(TITLE)

Matching the '5 R' concept: Flexible Operation of fossil fired Power Plants – the new challenge

Abstract:

Worldwide the energy market is changing and a shift from fossil based to renewable based generation is happening. The resulting need for flexible operation creates a major challenge to the installed fleet of coal-fired boilers, both for the materials used as well as the stability of the combustion process.

Fossil-based power generation is set to stay, however its overall share will be reduced, which also reduces the power generation's environmental impact. As a result of the shift the challenges to boilers originally designed for full-load operation and now required to operate in alternating mode at medium- or even low-load levels is significant. To be able to cope with these challenges Renovation and/or Rebuilding (redesigning) of existing coal-fired boilers is required.

Looking at the combustion area there will be thermal stress on the combustion chamber's materials (walls, water tubes, etc.) due to the very frequent temperature changes. Additionally the stability of the combustion/flames itself is challenged – unstable flames mean increased possibility for boiler trips, extended use of start-up and support burners, and therefore increased fuel cost and emissions. The paper discusses enhancements and requirements for ignition (plasma based), coal flow analysis, flame monitoring, and thermal flame analysis.

Authors(s)

Roland Zepeck, Director Global Marketing,
Durag Sales & Marketing GmbH & Co. KG, Hamburg

Matching the ‘5 R’ concept: Flexible Operation of fossil fired Power Plants – the new challenge

Author: Roland Zepeck, Director Global Marketing, Durag Sales & Marketing GmbH & Co. KG, Hamburg

Abstract

Worldwide the energy market is changing and a shift from fossil based to renewable based generation is taking place. The resulting need for flexible operation creates a major challenge to the installed fleet of coal-fired boilers, both for the materials used as well as for the stability of the combustion process. Fossil-based power generation is set to stay, however its overall share will be reduced, which also reduces the power generation’s environmental impact. As a result of the shift the challenges to boilers originally designed for full-load operation and now required to operate in alternating mode at medium- or even low-load levels is significant. To be able to cope with these challenges **R**enovation and/or **R**ebuilding (redesigning) of existing coal-fired boilers is required.
Looking at the combustion area there will be thermal stress on the combustion chamber’s materials (walls, water tubes, etc.) due to the very frequent temperature changes. Additionally the stability of the combustion/flames itself is challenged – unstable flames mean increased possibility for boiler trips, extended use of start-up and support burners, and therefore increased fuel cost and emissions. There are several possibilities (some of them are pointed out here) to tackle these challenges and solve the arising problems.
One possibility for a power plant’s flexible operation is the increased flexibility of the heat capacity input (reduced mill operation). This type of operation requires reliable and fast starting ignition systems to secure a stable firing system at reduced mill operation. Plasma-based ignition systems are practically immediately available, as no preheating, pumping etc. of oil (ignition fuel) is required. Two technologies are available - Electric arc based plasma igniters and Microwave-induced Plasma Ignition Systems. Their pros and cons will be discussed in the presentation. Additionally to a plasma-based igniter’s ability of immediate ignition

the usage of the oil-based igniters can be significantly reduced and therefore much less fuel oil will be required.

Load changes will influence form, position, and radiation intensity of the flames and fireballs. Flame monitors are safety devices detecting the presence of a flame and, based on the burner management system‘s logic, tripping the burner or boiler, if flames are extinguished. Low load factors might lead to low radiation intensity and “simulate” the extinction of flames, therefore flame monitors need to be able to adjust automatically to the load situation and safely operate within a very wide dynamic range.

Load changes will influence the position of the flames and the temperature distribution within the combustion chamber as well. Visualization and real-time temperature analysis of the flames / combustion area provides information about the combustion chamber’s thermal balance leading to better control of the flame positions, less thermal stress, and less sooting.

These measures, among others, make it possible to reduce a 500 MW_{th} boiler’s minimum load factor from 36% down to 20% and therefore help making the boiler fit for the required alternating operation. The reduced usage of oil as start-up fuel and the higher flexibility of the power plant result in ROI (return on investment) with typical payback periods of 3-4 years.

Keywords: Flexible power plant, alternating operation, load factor, integration, plasma ignition, flame monitor, thermography, thermal balance, coal flow

Introduction

The landscape of energy production has experienced rapid and significant changes over the last years. In many countries these changes where not even on the horizon several years ago – and today they are an established fact. Renewable energy sources (solar, wind, hydro, and biomass) have captured a more and more important part of the overall energy mix. Electrical energy produced from wind and photovoltaic systems is preferred feeding into the grid. However, the volatility of these sources leads to significant challenges for plants producing electricity from conventional sources, primarily fossil fuelled combustions, as they can no longer operate in baseload mode, but have to follow the alternating production of the renewable sources.

Challenges for fossil fired Power Plants

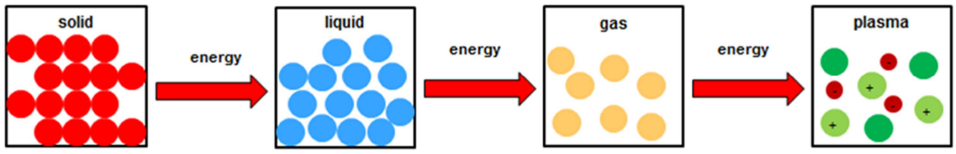
Most existing boilers have been designed for baseload operation, e.g. operating continuously with relatively constant load factors. The fossil fuel fired boiler maintained its temperature / pressure / flow situations, often only interrupted by scheduled maintenance activities or by unexpected boiler trips. The whole focus was on stable, uninterrupted, and efficient operation.
With the rise of the renewable energy sources and them becoming the preferred input into the grid the requirement of operation for the conventional fleet of combustors is completely changing: It becomes a requirement for the fossil fuel fired boiler to operate in peak load mode filling the gap when renewable sources are not delivering. There are multiple reasons why renewable sources are feeding into the grid in a reduced way or even not at all: changes in wind force (no or very low or too high wind speed), changes in solar activity (day/night shift, cloud covering, solar eclipse events). Some of these changes can be predicted, some of them are happening uncontrolled and in relatively short time sequence.
This requires the installed fleet of conventional boilers to react relatively fast to these changes creating significant challenges for their stability and efficiency. Rebuilding / redesigning the plants with modern controls and combustion systems is required to make the plants fit for this new challenge. In some way smaller (however on the other hand often somehow less efficient) plants can react faster

to these changes and can more easily fill-in as peak power plants. Compared to coal fired plants gas fired plants and gas turbine plants are also more capable for fast load changes, however this requires the secured availability of gas or LDO as fuel. The trend over the last years, however, was to build more and more large boilers, as they show significant advantages in efficiency. In the changing energy world this seems to be counterproductive (even as their overall range of load changes is significantly higher compared with small boilers) and it requires measures to be implemented supporting the flexible and alternating operation of fossil fuel fired boilers. Reduced mill operation (1- or 2-mill operation) reduces the fuel and therefore heat capacity input into the boiler, however, in order to be stable, requires refined controls and fast available ignition systems.
Looking at the firing system the alternating operation (i.e. frequent and significant load changes) creates thermal stress and unbalance, unexpected boiler trips, excessive sooting, and frequent re-ignition.

Ignition System

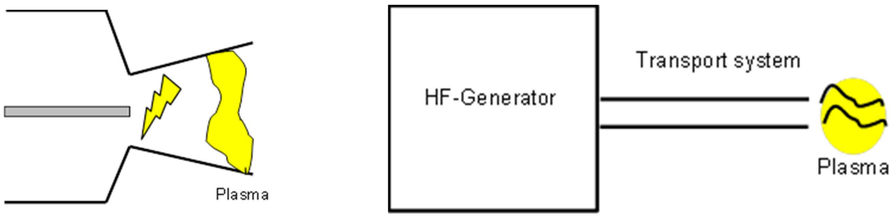
Conventional ignition systems are based on electrical high energy ignition and gas or oil (LDO or HFO) fuelled ignition burners. These systems are both used for preheating of the boiler (typically performed by oil igniters), as well as for the ignition of the main PC burners. Operation of an oil-based igniter requires preheating of the oil, pumping of the oil, preheating of the combustion air, vaporizing of the oil (typically with steam), and operation (mechanical inserting, starting) of the electrical high energy igniter (or the gas igniter, if this is used). To reach stable and successful operation of the ignition system, substantial time is required which reduces the boiler’s ability to follow the demand-required load changes fast and frequently. An ignition system with virtually immediate full availability would support these load changes. Over the past years plasma-based ignition systems have been developed filling this gap. In a plasma ignition system a plasma beam is created being capable of direct ignition of solid fuel (PC).

Plasma is the fourth aggregate condition – an ionized gas volume. The plasma beam provides a very high ignition potential due to a core temperature of app. 3500°C.



(Source: DURAG GROUP)

Basically two different ways are used of transmitting the energy into a carrier medium (gas) to create a plasma beam: Electric Arc or Microwaves.



Electric Arc Microwave *(Source: DURAG GROUP)*

An electric arc is a self-containing electric discharge in a gas between two electrodes providing an adequate high potential difference (= tension) to maintain the current density by collision ionization. Comparable with the technology of the electric steel melting low power (300 V) and very high current (>300 A) are necessary. This results in high infrastructural efforts because large transformers or switching equipment is required. Disadvantages of this technology are extensive wearing of the electrodes, high cooling requirements, challenging heat dissipation, and a low efficiency (20%). Both cooling requirements and electrical supply result in high operational costs. Advantage of the electric arc technology is the simplicity of this technology.

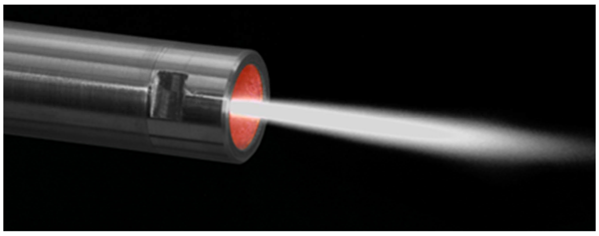
Microwaves are a known and available technology. The microwaves are created in a high frequency (HF) generator (magnetron) and electrically transported through the plasma lance to the lance tip, where an initial ignition (ignition spark from transformer) takes place. In the carrier medium (typically air) this creates the plasma which is an electric arc blown-out in volume. Advantages of the plasma created by high frequency are the compact construction of the system (no extensive infrastructure with large transformers or switching equipment), high efficiency (app. 70%), and low power loss. Operational costs are low because of, due to the high efficiency, low cooling water requirements. There is almost no wear and tear of the lance tip because the carrier medium blows-out the plasma as ionized gas cloud. Additionally after successful ignition a retraction unit retracts the plasma lance out of the combustion chamber.

Fuels – suitable for ignition with a plasma ignition system include:

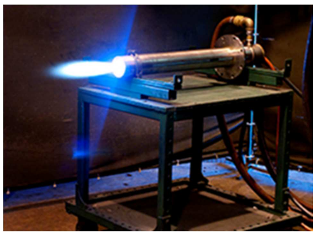
- Pulverized Coal (PC) is powdered dry lignite or hard coal. Pulverized lignite contains up to 50% solvents (aromatic hydrocarbons); the carbon content constitutes of app. 55 – 65%. Based on provenience hard coal contains between 10 – 30% solvents, the carbon content constitutes of app. 60 – 80%.
- Biomass dust is pulverized material coming from plants, animals, and their waste.
- Any kind of oil and gas.

Following parameters influence the functionality of a plasma ignition system:

- Combustion air temperature
- Fine dust content of the fuel (coarseness setting)
- Content of solvents
- Water content in the fuel
- Fuel-/air ratio inside the plasma volume and fuel's flow rate (residence time) inside the plasma volume
- Position of the plasma lance within the burner
- Through-ignition of the burner (flame stabilization)



Plasma Beam
(Source: DURAG GROUP)



Plasma Burner
(Source: Westinghouse)

A plasma-based ignition system allows the partial or complete replacement of the oil-based ignition burners as part of a higher flexibility (load control range and speed of load control changes) of the coal or lignite fired boiler. There are in principle three scenarios possible, described from actual installations in Germany:

Partial replacement of the oil burners:
The combustion process is classical pulverized hard coal combustion with 4 coal mills. For start-up and support firing in each main burner a heavy fuel oil start-up and support burner with natural gas or electrical high energy ignition is installed. As part of higher flexibility operation with 1 or 2 mills should be possible. The heavy fuel oil start-up burners remain for the cold-start, whereas the plasma ignition system as a fast available ignition system will be used for direct ignition of the main PC burners in the running, operating, and therefore hot boiler. This will be utilized mainly during low load conditions and resulting firing process instabilities of the mills and main burners. Adaptations at the existing burners might be necessary.
The advantages result from the instantaneously available plasma ignition system providing permanent reliable direct ignition of the hard coal burners; no more time-consuming conditioning of the oil start-up burners and no oil required as support fuel. 1 and/or 2 mill operation will be possible with higher boiler system availability. Higher flexibility of the load control allows higher plant availability with the grid control resulting in higher compensation for electricity fed into the grid.

Complete replacement of the oil burners – Lignite-fired boiler:
In a lignite-fired boiler (500 MW_{th}) the combustion process is classical pulverized lignite combustion (raw lignite) with eight oil burners installed as start-up and support burners.
These start-up oil burners were replaced with eight new burners (30 MW_{th} each) for pulverized dried lignite (PDL) including microwave plasma ignition systems, as well as silo and dosage system for PDL. The plant owner Vattenfall installed the retrofit as a solution for increased flexibility of the boiler system.
After the retrofit the start-up of the entire boiler takes place without the use of oil as start-up- and support-fuel; the boiler can operate in a wide load control range with high availability. The use of PDL instead of heavy fuel oil provides a cost reduction for the start-up processes as well as allows reducing the boilers low-load from 180 MW_{th} (36% load) to 90 MW_{th} (18% load) With the reduced low-load the number of start-ups and shut-downs (required by the grid) are reduced.

Complete replacement of the oil burners – Hard Coal-fired boiler:
At cold start condition the PC burners can also be ignited directly with a plasma ignition system. Technically modified burner designs are required. The technical adaptation relates to:

- Fuel/air ratio at the PC burner's point of ignition
- Flow velocity (retention time) of the fuel inside the plasma volume
- Positioning of the plasma lance in the burner
- Through-ignition of the burner (flame stabilization)

The advantages are:

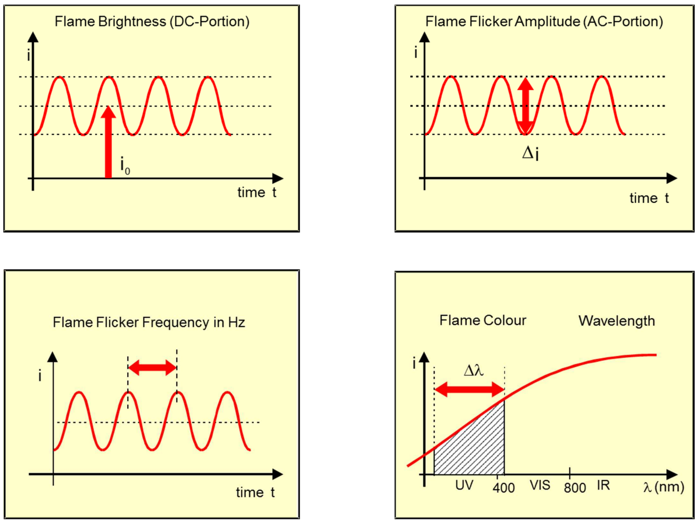
- No additional components (infrastructure) for fossil ignition fuels (gas, oil) required (costs for installation, maintenance, inspection, and acceptance)
- No additional fuel consumption (less operational costs)
- Less pollution, less environmental impact

Coal Flow Analysis

Primary air (fuel air) transports the pulverized fuel from the mills to the respective burners. Knowledge about the stability of the fuel flow and the actual mass flow of the coal helps for optimizing the combustion and selective load reduction or shut-down of burners. Higher flexibility of power plants requires higher flexibility of the fuel flows. Especially for 1- or 2-mill operation an accurate knowledge and control of the fuel flow is essential. Over the years multiple approaches have been taken to develop reliable and rugged sensor systems for this application. Non-intrusive measurements (e.g. using high frequency microwave technology) have proven to be both reliable and accurate. The signal can be used either individually as information system or can be connected to overall optimization systems for the combustion.

Flame Monitoring

Flame Monitors are responsible to ensure a safe combustion process by detecting the presence of the flame and eventually trip the burner or elevation or boiler (depending on the burner management system's control sequence, e.g. single burner trip or 2-out-of-4 elevation trip or adjacent elevation trips resulting in boiler trip). The boiler's load changes significantly influence form, position, and radiation intensity of the flames and fireballs. Typically, the higher the load factor is, the brighter and larger the flames become. This also results in smaller and darker flames at lower load conditions. Changes of the fuel (both provenience of the mine as well as the milling) also influence the nature of the flames. Nevertheless it needs to be ensured that the flame monitors at any situation safely detect the presence or absence of the flames. This requires the flame monitors to be able to operate in a very large dynamic range and especially not to depend on the detection of the light intensity only, but use other flame characteristics like frequency, flicker rate, and harmonic detection as well to detect the presence of the flames. The light radiation intensity is very high at full load, whereas it might be very low at low load (especially when higher ash content is present). If a flame monitor does not have a very large dynamic range the detection at low load situations might be instable and/or at full load situation might be over-saturated, both possibly leading to not recognizing the flame safely and reliably.

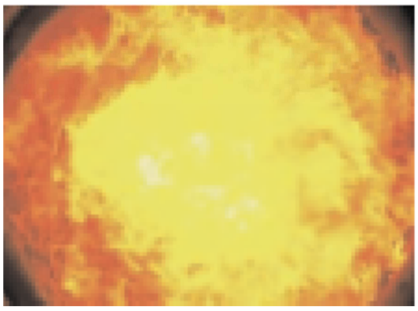


(Source: DURAG GROUP)

Preferably flame monitors should be equipped with automatic attenuation control whereas the sensitivity of the flame monitor to the flame’s light radiation is automatically adjusted following the load factor of the boiler. This can be either an optical or an electronic adjustment and ensures the reliable detection of the flames especially under the increased requirements during alternate and flexible operation of power plants.

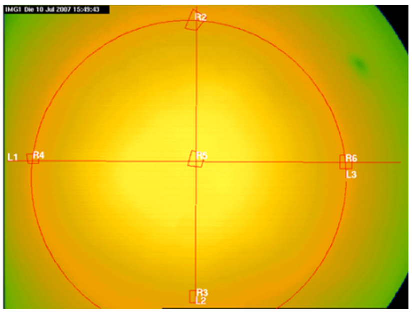
Flame Analysis and Combustion Optimization

As described above, load changes will influence the flames, not only the intensity, but also the geometrical location inside the combustion chamber, both in relation to each other as well as in relation to the furnace chamber's walls. This can lead among others to excessive sooting, flame impingement, overheating and heat stress, thermal corrosion, and higher UBC (unburned coal) content in the ash. Online real-time thermal image analysis (thermography) of the flame and/or fireball helps to control and possibly avoid these influences which will significantly increase during alternate operation of the boiler. Thermal balance of the flame area will help optimizing the combustion, especially during fast load changes. A thermography system works like a pyrometer, however creates thermal images of a larger area and not only from a single point.



Fireball image

(Source: DURAG GROUP)



Fireball thermography

Overall optimization systems will help operating boilers under the new requirements for flexible and alternate operation. Signals of the above described sensor systems can be connected as input to an optimization system supporting the alternate and flexible operation of power plants.

Cost and Summary

The increased production and use of electrical power from renewable energy sources (PV, wind) creates new and significant technical challenges for the installed fleet of conventional power plants, especially fossil fuel fired boilers. This requires renovation and (to some measure) redesign of the existing boilers to be able to efficiently operate under the new power mix structure.

The additionally desired increased efficiency has two sides which both need to be achieved, the technological efficiency as well as an economic efficiency. Rebuilding existing aging thermal power stations might proof to be both technical and economical efficient depending on the right measures are put in place. It will also increase the flexibility of the overall fleet allowing the successful integration of renewable energy sources.

Nevertheless it should be clear that the integration of new energy sources into the energy mix and the required adaptation of the existing grid operation to maintain a stable grid do not come free of charge and the necessary changes require significant financial investments which need to be allocated, very most likely to be paid through the electrical tariffs. However, this is a well-paid investment into the ecological future of our planet.