Advanced Furnace Control

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Abstract

This paper describes a furnace resistance controller which can be integrated into new or existing control systems for submerged arc smelting furnaces. The controller is entirely software based and calculates all furnace, transformer and secondary circuit impedances from real time electrical measurements. The controller functions without reference to electrode-to-bath voltage measurements which are prone to error, thus enhancing the accuracy of the circuit calculations.

Introduction

With the competitive nature of the global marketplace, control systems are increasingly being expected to not only perform traditional control functions, but to fit into the value chain of organisations, adding as much value as possible to the entire process and enabling those organisations to be optimally cost effective and competitive.

Optimum furnace control is vital to ferroalloy smelters as a marginal increase in power input can make a significant difference to profitability. To optimise a furnace with a single 3 phase transformer is reasonably straightforward, even in a manual control mode, for an experienced operator. However, a furnace with three independent tap change, single phase transformers requires a more complex approach. It is not always obvious to the operator which is the correct tap changer or electrode to move and this often leads to wasteful trial and error operations. This results in the furnace not being fully optimised and tap changers requiring frequent maintenance. In addition, a controller based on resistance control improves the quality of the tapped metal.

To meet the growing demand for a controller which overcomes these problems, an Advanced Furnace Controller has been developed. The controller is a multi-variable furnace controller which predicts the results of all the control change options before taking any action. The control option that will bring the furnace closest to the required setpoints is then chosen and action is taken. The controller optimises the furnace by operating the electrode movement controls as well as the individual tap changers.

The advanced furnace controller has been in operation for one year on a large ferrochrome furnace and significant improvements in furnace efficiency have been achieved during this time. It has demonstrated its ability to achieve steady furnace power input over a wide range of operating conditions.

Features and Benefits

Traditional automatic furnace control has provided users of submerged arc furnaces with many benefits. These benefits include higher average and consistent power input, less time spent on furnace control by plant operators and increased plant utilisation. However, the Advanced Furnace Controller provides some additional, previously unavailable benefits.

Automatic Resistance Control

Automatic control of power and resistance under the electrodes, leads to stable furnace power input and operating conditions. This, in turn, allows a higher average power input without overloading or tripping the electrical supply system. The benefits realised from these are :

- Increased productivity due to higher average power input.
- Increased metal quality due to stable resistance control.
- Increased furnace efficiency due to stable power input.
- Increased operator efficiency due to less time spent on furnace control functions.
- Increased utilisation due to fewer trips and downtime.
- Increased profitability due to all of the above.

The Controller is Predictive

The predictive nature of the controller ensures that the optimum furnace conditions are reached in the shortest time possible. It also utilises the tap changers more economically and ensures an overall stable furnace operation even under unbalanced electrical conditions.

Tap changers require regular maintenance based on the number of operations they have undergone and it is therefore important to avoid unnecessary tap change operations. By predicting the best possible action prior to taking action, the tap changers are used more economically.

Unbalanced conditions usually result from long or short electrodes, or from an electrode being restricted to a baking schedule. Furnace tapping operations also cause an unbalanced condition on the electrode nearest the furnace taphole. It has been found that some voltage imbalance and circulating current is acceptable in the furnace and therefore it is not necessary to change all three tap changers together. Thus, the controller cuts down on the use of tap changers and limits the effects of unbalanced conditions in the furnace.

In addition, the more stable operating conditions allows the furnace to operate efficiently even when fines are used instead of lumpy ore. This factor alone could provide significant benefits with the growing shortage of lumpy ores and increased necessity for the use of fine ores.

Excluded Electrode-to-Bath Measurements

Electrical calculations are more accurate with the Advanced Furnace Controller. Electrode-to-bath voltage measurements are prone to error due to the magnetic fields surrounding the high current secondary circuit components. This independence from electrode-to-bath measurements and the electrical parameters relating to the transformer and secondary circuit conductors, ensures that the controller operation is based on accurately calculated information, thereby providing better, more accurate control under all conditions.

Software Based Controller

As the controller consists mainly of software algorithms, it is to a large extent independent of existing hardware and can be implemented on most furnaces. The controller is easy to implement on a new or existing plant control system, provided that the system complies with IEC-1131 and open client-server architectures. As the Advanced Furnace Controller complies with open client-server technology, the controller is able to interface to management information systems and advanced engineering software to assist plant personnel in operating the furnace.

Universal Application

Although the controller has been developed to take advantage of the extra flexibility available when three single phase transformers are used, it can also be used on furnaces with only one three-phase transformer and tap changer, or for different primary circuit connection arrangements (star or delta). The control algorithm used varies slightly to cater for the connection arrangement, but retains all the features and benefits as discussed.

Control Model

Figure 1 shows the electrical model of the furnace.

Note that this model represents a primary delta connection and that the control algorithms must take into account whether the primary circuit is connected in star or delta.

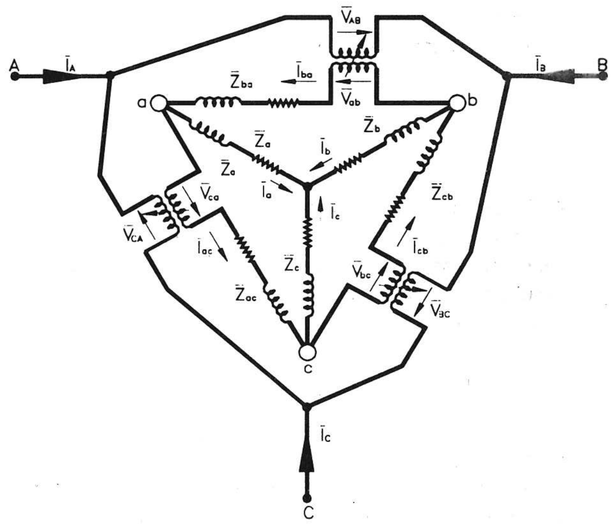

Figure 1 : Advanced furnace control model.

The model represents a three phase unbalanced system. Hence, the standard electrical equations for a three phase balanced system do not apply. To solve the model, one needs to go back to basics and solve the problem using vector analysis, trigonometry, complex mathematics and matrix arithmetic. For the controller to function correctly, equations must be derived for all the resistances and reactances shown in figure 1. This leads to defining a set of simultaneous equations which need to be solved.

The furnace controller thus controls all three electrode positions and all three tap changers as part of a single, multi-variable input-output system, instead of three independent control systems which tend to interfere with one another, especially in the case of electrode movement. The effect of mutual interference on electrode control systems, plus the added complication of unbalanced voltages applied to pairs of electrodes, makes a multi-variable controller much more accurate and stable.

Control Algorithm Outline

The automatic furnace controller follows a four step cycle as follows :

(i) All furnace impedances are calculated (not assumed) from electrical measurements on the furnace power supply system. No electrode-to-bath voltage measurements are used in the calculations, as these measurements are inaccurate.

(ii) The electrodes are moved incrementally, within limits set by the operating personnel, to track the resistance setpoint.

(iii) This affects the resistance in the furnace, so the furnace impedances are calculated again by the mathematical routine, to examine if any tap change operations are required.

(iv) A rule based decision matrix is then employed to decide what corrective action is required to improve on the present furnace operating conditions. If none of the available options are better than the present one, then no tap change takes place.

The cycle then repeats.

The controller is rule based, which gives the controller a predictive nature, as the controller is prevented from making a corrective action that it will immediately be forced to reverse. The rules are also configured in a hierarchy of importance. For example, there is a high level rule which will accept a tap change choice which results in one or more transformer currents above the maximum transformer current limit, if the projected currents are less than the present values. This rule allows the controller to back out of overload conditions, such as during tapping operations when the taphole electrode tends to rise out of the furnace before tapping and then lower after tapping.

Once clear of the overcurrent rules, the controller would act in accordance with another set of rules, which would drive the furnace towards a power setpoint. Other rules are configured to allow the furnace to operate at the highest possible power while one electrode is limited to a baking schedule. The controller can cater for other conditions such as transformer overtemperature, maximum demand constraints and so forth.

The Advanced Furnace Controller has already demonstrated its ability to achieve steady furnace power input over a wide range of operating conditions. Figure 2 shows a trend of even power input to a 43 MVA ferrochrome furnace over a 12 hour period.

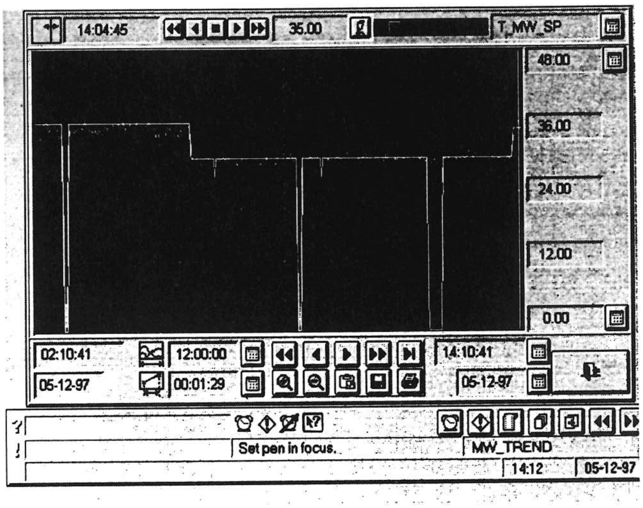

Figure 2 : Power input to a ferrochrome furnace.

The trend shows the power setpoint for the furnace (straight line) which drops to zero when the operator switches the furnace off. The varying trend line is the measured power input to the furnace.

Control Architecture

Figure 3 shows the definition of the five functional levels of plant control from the plant floor instrument level to the financial control level.

The advanced furnace controller must be implemented either at level 2, also known as Process Optimisation Control, or at level 1 - the Basic Automation and Control level. Most furnace controllers have been developed as level 2 systems, mainly due to the ample availability and knowledge of high level software to program the algorithms required for furnace control.

As computer technology has advanced considerably and better equipment and software have become available, it has become possible to implement furnace control as a level 1 control system. This allows the furnace controller to take full advantage of controlling a complex plant at the basic level of control, thus making it much more reliable. All alarming, optimisation, sequencing and interlocking can now be performed as part of one controller without having to pass data to a high level system for processing.

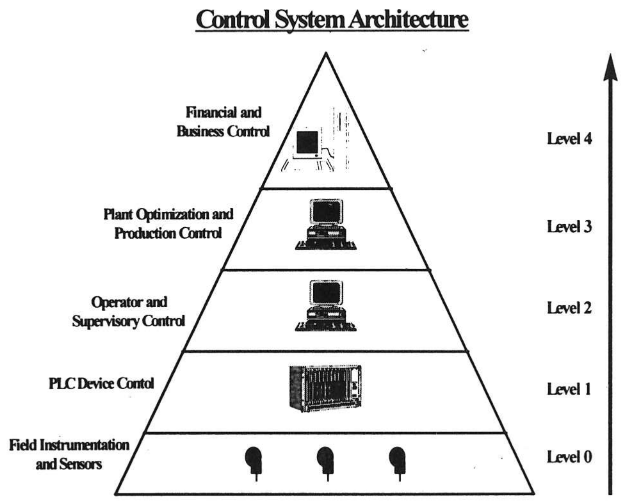

Figure 3 : Functional levels of plant control.

The Advanced Furnace Controller has been developed to meet the criteria of being easy to program, flexible and be able to interface with most modern control systems. The level 1 version of the Advanced Furnace Controller has the added advantage of making full use of IEC-1131 programming software, uses standard control hardware and can be interfaced via standard Ethernet protocols.

The controller allows a complex plant to be controlled in real time, with various programs running simultaneously with multi-tasking capabilities. As an open system, it allows any system to communicate with it, without any special communication links. It also makes full use of 32-bit technology, for speed or processing power. The level 1 controller has an advantage in that it is far more reliable than a level 2 controller, as it does not suffer from operating system stability problems. However, the level 2 system has proven its stability by interfacing directly with the plant control system for over a year on a 43 MVA furnace.

By using open client-server technology, the controller is able to perform even more functions than merely controlling the furnace. The controller is able to provide information for simulation, neural network modelling and expert systems to assist in operating the furnace. These features allow the furnace controller to grow with the individual client's needs.

Applications

The essence of the Advanced Furnace Controller is a set of complex mathematical equations and control algorithms. Implementation of the controller is a matter of implementing these on the required control platform and setting up communication signals and parameters to the overall plant control system. An operator interface, usually in the form of SCADA screens are then configured.

To implement the Advanced Furnace Controller on any existing plant or new plant, the controller must maintain the integrity of normal plant control, sequencing and interlocking. For example, the controller must take into account the electrode position limits and consider the basic electrode movement control, its characteristics and limitations.

There are various options for implementing the Advanced Furnace Controller :

(i) It can be implemented as a level 2 system as a separate stand-alone controller and communicate to the level 1 control system, which will execute the instructions from the controller. The system may also be implemented on certain existing level 2 systems if it conforms to the open client-server technology and interface constraints.

(ii) The controller can be implemented as a level 1 system as a separate and dedicated furnace controller. Signals will have to be hard-wired to the controller and all actions, interlocking and sequencing would be performed by the controller. Setpoints could be downloaded and the controller monitored via an existing operator interface, or a separate operator interface could be provided. If an acceptable level 1 plant control system is already installed, then the controller could even be implemented on the system as a sub-program.

These arrangements provide enormous flexibility to allow an automated control solution to be engineered to suit almost any given situation. It must be noted, that each situation must be examined before a choice of implementation is advised. Not all existing control systems are suited to the Advanced Furnace Controller requirements. To install a controller, the plant control system would have to be examined and any special requirements or limitations imposed by the plant equipment or end user, would be taken into account. The furnace controller is flexible and can be customised to suit the client's individual needs.

Summary

The Advanced Furnace Controller offers a complete solution to furnace automation, for both existing furnaces and those that are in the process of being built or planned. The controller has been developed and is supplied by a company that has extensive knowledge and experience in designing, building and operating submerged arc furnaces. Real benefits can be achieved by using the Advanced Furnace Controller as operators of furnace plant can gain maximum return on their investment, by ensuring that it is controlled as efficiently as possible.

Acknowledgements

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