Advanced Process Control for Wet Grinding Circuits: Unlocking the Potential for Throughput Improvement and Energy Savings in Ball Mils

Sasmita Samal[1] and Jyoti Ranjan Swain[2]
1. Head, Technical
2. Production In-charge, Red Area
Vedanta Limited, Lanjigarh, Odisha, India
Corresponding Author: sasmita.samal@vedanta.co.in

Abstract

Volatile market conditions, price fluctuations, variability of bauxite ore, increasing focus on energy savings and efficiency has pushed the alumina industry to achieve higher production with maximum efficiency. Increased market competitiveness, increasing commodity process, volatile coal prices and quality and tighter emission standards mean production and processing method must be modified to reduce energy consumption and lower carbon dioxide output. Data driven technologies – AI/ML, **Robust Multivariable Predictive Control Technology (RMPCT),** mobile based apps, automation and robotics, the Internet of Things (IOTs), modern data architecture (including the Cloud) can provide solutions to many such problems and open a plethora of potentials to unlock the true value of any operation/process. Milling operations contribute to a larger extent of energy usage in any alumina refinery and improving the process control strategy in this area can significantly improve the productivity of the asset and efficiency of the process. This paper outlines the development and implementation of an advanced control and optimization technology in Milling circuit in Vedanta Lanjigarh with an understanding of the design considerations and potential of the unit along with the current and future operating constraints of the unit.

Keywords: Robust multivariable predictive control technology, Advanced predictive control, Ball mills, Feedback control loops, Feed forward signal.

1. Introduction

Volatile market conditions, price fluctuations, variability of bauxite ore, increasing focus on energy savings and efficiencyhas pushed the aluminaindustry to achieve higher production with maximum efficiency. Advanced process control (APC) for grinding is one important tool to operate this most energy intense area in an optimal way, finding the optimal trade-offs between highest throughput, energy efficiency based on variable ore properties, production targetsand management priorities.

The Main objective of Bauxite grinding area is to increase the surface area of the bauxite by reducing the size of the bauxite particle to 1.2mm. The size specification of the output is D80 = 812 microns & D50 = 350 microns. Grinding unit is a closed-circuit wet grinding process. Main inputs to the grinding unit are bauxite & test liquor.

Bauxite of size (<25mm) coming from crushing unit is stored in bauxite storage bins (silos). Then from Silo, bauxite is fed to Ball mill through Mill feed conveyor by controlling the speed of the Apron feeder as per the required bauxite flow. Test liquor is also added to ball mill to ensure optimal slurry density within the mill to maximize the grinding efficiency. The mill grinding media is comprised of high chrome balls of varying diameter from 30 to 90 mm. After grinding inside the Ball mill, slurry density of 1050-1150 gpl solids exits from the mill via a chute into the

Figure 1. Ball Mill.

trommel screen.The trommel screen has an aperture of 8 mm & is sized to allow only ground bauxite to pass through the mesh to discharge tank. Any unwanted particle such as small broken balls, mill scats is ejected into a scat bin for disposal. Then the bauxite slurry from discharge tank is pumped to the Vibrating screen through mill discharge pumps. The rapid vibration of the banana screen allows the correctly sized slurry to pass through the screen without any choking. And oversized particle again returns to the mill via a chute for further grinding. The correctly sized particle (1.2mm) flows via an underflow chute to the final product tank. Then from the final product tank slurry is transferred to the pre-desilication area through product pumps. There is also provision of addition of test liquor in Mill Discharge tank to ensure the required slurry density (720gpl). And a small amount of test liquor is also injected into the underflow chute of the banana screen just to assist the slurry flow & to prevent choking.

2. Bauxite Grinding Operation Overview

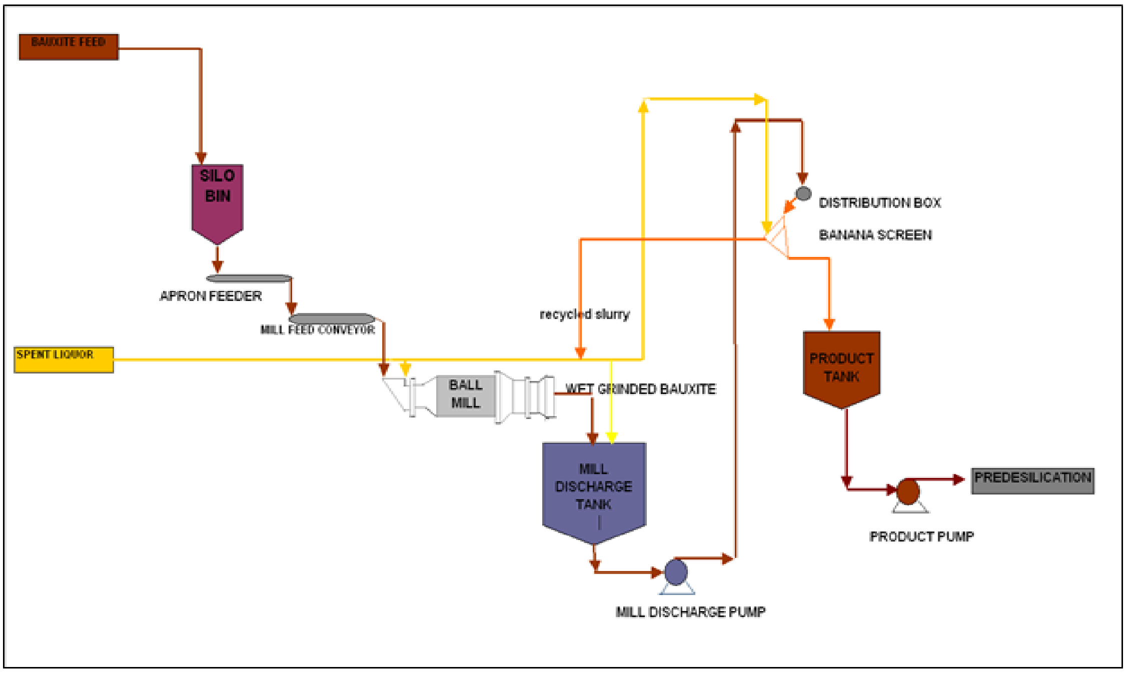


Figure 2. Ball mill grinding circuit PFD.

An optimal grinding process controller must manage to maintain the product size within a given range. To accomplish the, it is necessary to manipulate the ore feed rate & test liquor feed rate. These variables will have a direct impact on mill load, power draw and a slurry density. Disturbances adding another degree of complexity to this control problem are ore size and moisture of the ore.

2.1 Operation Strategy Before APC

In wet grinding operation there were no proper feedback control loops, but rather operator enters feed forward signals, such as manually setting the test liquor flow as per the throughput of the mills.

The chosen control goal is to maintain circulating load at a given target. This is accomplished by monitoring this magnitude and controlling it by changing in throughput. Additionally, there exist sensors to measure the slurry density at the mill output and this is used to control the test liquor addition rates.

The resultant control actions were determined entirely on current data and thus were “reactive” by definition. Consequently, it became difficult to deal with the constraints of the process and its dynamics.

2.2 Operational Challenges

The obvious result of the situation is high variability of the key process variables leading to product quality outside the specified limits, increased energy consumption, and highgrinding media costs.

3. Advance Process Control & Ball Mill Operation

Advanced process control and real-time optimization are techniques that can improve a plant's profitability and efficiency by maintaining a process at desired operating conditions while taking process constraints into account. M/s. Vedanta Limited, Lanjigarh engaged M/s. Honeywell to implement the Advanced Process Control for Ball Mill Unit by developing predictive model for control and optimization of throughput & energy. Profit Controller applications stabilizes the process operations, provides tighter control of the operating targets and reduces the variations of the process variables. This reduction in variation permits operating the unit closer to constraints. As a result, unit profitability is improved.

The Profit Controller manipulates a set of independent variables (manipulated variables) to maintain aset of dependent variables (controlled variables) at targets or within constraints. The controller canalso use disturbance variables as feed-forward control to reject the disturbances.
The predictive control algorithm uses dynamic models relating the controlled variables to the manipulated variables and disturbance variables. The models generated during step test of the unit.

A linear or quadratic program optimizer and a predictive dynamic control algorithm coordinate the movement of the manipulated variables. The optimizer cost function is configured to meet the plant operating objectives. The cost function adjusted to reflect the changing of the unit objectives and economics.

3.1 Robust Multivariable Predictive Control Technology (RMPCT)

Complex and highly interactive industrial processes require more than traditional process control strategies. Honeywell's Profit Controller application allows easy implementation of multivariable control and optimization strategies and provides safe control of complex industrial processes. As a result, users benefit from increased throughput and improved production of high-value products at lower costs. Based on patented Robust Multivariable Predictive Control Technology (RMPCT), Profit Controller stabilizes complex processes to reduce operating upsets and drives processes to their optimal operating level. Its increased robustness enables the controller to stay on-line over a wider range of operating conditions, resulting in higher controller uptime and more profitable operations.

3.2 Controlled Variables (CV) & Manipulated Variables (MV)

The major Ball mill operational parameters are divided into two sub-groups:

1. Control Variables: The variable which can be controlled to regulate the major output KPIs of Ball mill operation.
2. Manipulated Variables: The performance Parameters of the Ball Mill Operation which define the efficiency of milling.

The Major control variables which are considered to Ball mill operation are tabulated as below:

Table 1. CV & MV.

S. No.	Tag Name	Description
1	022_FIC_1113.PIDA.OP	Bauxite feed Apron RPM OP
2	REC_FL1.DACA.PV	Recirculation Flow
3	022-II-ML1101A.DACA.PV	Mill Current
4	022-DIC-1138A.DACA.PV	Density outlet at discharge tank
5	022-DIC-1138A.DACA.PV	Density outlet at discharge tank
6	022_FIC_1136A.PIDA.OP	Discharge Pump level OP
7	022_FIC_1136A.PIDA.OP	Discharge Pump level OP
8	022_LIC_1140.PIDA.OP	Product tank level

S. No.	Tag Name	Description
1	022_FIC_1113.PIDA.SP	Bauxite Feed Note 1
2	RATIO1.PIDA.SP	Spent Liquor to Feed Flow ratio Note 1

3.3 Dynamic Process Model

As a part of the Machine Acceptance Test (MAT), during the step test of the advanced process controller, the impact of variation of control variables (CVs) are studied on the manipulated variables (MVs). During the test was done to establish the impact of control variables in different test scenarios to establish the optimal control of CVs in operation, so we can get the maximum benefit by reduction of standard deviation. All the scenarios are built and tuned in the controller to obtain maximum efficiency of the controller. Because of the scenario testing, the controller can adopt to different operational scenarios of the Ball mill operation and stabilize the system efficiently which is not possible in single control modes.

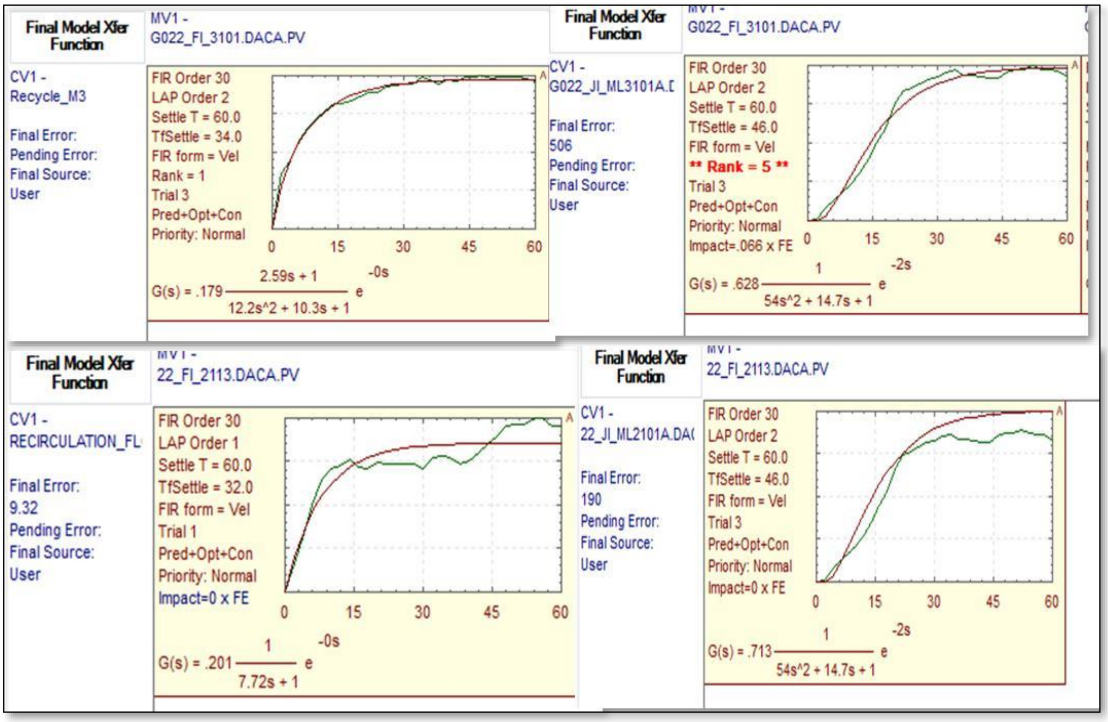


Figure 3. Variation of CV & MV.

Table 2. CV & MV.

Select Report Starting: 1/17/2020 9:00 AM | Select Report Ending: 1/18/2020 9:00 AM | Select Sampling (Min): 1 | Generate Report for all Controllers | Generate Report

CV #	Description	Cntl ON Average	Cntl ON Std. Dev.	Ave. S.S. Target	Cntl OFF Average	Cntl OFF Std. Dev.	% Out of Service	% < Low Limit	% > High Limit	% SS @ Low Limit
1	AF-2101-MTR SPD CTRL	50.401	2.9932	50.796	40.294	9.8666	0.00	0	1.6204	0
2	Recirculation flow	0.49033	1.6931	0.85275	-1.9943	4.5459	0.00	0	0	0
3	ML-2101 DRV CURR	147.35	1.5536	147.46	118.25	52.299	0.00	0	0	0
4	PU-2101A-M1 BXT DSG PMP DEN	---	---	---	1.004	0.00019877	100.00	---	---	---
5	PU-2101B-M1 BXT DSG PMP DEN	1.6889	0.033027	1.6973	1.3532	0.26018	0.00	0.15432	0.92593	0.07716
6	MILL 2101 DISCHARGE FLOW CONTROL	---	---	---	20	0	100.00	---	---	---
7	MILL 2101 DISCHARGE FLOW CONTROL	---	---	---	89.269	8.3943	100.00	---	---	---
8	MILL PRODUCT TANK TK2102 LEVEL CONTRO	---	---	---	102.26	9.5696	100.00	---	---	---
9	MILL 2101 DISCHARGE TANK LEVEL CONTROL	63.078	5.0918	64.82	50.486	13.704	0.00	0	0	0
10	MILL PRODUCT TANK TK2102 LEVEL CONTRO	68.928	9.7931	70.662	50.727	11.782	0.00	0.61728	13.194	0

MV #	Description	Cntl ON Average	Cntl ON Std. Dev.	Ave. S.S. Target	Cntl OFF Average	Cntl OFF Std. Dev.	% Opr Cntl	% SS @ Low Limit	% SS @ High Limit	Ave Opr Low Limit	Ave Opr High Limit
1	AF-2101-MTR SPD CTRL	231.02	10.936	237.11	87.571	94.3	0.39	0.92951	72.889	191.24	242.25
2	Spent Liquor to Feed Ratio	0.59803	0.01063	0.59796	0.59242	0.005369	9.41	94.719	5.2811	0.59595	0.63208

The algorithm was developed based on the step tests and with fine tuning of certain other related variables in the model, the final model for the controlled was obtained which can automatically control the CVs to optimized the MVs of the system.

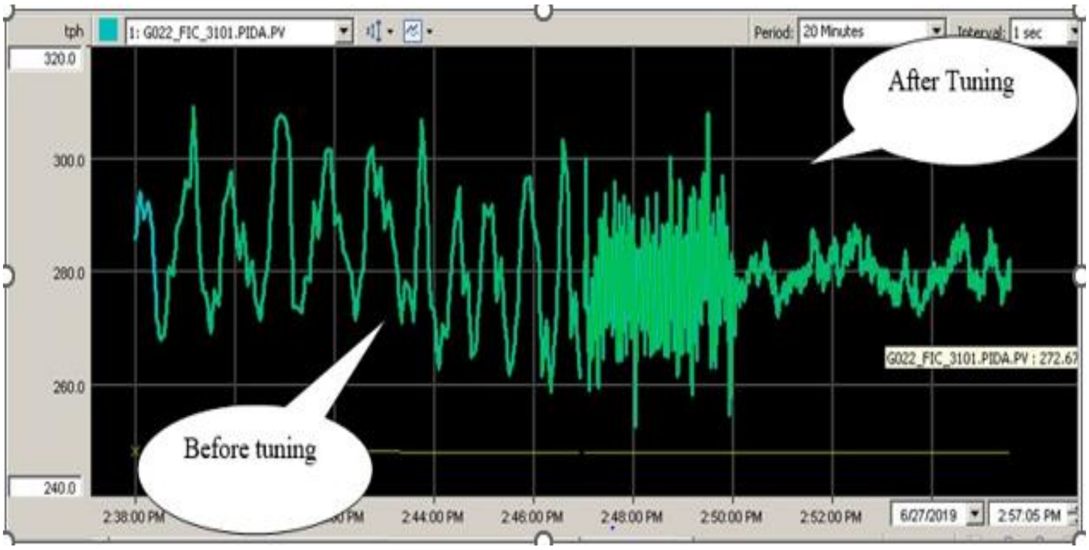


Figure 4. Mill throughput after tuning of parameters.

3.4 DCS APC Operation

Basic controls of APC reside in DCS, making APC operation easier by providing a single window having all CVs, MVs and indication of the parameters range which need to be changed for process optimization. Mill discharge density is controlled with minimum deviation to maximize the throughput, reduce the specific power consumption and increasing the overall production rate allowing for the stable operation of the plant.

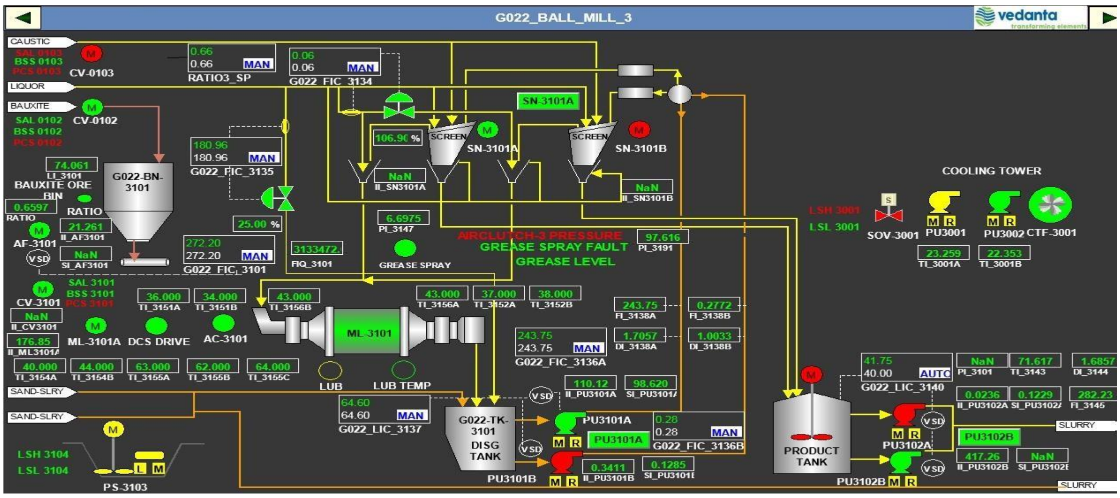
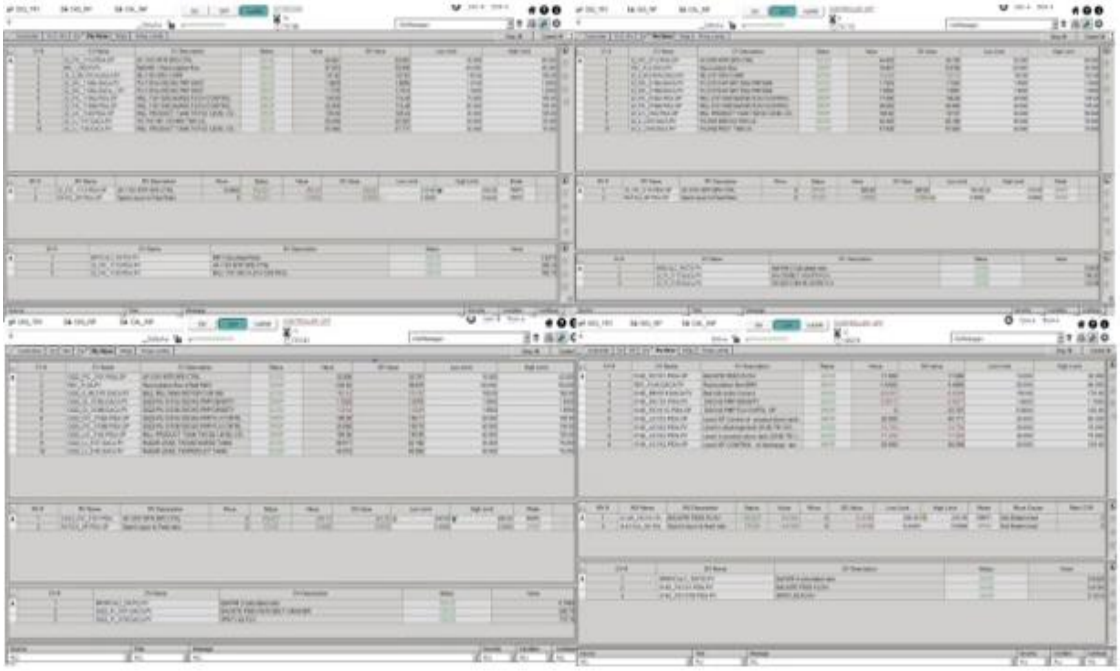


Figure 5. DCS graphic of mill operation.

Table 3. Mill APC Operation (DCS).



3.5 Benefits

The iterative process of optimization through the advance process controller led to stable operation of the equipment with minimum manual interventions from the operator This optimization led to stable operation with minimum deviation in Mill throughput.

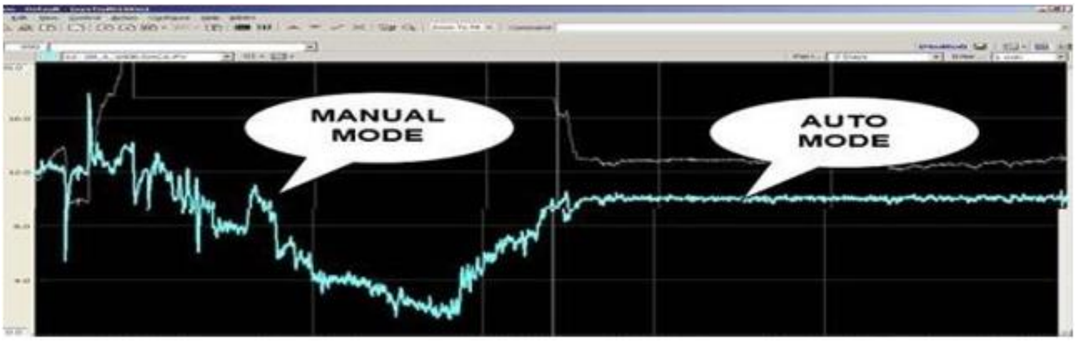


Figure 6. Mill throughput variation (with and without APC).

During the regular operation, the throughput enhancement in the Mill was clear in all the Mills. The enhancement in the throughput in each mill was as follows:

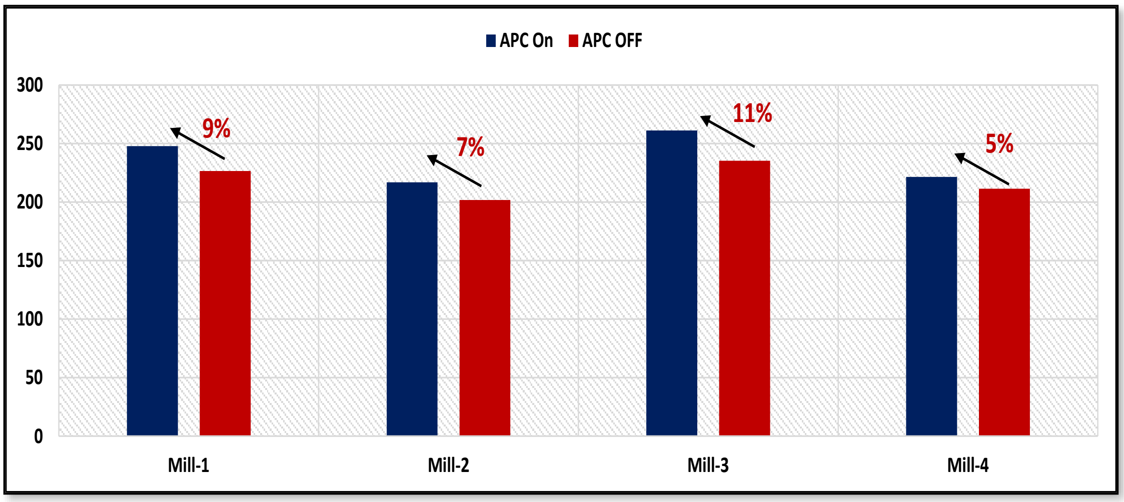


Figure 7. Actual throughput improvement in mills.

The throughput enhancement in the mills led to reduction in the specific energy consumption of the Mill.

4. Conclusion

Advanced process control has several advantages like improved production capacity, minimized power consumption, lower feedstock variability to downstream units, better analysis, and modification of operating objectives as per new requirements, improved monitoring of key performance indicators, increased process safety, reduction in process setting time, increase in equipment reliability, and better operational understanding of the unit over conventional process control technology. Use of advanced process control software allows monitoring of process parameters at a granular level as compared to normal process control technology. This allows for better monitoring of process parameters and helps in predictive maintenance of the system. With more stability, all plant equipment can be operated efficiently, leading to an increase in the production capacity and thus, plant profitability.

5. References

1. C.E. Garcia, D.M. Prett and M. Morari, Model predictive control: Theory and practice - a survey, *Automatica*, Vol. 25 (3), 1989, 335–348.
2. J. Qin, T. Badgwell, *An Overview of Industrial, Model Predictive, Control Technology*, Department of Chemical Engineering, Rice University, USA, 1977.
3. R. Lopes, J. Charr, Alunorte Digestion Phase I Detail Design V2.1, Belém, 2007, Brasil.
4. M. Ribeiro, Benefícios Encontrados com Implementação RMPCT Honeywell, Belém, 2007, Brasil.