked for advice, will often say there are at least four ways to eventually destroy either the collection efficiency or the ESP mechanical parts:

- By providing gas/dust conditions that will cause the ESP casing to corrode and insulators to crack
- Excessive sparking and arcing, especially in the fields downstream the first field
- Malfunctioning dust evacuation from the hoppers are a major reason for massive ESP emission excursions
- The rapper operation will sooner or later cause mechanical fatigue that requires maintenance and - at a later stage - exchange of ESP internal parts

The corrosion inside the ESP is – if the ESP supplier has not built the ESP from unsuitable material or has used insufficient heat-insulation – not in the hands of the ESP supplier.

The philosophy of spark handling throughout the ESP is a major factor for a modern ESP controller, but not the topic of this paper.

The rapper operation is really in the hands of the ESP control system supplier. By extending the waiting interval - as we typically do with aggressive PCR – the rapping events will occur much more seldom.

Just to mention a figure: Let's say we increase the rapper cycle of the first field from every 5 minutes to every half hour to improve the cleaning efficiency: This automatically also extends the mechanical ESP life expectancy with a factor 5x.

For an old ESP where an ESP service provider company has honestly and correctly predicted an upgrade requirement, like: "Must change ESP internals in three years" – the above mentioned factor 5x would actually extend the ESP remaining operational service life from a short 3 years to 15 years from now!!

Or perhaps the ESP exchange of internals will never be needed at all if the plant in question shall be taken out of service within the given 15-year interval!!

So, the economical value of using aggressive PCR may be extremely high – especially considering that the reduced service and repair requirement comes as a golden side effect of the reduced emission!

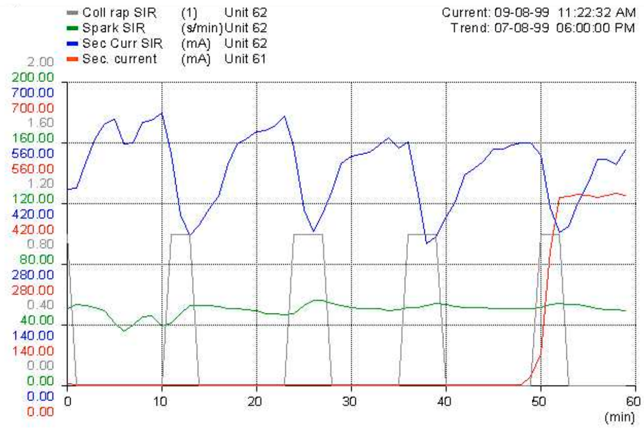

Fig 3. The upper curve shows corona current and the staples show the rapping event. This diagram clearly shows how frequent rapping heavily disturbs the corona formation.

Some points of concern when using PCR: Excessively high gas velocity

The use of POR, PDR and PCR always targets to reduce the dust holding force. This is fine and well and helps the collecting plate rapping system to keep the plates clean. But there is one point of concern where the reduction of the dust holding force my give problems: ESPs that have an excessively high gas velocity.

Today's modern ESPs will usually be designed to give a gas velocity in the range of 0.8 –1.2 meter per second. But in some existing [old] ESPs we have seen gas velocities that are 2 meters per second, and even some "horror ESPs" – that have gone to court for none-compliance – with up to 3,5 meter per second are known. Depending on secondary dust properties (secondary to resistivity) which are different in each specific case, like:

- Dust particle size,
- Dust fluffiness/density

An excessively high dust velocity may – or may not - render the use of PCR useless. In ESPs with a high gas velocity, the reduction of the dust holding force may result in dust "pull-off" by the gas velocity – with the result increased emission. For clarity it might be appropriate to denominate this "gas-velocity induced reentrainment".

Sometimes the current must then be set higher during the PCR rapping than would be otherwise desirable. Sometimes PCR can only successfully be used in a few fields. And sometimes a [very] high gas velocity may prohibit the use of PCR altogether.

Expressed in a definition manner: If the increased gas velocity induced reentrainment effect overshadows the positive dust dislodging effect created by the use of PCR, then PCR can not be used.

Some points of concern when using PCR: High dust concentration at the ESP inlet

Most of the ESPs in which we have combined the use of EPOQ and aggressive PCR are located in Europe. The very highest emission reductions have been seen with high-resistive dusts. In Europe the large coal fired utilities generally combust solely low-sulphur coals, because these coals produce low levels of SO2. SO2, of course, produces acid rain. Low sulphur coals – especially with the import coals available in Europe coming from South Africa and Australia – give ash that is usually very high-resistive indeed. Import coals are usually selected or washed to have as low as possible ash content – because nobody wishes to pay for shipping ash around the globe. In Europe, the import coals therefore have an ash content at a level of around 10-15 %.

With the worlds ESPs after coal fired power station being our most important business targets, we see EPOQ combined with the use of aggressive PCR to be most valuable in Utility ESPs burning coal from:

- South Africa
- India
- Australia (most coals)
- Mongolia (some coals)
- Indonesia (some coals)
- Russia (some coals)
- Greece (some coals)

Please note, that Utility ESPs located in USA that suffer from back-corona problems usually have ashes with a resistivity which is typically several magnitudes lower than many of the above listed. Ashes after combustion of PRB coals would – in a comparison - usually belong to an easier-to-collect category of ashes.

In the homelands of high-resistive coals, the ash content of the coal combusted is very often much or very much higher than the 10-15 % we see with import coals. In India, the ash content is rarely as low as 15%, and may in some cases even reach as high as 40 – 60 %. So, when transferring our experience from Europe on the use of EPOQ and aggressive PCR to the homelands of coals with high-resistive ash, we have had to look out for the possible problems that may be created by the high dust concentrations in the gas that enters the ESP. Instead of about 10-15 g/Nm3 of gas that may be common in Europe, the dust concentration at the ESP entry may with the high-ash coals reach multiples of that figure, or 30-50 gram/Nm3.

A high ash concentration in the coal/ash may overload the ash handling system when aggressive PCR would perhaps ideally require the use a factor 5x longer waiting intervals (half-hour or more) than earlier between the collecting plate rapping events. The momentary very high dust amount landing in the hopper especially under the first field may choke, overload or even block altogether the existing ash evacuation system, and plugging may then even create serious overfill of the hoppers and lead to enormous smoke puffs.

To "help" the ash handling system, it may be helpful to rap only parts of the bus section. Thus, a split-up of the normal 1 minute revolution of a complete tumbling hammer collecting plate rapping operation into e g 5 parts that are each 20 seconds long only, might be one way out. This may lead to a minor variation in the dust layer thickness within the bus section, but will still be a good compromise solution compared with the alternative of having to increase the temporary load capacity of the ash handling system under the first and possibly also the second field of the ESP.

Some points of concern when using PCR: Reentrainment considerations when rapping the last ESP field.

When aggressive PCR is applied in the last field of e g a five-field ESP, an optimal waiting time between the rapping event can become extremely long. We have seen successful ESP emission improvements with ***rapping intervals as long as one week between PCR rapping events*** in a last field. It should be mentioned that we also then have used normal rapping without PCR about once per night. When rapping a week's amassed dust in the last field, there will inevitably be a MAJOR size smoke puff. But if this way of rapping positively does reduce the average emission with double-digit percent figures?? One possible solution is to split up the rapping minute into smaller sections – as appropriate with Authorities limits and demands:

In USA the emission figures are given by the Authorities in permissible opacity – and usually as six-minute averages. So, a last field PCR rapping strategy that gives a sufficiently low six-minute average opacity must be found.

In Europe the emission figures are given by the Authorities in mg dust per normal cubic meter – and usually as half-hour average values. So, a last field PCR rapping strategy that gives a sufficiently low half-hour average emission must be found.

The reentrainment emission contribution created by the collecting plate rapping that reach the stack are sometimes large when rapping the first and always when rapping the last ESP fields. In the first field the smoke puffs are large because of the very large amount of dust that is released during each rapping event – and the higher frequency of the rapping events. In the last field the smoke puff itself is very large because there is no subsequent field that can assist by collecting the reentrained dust. Therefore It might be appropriate to mention here – as a side-track – that, whenever possible, a first ESP field and a last ESP field should never ever have their collecting plates rapped simultaneously, because this would mean - from the emission point of view - "double trouble".

With a quite large percentage of the worlds Utility boiler fleet operating at customer demand electricity load, it is very common indeed that boilers operate at minimum load during nights and weekends or at least during parts of Sunday and the night before Monday morning. With a real time clock in the PCR rapping system and no drift of the real time clock, we use - as a quite common to set - the weekly last field collecting plate rapping event to always reoccur during such a known low boiler load time. At low boiler load the ESP is anyway going to be grossly oversize, so even very aggressive PCR applied with no precaution at all is then very unlikely to create an emission excursion.

An important factor when introducing new rapping philosophies is that the move from normal operation to the use of the intricate, new rapping philosophies unconditionally requires the existence and use of two rare human properties:

- Patience
- Confidence

The first week with a new rapping and PCR strategy will inevitably dislodge old dust build-ups. Because of the sometimes enormous amounts and also because of the high-resistive properties of this dust - some of it will reenter the gas-stream and leave the ESP via the stack – which can get very nasty indeed. Other reasons for increased emission during the first week are insufficient capacity of the dust handling system (for the additional load created by loosening old dust), extra aggressive POR measures used during the initial stages to really get the collecting plates maximally clean – and the ESP optimising experts' need to really get down to a virgin-clean collecting plate surface in the ESP to optimise. Then he/she can judge the mechanical status of the ESP. And then the ESP tuning work can commence (EPOQ and possibly less aggressive PCR).

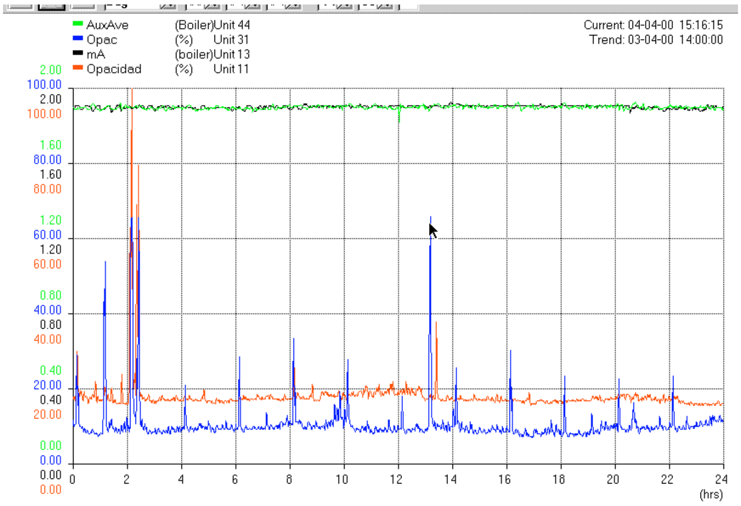

Fig 4. Here the upper curve shows the opacity for an ESP being tuned. The lower curve shows a trend from a casing already stabilised some three days ago. Note the peaks every second hour and the early morning POR cleaning of the exit fields. Midday another exit field cleaning, but with full power.

It is interesting to note, that the huge emission peaks during rapping in the first field during the first few days, will later on be followed by almost no emission peaks at all – not even during POR events.

Once this "cleaning week" is over, the emission may have returned to a similar level as before the "cleaning" was commenced. Then, and only then - is it appropriate to apply the new rapping strategies that may allow EPOQ to find back-corona at new operation points - which gives the ESP a higher collection efficiency. Gradually, with EPOQ switched on, the ESP optimising expert can then use PCR and aggressive PCR as required to get the ESP emission down to levels of emission that have earlier never been in reach with the ESP in question. Still, there is a need for confidence and patience as this can take a lot of time.

The last incremental percents of ESP collection efficiency increase are tedious to come by. Especially the PCR rapping optimisation requires a big man-hour investment. Sometimes, the temporary emission excursions may force a less aggressive cleaning operation, and the "cleaning week" would then have to be extended accordingly, of course. Time is needed – and a lot of patience – before things turn for the better.

On the importance of getting things right - and at the right time…

The EPIC and SIR range of TR/rapper controllers and HVDC supplies, are all designed with a few, possibly unique, features:

- Distributed intelligence – one controller executes all energising and rapper control in one bus section, and has its own and complete EPOQ and PCR software
- Independence – each controller works on its own – without knowing what the others do
- Each controller uses many more timers than there are rapper motors to facilitate the use of intricate rapper strategies.
- An individual real time clock in each controller and a daily synchronisation assures that all controllers always have the same real time

So, what is so important about this? Lets look at the items one by one:

Distributed rapper control provides redundancy that improves the ESP reliability
With one controller that controls both rapping and energising in its bus section, a controller that would fail will create a problem only in its own bus section. In other ESP control systems there are individual TR controllers where each one controls only the TR. Then there is one separate controller that controls all the rappers. If such a rapper controller would fail, then the whole ESP becomes inoperative very quickly indeed, and e g an immediate boiler shutdown might be unavoidable. Admittedly this does not happen often: Today's microprocessor based controllers usually have a quite high reliability. But if it happens the consequences may be "very dear indeed".

Synchronised real time gives the ESP optimiser a lot of freedom – but also imposes responsibilities
With the TR controller and rapper controller software in the same controller, it is just a software parameterising issue to let the PCR software do whatever tricks that the ESP process expert wishes. With EPOQ software in the same controller as the PCR software, it is also convenient for the ESP process expert to set up the different timers used – to avoid negative interaction.

Exact time – and timers that allow days' and several weeks or months of intervals in one end of the range - and split second partitions when so required, are a necessity when EPOQ and PCR are used in combination.

A strong advice was given above to never let the first field and the last fields of an ESP have the collecting plates rapped simultaneously. With the distributed design that we use, this is easy to achieve because our controllers use exactly the same real time and can therefore be programmed accordingly.

By using exact real-time clocks in our systems we give freedom but also responsibility to the ESP process expert. It is up to him/her only to parameterise the rapping events (and EPOQ events) in such a way that e g:

- A bus section where an EPOQ calibration is just made, shall not at the same time have a collecting plate rapping event
- A bus section upstream to the bus section where an EPOQ calibration is made, shall not at the same time have a collecting plate rapping event
- PCR (or any other collecting plate rapping) should not occur simultaneously in the first and the last ESP fields.

There are a lot of other undesirable "interactions" that the ESP process expert may wish to avoid at individual ESP sites. Some of these are mentioned in this paper. With the exact real time clocks it is freely up to the ESP process expert to set up all timers as he desires – and the daily synchronisation of the timers assures that the same real time is always followed throughout the system - year after year.

What we know but cannot disclose in this paper
At this stage we are - for commercial and other reasons - not yet in a position where we can freely satisfy the curiosity of this audience of ESP scientists with answers to the following questions:

- When is it appropriate – and when not - to use PCR or aggressive PCR?
- How do we determine the correct PCR current reduction value?
- How do we determine if and how much of PCR time shift shall be used?
- How do we inter-relate the use of time-shift and PCR current setback?
- How do we, in detail, use the extra timers that reside in our latest controllers?
- How do we determine if all collecting plate rapping events shall be with PCR – or only some or very few ?

Let it be said, that finding the collection efficiency optimal Semipulse™ charging ratio and pulse current for the entire ESP takes about 3 hours after switch-on of automatic operation for the 20 individual EPOQ software in an ESP that has 20 bus sections. And EPOQ performs this emission minimisation continuously and without any use of opacity meter signal at all.

To find optimal PCR parameters for an ESP is a much more tedious task, and requires a specially trained ESP process expert to first insert initially "good settings". Then he has to come back after a week and modify those settings, and come back again a week later and again modify. Later the modification intervals can be longer, maybe be extended to a month or so, and finally the specialised ESP process expert will be satisfied that the parameterised PCR operation is "optimal".

For cost reasons only, such reappearance's at site by a specialised ESP process experts can not be made in person – except perhaps for a first introduction and education week. After the first visit all the subsequent site visits will be made electronically - by modem. The only tool available to verify the emission reduction results of the ongoing PCR optimising, is to follow the logged opacity meter trend curves which is a part of our ProMo III software. Let it therefore be noted here, that unless a relatively reliable and well-functioning opacity meter is installed, it is only possible to set PCR rudimentarily well from experience, but a fine-tuning and verification without any opacity meter can not be made.

Tomorrow's standard arrives: Smooth HVDC power supplies, EPOQ and PCR software

It is by now completely clear to all ESP process experts within ALSTOM, that for new ESPs high-frequency power converter HVDC supplies give a lower investment cost and give a higher specific ESP collection efficiency than conventional TRs.

Hitherto, with nearly 1000 SIR units in operation [SIR is ALSTOM´s commercial name for our high-frequency power converter HVDC supply] all over the world, SIR has been used mainly in ESPs that benefit from SIR´s capability to provide more power into its ESP bus section than a conventional TR. We started to use SIR in ESPs installed after black-liquor fired boilers in the Pulp and Paper industries – and have seen extremely high emission reductions after such ESPs. A paper that we presented at the ISESP conference in Birmingham USA in 2001, gives a fairly good description of the ca 350 SIRs that we by then had in operation all over the world – all the time with quite good (or impressive) emission reductions.

Since 2001, a large number of ESPS have been upgraded with SIRs, with a massive percentage installed in old utility ESPs in USA – always with a target to reduce the emission. Quite frequently the emission reduction has been great, often better than 40 %. In most of these ESPs the emission reduction was achieved <u>without</u> the use of PCR and EPOQ software – possible because of the quite low ash resistivity. The use of PCR may very likely reduce the emission even further in these ESPs.

All large new ESPs [e.g. after coal fired boilers] must for cost competition reasons be built with 400 mm spacing [or possibly even wider spacing in the future]. This means that the largest SIR size presently commercially available [rated 70 kV at 800 mA] would be too small. For a 400 mm spacing ca 95-100 kV will be required. Therefore, ALSTOM has now designed a next generation of SIRs with 120 kW HVDC power output. The first pre-series 120 kW SIR is rated 70 kV 1700 mA – and we target to also have a SIR rated 100 kV 1200 mA ready for production and sales by early 2005.

In all the cases where we now install SIR we also strongly insist that the SIR controller and SIRs in-built rapper motor groups must also control the bus section rappers. The reason is, of course, the much reduced emissions that we can achieve with the use of EPOQ and PCR software. And, of course, for some higher-resistivity ESPs we wish to avoid the risk for dust build-ups if PCR is not used at all or if PCR is not used aggressively enough. The increased corona current made possible by the SIR technology may, just because of the increased current, also increase the holding forces.

ALSTOM has for many years strongly advocated ESPs of European design, with tumbling hammer rapping located at the bottom of the collecting plates. However, perhaps as much as 70 % of the USA fleet of utility ESPs are built with rappers that are installed at the ESP rooftop. ALSTOM´s controllers in the EPIC range [for conventional TRs] and in the SIRs are designed primarily to control tumbling hammer rappers. In several USA ESP plants we have therefore during the last decade made a few "special USA solutions" to enable us to control also electrically activated rappers mounted on the rooftop. Either we interfaced our ESP control system with existing USA top-rap controllers, or designed local solutions for each individual plant.

ALSTOM soon starts to market our first rapper control unit that can directly control many USA-design top-rap "impactors" - and on the other end communicates seamlessly with our EPICs, SIRs and the ProMo ESP HMI. The introduction of our top-rap control system is due end of 2004.

We now introduce our methods to tune ESPs using EPOQ and aggressive PCR software all over the world. This means we are on the move from a stage of maturing research to enter a stage where logistics and marketing organisational issues become increasingly important ***– targeting to achieve a reduced emission after all ESPs in the world.***

Some abbreviations explained:

EPIC
EPIC II (and EPIC III that now is in the world-wide release phase) is ALSTOM´s brand of TR controller. Each EPIC controls both the TR and the rapper operation.

SIR
SIR is ALSTOM´s brand of high-frequency power converter HVDC supply for ESPs. SIR is 3-phase powered, and is built as one complete unit in one box. SIR thus has no separate control cabinet. Rapper outputs are also included in each SIR. SIRs provide the ESP bus section with an almost ripple-free HVDC compared with a conventional TR that may have a ripple of 30-40 %.

ProMo
ProMo is ALSTOM´s brand of HMI-interface for ESPs (HMI stands for Human-Machine-Interface). ProMo is also a logger and has provisions for remote tuning the ESP via a telephone line. Much of the research and results presented in this paper could only be made in an efficient way thanks to ProMo. Tuning of PCR would be impossible for travel cost reasons if ProMo and remote communication were not available.

Semipulse™
The TR controller when set to operate a TR in Semipulse™ mode does not use all half periods of the mains frequency (50 or 60 Hz), but only every 3rd, every 5^{th,} every 7th etc. The Semipulse™ ratio in the above cases would be 1/3, 1/5, 1/7 etc. Semipulse™ is used with high-resistive dusts to increase the ESP collection efficiency. Semipulse™ technology was invented in the early 1980ies, and is also known as "Intermittent Energisation" or "IE".
SIR units can use Semipulse™ with increased flexibility.

Semipulse™ saves the majority of the TR power consumption.

EPOQ
The EPOQ software is installed in EPIC II and EPIC III and can maximise the bus sections' collection efficiency. EPOQ is short for Electrostatic Precipitator maximising of "Q", where "Q" represents electrical charge. EPOQ continuously analyses mainly the kV waveform and selects both the optimal Semipulse™ ratio and the optimal pulse current level in each individual bus section.
Sometimes – mainly for very high-resistive dusts – our ESP process experts may find it more favourable to use EPOQ as a diagnostic tool, and then select to use fixed Semipulse™ ratios and currents.

PCR and aggressive PCR
Every EPIC and every controller in a SIR comprises rapper control outputs. PCR (short for Power Control Rapping) is a software tool for the ESP process expert that allows him or her to, among other things, set the TR energy during rapping to desirable values. PCR, as available e g in every EPIC III, comes with a very extended set of user-adjustable software-based timers. PCR must always be used in strict timer correlated operation with the EPOQ software operation - or there may be unwanted

interactions between the EPOQ and the PCR software. PCR makes it possible for an especially trained ESP process expert to reduce the amount of residual dust on the collecting plates, and this will always reduce the ESP emission.

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