
Original Research Article

ADAPTIVE AND PREDICTIVE CONTROL IN NIGERIAN INDUSTRIES: IMPROVING EFFICIENCY AND RESILIENCE

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Abstract: Nigeria's industrial sector faces ongoing challenges like fluctuations in raw material quality, aging equipment, power inconsistencies, and a lack of real-time optimization. Traditional control systems, such as PID and manual tuning, often struggle in these conditions, resulting in low productivity, high energy use, and frequent downtime. This article explores how adaptive control (AC) and model predictive control (MPC) can be applied in Nigerian industries, focusing on manufacturing, petrochemicals, food processing, and cement production. By using a mixed-methods approach, including surveys from 30 industrial plants and simulation case studies, the study compares traditional control with AC and MPC based on set point tracking, energy savings, and disturbance rejection. Results indicate that AC and MPC can reduce settling time by 42%, cut energy use by 18-25%, and lower variability in product quality by 35% compared to traditional methods. Challenges to implementation include high startup costs, a shortage of skilled personnel, and inadequate sensor infrastructure. The article recommends a phased adoption strategy, local training programs, and government financial support. The findings offer a practical framework for modernizing Nigerian process control to align with Industry 4.0.

Keywords: Adaptive control, predictive control, Nigerian industries, process optimization, Industry 4.0

INTRODUCTION

Cement industries in Nigeria, such as Dangote and BUA, along with petrochemical companies like Eleme and Indorama, and food and beverage manufacturers like Nigerian Breweries and Flour Mills, operate in a highly challenging environment. The national power grid is unstable, causing frequent voltage drops and generator switches (Okafor & Adebisi, 2021). Raw material properties can vary significantly, like the consistency of cassava starch or the sulfur content in crude oil. Equipment maintenance tends to be reactive instead of predictive (Nwankwo et al., 2020).

Conventional control strategies, mainly PID controllers with fixed settings, struggle with changing conditions. As the process environment shifts, the controller becomes out of tune, leading to oscillations, higher energy use, and off-spec products. Adaptive control automatically updates controller parameters in real-time, while model predictive control relies on a process model to predict future outputs and optimize inputs. Both have shown effectiveness in developed nations (Qin & Badgwell, 2003), but their use in Nigeria is still limited.

This article addresses the following questions:

1. What are the existing control practices in major Nigerian industries?
2. How do AC and MPC perform compared to traditional methods under local conditions?
3. What are the technical and economic obstacles to implementation?

The scope covers both batch and continuous processes across five industrial subsectors. The significance lies in providing data-driven guidance for industrial digitization following the Nigerian Industrial Revolution Plan (NIRP).

2. LITERATURE REVIEW

2.1 Fundamentals of Adaptive Control

Adaptive control includes self-tuning regulators (STR), model reference adaptive control (MRAC), and gain scheduling. These methods estimate process parameters online and adjust the controller accordingly (Åström & Wittenmark, 2013). In industries with changing conditions, like exothermic chemical reactors or extruders with changing viscosity, adaptive control can maintain performance without needing manual adjustment.

2.2 Model Predictive Control

MPC uses a dynamic model, usually linear or piecewise linear, to foresee future plant behavior over a specific time frame. It then calculates the best manipulated inputs by solving an optimization problem at each step (Camacho & Bordons, 2007). MPC effectively manages constraints like valve limits and safety boundaries and handles multiple input/output relationships. For instance, in cement mills or crude distillation units, MPC has cut energy use by 10-30% in global studies (Qin & Badgwell, 2003).

2.3 Applications in Developing Economies

Research on this topic in sub-Saharan Africa is scarce. A study on a South African sugar mill found that MPC reduced steam consumption by 22% compared to PID (Moyo & Kgare, 2019). In Nigeria, (Ogundare and Salawu, 2023) remarked that sensor drift caused by humidity and dust leads to frequent recalibrations, which adaptive estimation can help address. (Adeyemi, 2019) reported that a self-tuning regulator improved temperature stability in a Lagos polyethylene plant by 60% during power dips.

2.4 Gaps in Knowledge

There is no large-scale study comparing the performance of different control methods across various Nigerian industries. Many local plants still depend on manual tuning methods. Moreover, there is no economic analysis of AC and MPC that takes Nigeria's specific power and maintenance context into account. This review highlights the need for a focused empirical evaluation.

3. METHODOLOGY

3.1 Research Design

We employed a mixed-methods design:

- Quantitative: Performance data gathered from 30 industrial plants across Lagos, Ogun, Rivers, and Kano states (10 each in food processing, petrochemicals, and cement).
- Qualitative: Semi-structured interviews conducted with 15 control engineers and plant managers.
- Simulation: MATLAB/Simulink models of three representative processes (cement rotary kiln, oil refinery distillation column, cassava starch dryer) compared PID, adaptive (MRAC), and MPC.

3.2 Data Collection

For each plant, we noted:

- Current control system type (PID, manual, or a few with adaptive).
- Setpoint tracking error (IAE – integral absolute error) during one 8-hour shift.
- Energy consumption per ton of product (kWh/ton).
- Product quality variance (e.g., cement fineness, starch moisture).
- Number of unplanned shutdowns per week.

Simulations were based on actual Nigerian plant data, including a power supply with $\pm 15\%$ voltage changes and raw material moisture varying by $\pm 20\%$.

3.3 Table 1 - Summary of Surveyed Plants

Table 1: Industrial plants surveyed for control system assessment

Sector	Number of Plants	Typical Process	Existing Control	Plant age (years)
Food processing	10	Cassava starch dryer	PID + manual	8–20
Petrochemicals	10	Crude distillation	DCS with PID	12–35
Cement	10	Rotary kiln & mill	Mostly PID	5–40
Source: Field survey, 2024 (author’s compilation)				

4. RESULTS AND DISCUSSION OF FINDINGS

4.1 Current Control Practices

Among the 30 plants surveyed, 28 utilized PID controllers with fixed settings, which were adjusted at commissioning and rarely readjusted (only during major outages). Two newer petrochemical plants had basic gain-scheduling adaptive loops for a reactor. None employed full MPC, although one cement plant had a consultant trial MPC in 2019, which was later discontinued due to a lack of support.

4.2 Simulation Performance Comparison

For the distillation column with a +10% feed composition disturbance:

Table 2: Performance indices – PID vs. Adaptive vs. MPC

Controller	Settling time (min)	IAE (setpoint error)	Energy (MW/ton)	Off-spec product (%)
PID (fixed)	34	128	1.45	8.2
Adaptive	19	72	1.21	4.5
MPC	15	55	1.09	2.9
Source: MATLAB simulation based on Nigerian petrochemical plant data				

Interpretation: Both advanced controllers outperform PID. MPC provides the best setpoint tracking and energy reduction. Adaptive control, while simpler to implement, reduces settling time by 44% compared to PID.

4.3 Field Observations – Energy Savings

In the food processing sector, a retrofitted adaptive controller (a low-cost Arduino-based self-tuning device) was trialed for three months in two plants. Energy consumption dropped from 210 kWh/ton (PID) to 172 kWh/ton (adaptive), resulting in an 18% savings. Operators reported fewer manual interventions (2 per shift vs. 7). However, sensor fouling required weekly cleaning, affecting the adaptive estimator's performance.

Table 3: Energy and quality impact of adaptive control in three sectors

Sector	Baseline Energy (kWh/ton)	Adaptive Energy (kWh/ton)	Quality variance reduction
Food (starch)	210	172	31%
Cement (kiln)	98	78	38%
Petrochemical	305	229	35% (simulated)
Source: Author's field trial data, 2024			

4.4 Barriers to Adoption (from interviews)

- Cost: "A full MPC package from a vendor costs \$150,000. Our annual control budget is \$20,000," (Plant manager, Rivers).
- Skills: No local university offers a dedicated course on MPC. Only 3 of the 15 engineers had heard of adaptive control.
- Instrumentation: Reliable flow and temperature sensors are necessary; many plants use pneumatic or 4–20 mA transmitters that drift.
- Power: Adaptive controllers recalculate gains at each sample; voltage drops cause processor resets, which require better power management.

4.5 Discussion

The simulation and field results agree with global studies (Qin & Badgwell, 2003) but show more significant relative improvements in Nigeria due to subpar initial tuning. Adaptive control represents a practical starting point, as it does not need a process model, can be implemented with PLCs or low-cost microcontrollers, and manages gradual changes, like heat exchanger fouling. MPC offers superior performance but requires a reliable model and faster computation.

Considering Nigeria's situation, a blended approach is suggested: use adaptive control for smaller plants or those with frequent maintenance challenges, while adopting MPC for large-scale continuous operations where a dedicated control engineer is available.

5. CONCLUSION

This study evaluated adaptive and predictive control in Nigerian industries. The main findings are:

1. Conventional PID control is widespread but often poorly tuned and struggles with power fluctuations and raw material variability.
2. Adaptive control can reduce energy use by 18-25% and enhance product consistency by 30-40% in local case studies.
3. Model predictive control shows further potential benefits but faces high implementation costs and skills shortages.
4. The main obstacles to adoption include upfront investment, inadequate sensors, unstable power supply, and lack of training.

This article provides a quantitative benchmark for advanced control in a low-income, highly variable industrial environment. Nigerian industries can realize significant operational savings and reduced downtime by gradually implementing adaptive control, eventually moving toward MPC as conditions improve.

6. RECOMMENDATIONS

For industry:

1. Pilot adaptive control on one critical unit, like a dryer, kiln, or distillation column, using inexpensive platforms, such as Raspberry Pi with open-source adaptive libraries.
2. Upgrade sensors strategically by installing reliable temperature and pressure transmitters with digital communication capabilities.
3. Train in-house engineers through short courses on self-tuning regulators, such as those offered by the Nigerian Society of Engineers.

For government and regulators:

1. Provide financial assistance for advanced control retrofits through the Industrial Energy Efficiency Fund, aiming to cover 30% of costs.
2. Require energy monitoring in large facilities, tying tax incentives to the implementation of adaptive or predictive control.

For academia:

1. Incorporate adaptive and predictive control topics into engineering curricula to build local expertise. Create research partnerships focused on applying these control techniques in industrial contexts.
2. Develop local MPC models for Nigerian crude oil, limestone, and cassava to reduce dependency on foreign proprietary models.

For technology providers

1. Offer “MPC-lite” packages that require only 2–3 measured variables and run on existing DCS hardware, tailored for small budgets.

References

1. Adeyemi, B. (2019). PID vs. adaptive control in fluctuating feedstocks. *West African Process Engineering*, 5(1), 22–34.
2. Åström, K. J., & Wittenmark, B. (2013). *Adaptive control* (2nd ed.). New York: Dover.
3. Camacho, E. F., & Bordons, C. (2007). *Model predictive control* (2nd ed.). London: Springer.
4. Central Bank of Nigeria. (2021). *Industrial capacity utilization report*. Abuja: CBN.
5. Dangote Cement. (2022). *Internal technical report on kiln control*. Lagos: Dangote Group.
6. International Energy Agency (IEA). (2022). *Energy efficiency in emerging industries*. Paris: IEA Publications.
7. Moyo, T., & Kgare, S. (2019). MPC in South African sugar processing. *Southern African Control Conference*, 45–51.

8. Nwankwo, C., Eze, F., & Okonkwo, P. (2020). Maintenance culture in Nigerian process plants. *Nigerian Journal of Engineering*, 27(3), 112–126.
 9. Ogundare, A., & Salawu, S. (2023). Sensor degradation in tropical industrial environments. *African Sensors Review*, 8(4), 201–215.
 10. Okafor, E., & Adebisi, A. (2021). Power quality in Nigerian manufacturing zones. *Journal of Energy in Africa*, 14(2), 45–59.
 11. Qin, S. J., & Badgwell, T. A. (2003). A survey of industrial model predictive control technology. *Control Engineering Practice*, 11(7), 733–764.
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