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ADVANCED PROCESS CONTROL IN THE EVAPORATION UNIT

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Abstract

Energy consumption is a significant constituent of production cost in an Alumina refinery. Indian refineries are striving to reach global benchmarks and have made conscious efforts to minimize energy consumption. Evaporation plays a significant role in conserving energy and is responsible for 30% of the thermal energy consumption. In the Evaporation unit, due to a large number of interacting processes, frequent disturbances and the presence of single line equipment, it is necessary to maximize the utilization of assets to ensure the production volumes at targeted efficiencies. The need for reduction in process variability resulting in optimizing operations, challenged by plant constraints, was derived by adopting Advanced Process Control (APC) application in the Evaporation unit.

APC incorporates a matrix of modeled dynamic process responses with an optimizer to maintain the unit at the most profitable vertex of the allowable operating envelope. This paper will discuss the area selection criteria, activities carried out during the project tenure and post benefit analysis.

Introduction

The challenges for any alumina refinery are to minimize the cost of production per tonne of alumina, while meeting safety and environmental considerations, along with maximum production volumes. In view of the recent step increase in the cost of energy generated from fossil fuels, Alumina refinery operators are constantly looking for various ways and means to reduce specific energy consumption per tonne of alumina production. Utilization of new control technologies using existing infrastructure with a reduced support team has emerged as a new dimension for significant economic saving in alumina production. Multivariable predictive control technology becomes one of the main tools to optimize the capital investment.

M/s Vedanta Aluminium Limited is located at Lanjigarh, Orissa state, India, having a capacity of 1MMTPA smelter grade alumina production, employing the Bayer process with low temperature and pressure digestion. Evaporation consumes about 30% of the thermal energy and is an ideal unit in Alumina refinery for APC implementation to generate significant potential savings. Apart from this, other benefits accrue, such as uniform test liquor caustic concentration, which is a key parameter in the Digestion unit for improving productivity. In classic process control, a controller brings a single value close to a set point using a single manipulated variable, or it can involve a reactive process based on currently measured conditions. Classic process control can do things automatically, but it can't respond to other kinds of variables, such as cost constraints. Process variability reduction resulting in optimizing operations challenged by plant constraints was derived by deploying an effective APC application in the Evaporation unit.

Process Description

The evaporation unit removes water that has entered to the liquor circuit from bauxite moisture, mud washing, hydrate washing and miscellaneous dilution streams. The evaporation section consists of two identical parallel batteries of six backward feed, falling film evaporator units in each battery. The weak Spent liquor is collected and received in evaporator feed tanks. The weak liquor is evaporated in the six backward feed falling film evaporators and strong liquor is stored in the evaporator test tanks. In each evaporator train six nos. online calandrias are provided as tubular heat exchangers according to the falling film principle. Each calandria is equipped with a detachable cover and liquor distribution system (on top) for even distribution of spent liquor into the tubes.

Vapor separators and ducts are provided next to the calandrias for efficient separation of the vapor from the product. Low pressure (LP) steam provides the energy required for evaporation. LP steam is fed to the 1st effect from main header through flow control loop. A desuper heater is provided in the steam main header in order to extract superheat from the steam coming from main header and thereby preventing high temperature steam entering the evaporator body. Spent liquor is pumped from the feed tanks to feed flash vessel connected to 5th effect unit where it gets flashed and evaporated and then transferred successively to feed flash vessels connected to the 6^{th} unit and mixing condenser for further concentration. After flashing the feed in three flash vessels, the liquor is pumped to the 6^{th} unit. From the 6^{th} unit, the liquor is pumped successively to the 5^{th}, 4^{th}, 3^{rd}, 2^{nd} and 1^{st} units through transfer pumps. Finally the concentrate coming out of the 1^{st} unit is flashed successively in product flash vessels connected to 3^{rd} unit followed by 4^{th} unit and thus final concentration is achieved. Each body is provided with a recirculation pump and corresponding piping. The recirculation pump circulates the required flow of liquor ensuring the proper wetting rates (to avoid any dry spots on the evaporating surface) to the top of the calandria on liquid distributor. The steam condensate from the 1^{st} effect and 2^{nd} effect is extracted without flashing. Balance process condensate is flashed three times before being extracted at 60 ^{0}C. Non-condensable gases from 1^{st} unit to 6^{th} unit are connected to a common header and in turn are connected to a condenser. The vapors from the 6^{th} unit & last feed flash vessel are condensed in a direct mixing type condenser (Barometric Condenser) with cooling water from an alkaline cooling tower entering condenser at 35°C and returning at 50°C. The vacuum in the evaporator is achieved & maintained through a two stage steam ejector system. LP Steam is being used in the ejectors to maintain the desired vacuum in the system.

Area Selection criteria

Digestion, Calcination and Evaporation are the three major areas for APC implementation to generate profits in terms of yield improvement, increase in throughput, minimization of standard deviations of process parameters and reduced energy consumption. The digestion process has the most potential for APC benefits because it is a key production unit, critical for sustainability of the process and a good state of digestion control. Due to frequent changes in the quality of the bauxite feed to the refinery, it is difficult to control the process parameters in the digestion unit. So the option of APC implementation in the digestion unit was kept on hold tempora-rily. However, auto control of alumina to caustic ratio with test liquor and bauxite slurry has been implemented.

The existing Calcination unit has been planned for an upgrade in throughput by 20%. After completion of the upgrade and achieving the rated throughput, APC implementation will be done in Calcination.

The two Evaporation units are designed for 300 Tonnes/hr each. Due to lower bauxite quality than design (~37% Trihydrate alumina (THA) compared with a design of 41% THA), mud generation is on the higher side which results in more wash water demand per tonne of red mud to minimize residual caustic losses. So both the Evaporation units are operated with 65%-70% of their capacity. To maintain consistent product quality, minimizing the effect of disturbance and enhancing performance of single line equipment, raised a challenge to improve the steam economy, so as to reduce the specific energy consumption per tonne of alumina production.

Robust Multivariable Predictive Control Technology (RMPCT)

Control designs in the process industry are almost exclusively based on PID controllers these days. Even though they are simple to implement and easily integrated into the control system, they quickly reach their limits when more complexity is involved. The development of advanced control theory has received considerable attention and applications in the process industry are gradually increasing. APC opens new opportunities, as even complex situations can be mathematically described with process parameters or variables and used for automatic, flexible plant operation. APC employs robust control techniques and can handle several constraints simultaneously by handling multiple inputs and outputs, and maximizes the profits derived by pushing the operations closer to limits.

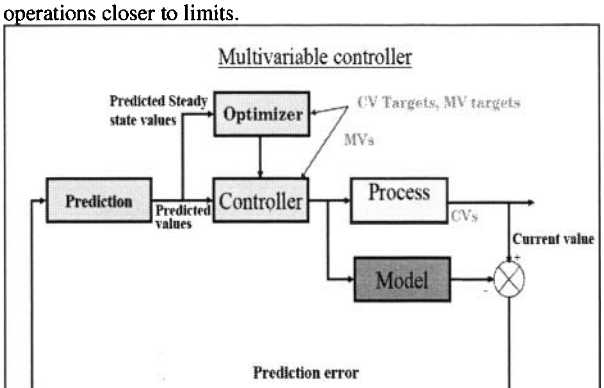

Figure 1. Advanced process control components

Advanced process control consists of optimizer and prediction model. The function of the prediction model is to predict the future response with respect to control. The prediction model will send communication to optimizer for taking moves on targets of Controlled Variables (CVs) and Manipulated Variables (MVs) and final control element will take action accordingly. The basic idea of the control strategy is to take action before a disturbance reaches the CVs. Disturbances which enter the process are detected using the predictive model and appropriate changes are made in the manipulated variables such that the controlled variables are held constant. Figure 2. shows the behavior of variables with and without control process.

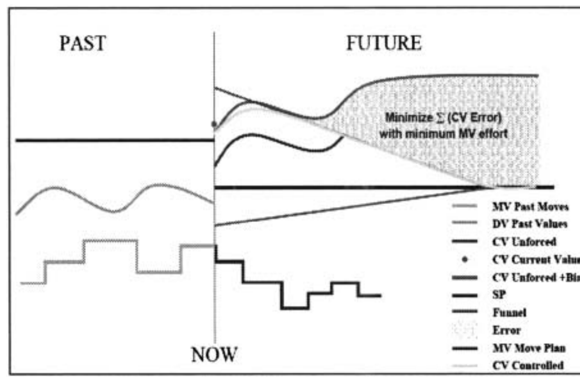

Figure 2. RMPCT controlling a CV inside limits

APC brings several values close to optimal targets simultaneously using several manipulated variables simultaneously. Also, APC includes a predictive process based on a process model that foresees how variables will behave in the future, and the controllers in an APC system find optimal trade-offs in case of conflicts among the goals. Because several actuators act simultaneously to achieve the best trade-offs, the application can achieve its goals in the fastest or most efficient fashion. In addition, APC's predictive character allows early recognition of potential violations and timely implementation of remedies, which means improved stability and reduced defects. It also lets applications work nearer to process constraints, which further reduces costs. A major objective of APC is to minimize the dotted area (Error) shown in Fig.2

APC Advantages

- Standard deviations are minimized and faster adjustment can be done
- Improvement in throughput, yield and consistent product quality
- Manual intervention will become significantly less, which leads to a reduction in operator stress
- Lifetime of the plant with the existing automation increases with less maintenance work
- Significant reduction in energy consumption

Project Implementation Steps

The scope of the project was the implementation of APC in both evaporation trains of the alumina refinery. A detailed project planning schedule was prepared in collaboration with M/s Honeywell. The following activities were carried out over five months.

Data Collection and Analysis
Base case data was collected to understand the operation of evaporation unit and evaluate the variability in process parameters. Six minute average data was considered for variability analysis. Minimum, maximum, average and standard deviation of all process parameters were collected for 15 days to understand the existing operation, and major process upsets during this period were discarded.

Preliminary Plant Test
The main objective of Preliminary plant test was as follows: Estimate step size, dead time and settling time of the variables, Evaluate the tuning of the DCS controllers and changes accordingly wherever is required, Check the existing instrumentation. Preliminary plant test was performed for one week. During preliminary plant test, the operation of a few controllers was improved from earlier Manual mode to Auto mode by making the adjustment in tuning factors of the controllers.

Fig.3 shows the controllability of steam flow in AUTO mode. This valve was operated manually earlier. After taking the controller in AUTO the fluctuation in steam flow has come down significantly.

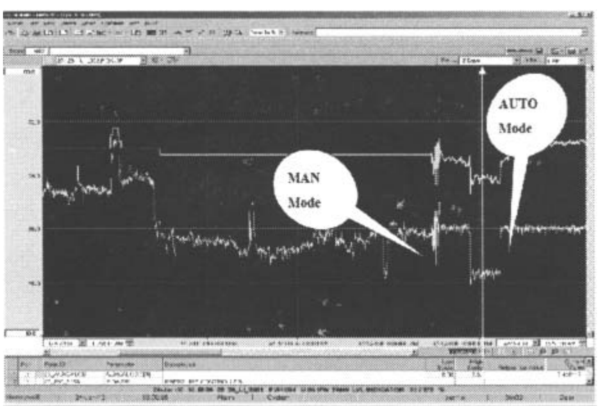

Figure 3. Steam Flow control before and after tuning

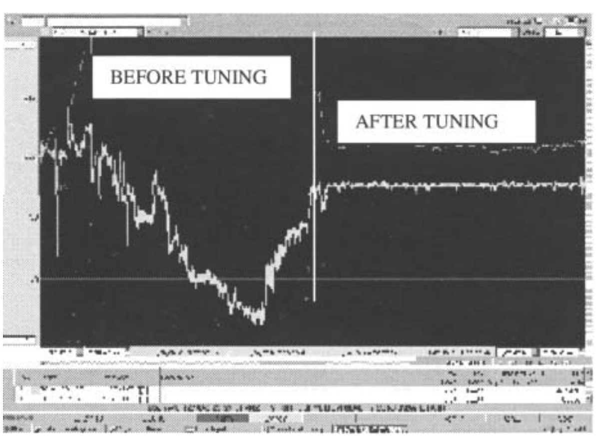

Figure 4. shows Product Flash Vessel#3 level before and after tuning

Functional Design
The functional design specification was based on preliminary plant test and earlier data analysis, discussion with plant operating personnel and engineers and information gathered on operating constraints and future operating strategy. Since the operating variables in the evaporation unit are interacting with each other, RMPCT was selected for advanced control.

Two identical RMPCT were selected for evaporation train 1and 2 to provide reliable operational control and optimization objectives, while maintaining the constraints within specifications. To achieve this, RMPCT manipulates a set of independent variables MVs to maintain a set of dependent variables CVs at target or within constraints. The controller also uses disturbance variables (DVs) as feed forward control to reject the disturbances. A linear programmed optimizer and dynamic control algorithm coordinate the movement of MVs. The optimizer functions were decided to maximize steam economy, improve product density control and to maintain process condensate conductivity within acceptable limit.

Step Test
A step test plan was prepared based on preliminary plant tests, functional design and earlier operational experience. The step test was required to build the process model, which is the basis of predictive control. The step test plan was designed to build up a good model without interrupting normal plant operation. A test was carried out for 15 days in both evaporation trains one after another. Eleven numbers of manipulated variables were considered for the step test plan. Those variables were Steam flow controller, Feed low controller, Bypass feed flow controller, Barometric condenser pressure controller, Barometric condenser cooling water flow controller and each effect's level controller.

During the step test, one variable was moved at a time and all other variables were kept in auto mode. The test was carried out round the clock and a normal range of operation of the evaporation unit was ensured. The results of each step were monitored and analyzed continuously. Based on this analysis step size and numbers of steps were increased and or decreased in a few cases.

A few snapshots of the correlation between the MVs and DVs with CVs obtained after the step test are shown below.

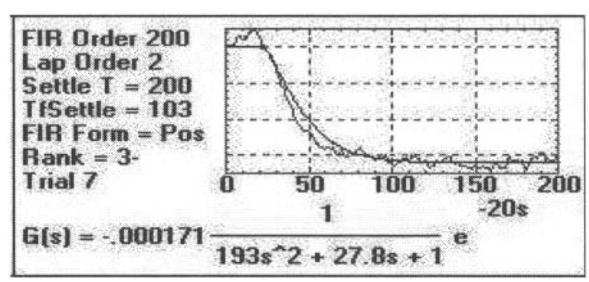

Figure 5. shows Correlation between Product Density and Feed Flow

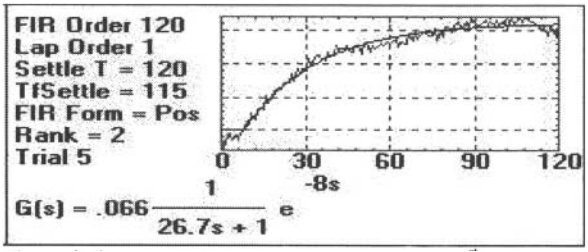

Figure 6. shows Correlation between Vacuum and 1st effect temperature difference

Training

Two types of training were given: 1). Engineer Training before Step test: 25 engineers attended engineer training. The objective of the training was to understand the basic function, design and implementation of APC. Also, identification of control models and tuning of the controller were covered in the training. 2). Operator Training after Commissioning: All concerned operators were trained under the operators training in which procedures for taking APC online, offline, and emergency control were covered.

Detail Design and Commissioning

The APC detailed design was developed based on the information generated during the Plant step test. To maximize the steam economy, the optimizer was designed to minimize the steam flow, maximize the vacuum, minimize the product density and minimize the temperature difference across each effect. In order to achieve the minimum temperature difference across each effect, optimizer was designed to maximize the feed flow through the evaporator and minimize the bypass feed. During the step test it was observed that the step change in level controller of each effect didn't give any correlation with CVs. So the basic controller was designed by taking five MVs which are Feed Flow Controller , Bypass feed flow controller, Steam Flow controller, Barometric condenser pressure controller, Barometric condenser cooling water flow controller and fifteen numbers of CVs out of which the important variables were Product Density, Process Condensate Conductivity, Temperature difference across each effect, first effect jacket temperature, Feed density, feed temperature, inlet water temperature to barometric condenser, deviation of feed flow and barometric condenser pressure from set point has been taken as DVs in the detail design. Preference has been given for MVs control in the following order: Feed flow Controller, Direct condenser pressure controller, Steam Flow Controller, Bypass feed flow controller, Direct condenser cooling water flow controller.

Two types of limits have been set for all MVs and CVs, one is the engineering limit and other one is the operating limit. The engineering limit has been set to ensure safe operating range of equipment. Operating limits are set to serve the process control and optimization. The operating limit is accessible to the control room engineer. The high limit and low limit of operating range are set based on forward unit's requirement and overall condition of the plant. After the detail design, the model was run in offline mode at M/s Honeywell, Pune. The validations with respect to achieving the objective were carried out at different input conditions. The direction of movement of each CV with respect to the step change in each of the MVs was checked and validated.

After the detail validation of the model, the APC Server configuration was done in the existing Experion Process Knowledge System (EPKS) network. Ole Process Control (OPC) client was installed in the APC server for the communication to the OPC server. Redirection manager was installed in APC server machine to communicate to the redundant server in case the primary server failed. A Distributed Control System (DCS) resident watchdog timer was maintained to allow mode shedding of MVs in case of any communication loss between DCS & the profit controller. The APC controller plan moves for all the MVs, and those moves, will be written to DCS MVs. Finally, the APC model was successfully commissioned in both evaporation units, 15 weeks after the start of the project.

Benefit Analysis

Reduction of Variability in CVs

Significant reduction of the variability of all the CVs has been achieved as measured by standard deviation and shown in normal distribution graphs. For example, Product density is the important controlled variable in the evaporation circuit for product quality control. Before the implementation of APC the product density variability had a range from 1.321 to 1.350 whereas, after APC implementation the range narrowed to between 1.302 and 1.310. Product density standard deviation has reduced from 0.006 to 0.001. The following figure shows the variability reduction before and after APC implementation.

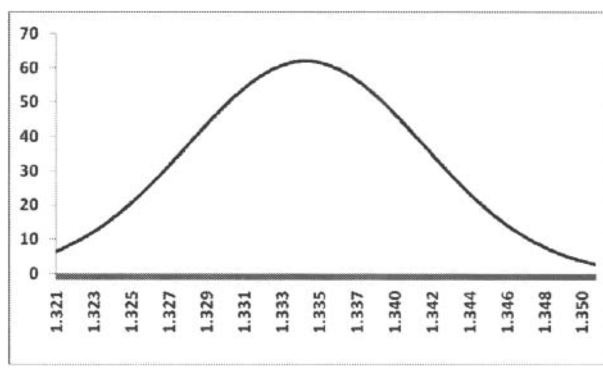

Figure 7. shows Normal distribution curve for the Product density before implementation of APC

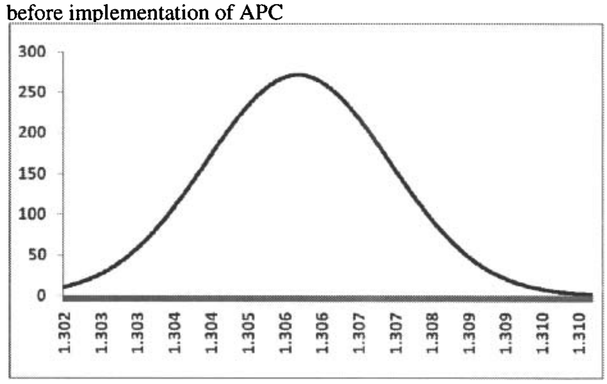

Figure 8. shows Normal distribution curve for the Product density after implementation of APC.

Maximization of Steam Economy:
Steam Economy has increased by an average of 2% after implementation of APC. This was achieved mainly by minimizing the direct condenser pressure and optimizing process parameters continuously. Before APC implementation, the average direct condenser pressure was -648 mmHg(g), which improved to –655 mmHg(g) after implementation of APC. Previously, maintaining pressure below –655 mmHg (g) was a constraint for operation as it was leading to an increase in process condensate conductivity intermittently, because of disturbances created by other process parameters. But under present conditions, due to continuous optimization by APC, lower pressures up to –662 mmHg were achieved without deterioration in the process condensate, as well as the direct condenser cooling water quality.

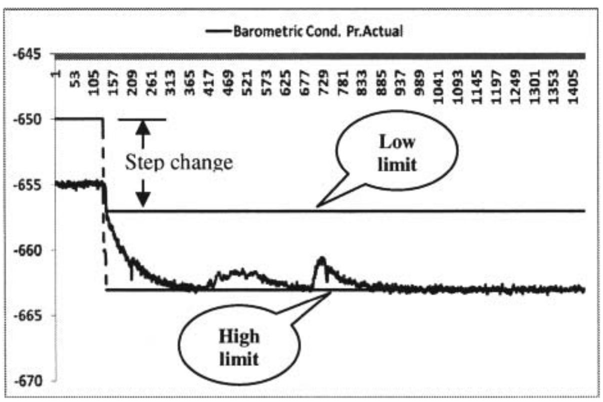

Figure 9. shows the direction of movement of condenser pressure towards high limit after giving a step change in the limits.

Conclusion

RMPCT implementation in the Evaporation unit at Lanjigarh was completed within the planned project tenure and has proven successful benefits. RMPTC provided an opportunity to operate the plant closer to the operational constraints which helped plant debottlenecking without adding assets. Project outcomes such as minimizing standard deviation of process parameters, improvement in throughput, plant uptime with less breakdown maintenance and finally improvement in steam economy were successfully delivered. The way forward involves Digestion and Calcination as the next key units for APC implementation to maximize the production volume and throughout.

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