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Development of Intelligent Monitoring and Control System for Electrostatic Precipitators in Cement Plants

[1]Taha N. DeKheel, [2]Mohammed O. Mustafa, [3]Mehdi J. Marie

[1,2]Electrical Engineering Department, University of Mosul, Mosul, Iraq
[3]Al-Zawraa State Company, Ministry of Industry and Minerals, Baghdad, Iraq
Authors E-mail: [1]taha.21enp14@student.uomosul.edu.iq, [2]mohammed.obaid@uomosul.edu.iq, [3]mehdijelo@gmail.com

***Abstract* - Cement plants are crucial industrial entities that supply cement for various applications, including the construction of buildings and bridges. While these plants play a vital role in infrastructure development, they are also recognized as significant sources of environmental pollution. To mitigate air pollution, Electrostatic Precipitators (ESPs) are employed, capable of reducing air pollution by approximately 99.99%. Consequently, ESPs warrant in-depth study, and development. This project focuses on investigating, and developing a monitoring, and control system for ESPs utilizing intelligent devices. The initial step involved deriving a mathematical model based on input/output data from the critical unit, the transformer/rectifier (T/R set). The Grey Wolf Optimization algorithm was employed to determine the optimal parameters (Kp=988, Ki=37.7, Kd=88.5) for the PID controller using the MATLAB package.**

Keywords: Cement plants, Electrostatic Precipitators (ESPs), Environmental pollution, Grey Wolf Optimization, PID controller.

I. INTRODUCTION

The introduction highlights the vital role that control systems play in regulating processes, assuring efficiency, and ensuring safety across a range of technological areas. Control systems are crucial for performance optimization and handling difficult problems in a variety of industries, including manufacturing, aircraft, and beyond. Control systems continue to play a critical role in promoting innovation and advancement in technology [1].

Sensors, actuators, and controllers that interact wirelessly replace cable connections in the Wireless Network Control System (WNCS). In a number of industries, including electronic systems, building administration systems, and automobile electrical systems, WNCS is becoming a vital infrastructure technology for essential control systems. This is mainly because of its capacity to provide increased flexibility, drastically lower installation and maintenance costs, and maybe improve safety precautions. Recognizing the deep interconnectedness between communication and control systems, concurrent development of these systems is a major problem in the field of WNCS. This all-encompassing strategy seeks to improve control efficiency and extend the life of networks by skillfully handling their complex interplay [2].

Wireless Network Control Systems (WNCS) policy development entails striking a balance between particular application-dependent requirements and reliability. In order to accomplish this, we utilise a cost-function-based methodology that provides flexibility in meeting the requirements and constraints of specialized services or devices. For example, it is necessary to give serious thought to problems like lowering buffer underflows in streaming traffic scenarios and improving energy efficiency in battery-powered node networks.[3].

The control problem is made much more difficult by these expectations, which go beyond the conventional emphasis on throughput optimization. They involve theoretical stability conditions that can be shown empirically. We also investigate many candidate cost functions designed for wireless networks with contemporary media traffic. Furthermore, we demonstrate how this framework can be modified to tackle problems like cross-layer control problems and power-efficient routing in wireless multihope networks. To overcome these issues, we suggest an interference control approach based on successive convex approximation. In order to evaluate our control system's efficacy, comprehensive numerical simulations are run in each situation [4][5].

Electrostatic filters find widespread use in industrial facilities, including chemical engineering, metallurgy, power stations, cement production, and paper production, employing electrostatic force to capture suspended dust particulates [6]. They are commonly preferred in coal plants, and chemical facilities for filtering exhaust gases. On the other hand, fiber-based filters create a dense mesh of fibers in the airflow path, increasing the fan's energy consumption to overcome pressure drop. While fiber-based filters, such as High Efficiency Particulate Air (HEPA) filters, can achieve high efficiencies for fine particles, they also exhibit relatively high-pressure drop compared to electrostatic precipitators. Moreover, fiber filters may not function effectively in high-temperature applications[6].

Electrostatic precipitators utilize plate electrodes along the airflow path, resulting in a lower increase in pressure drop. The combination of high filtration efficiency and low-pressure drop makes electrostatic precipitators highly attractive as air filtering devices. Some advantages of electrostatic filters include [7].

Electrostatic filters exhibit exceptional collection efficiencies, surpassing 99% for particles, including sub-micron sizes, even at minimal dust concentrations. This remarkable performance ensures thorough filtration. Additionally, these filters maintain a low-pressure drop within the range of 50-300 Pa, resulting in lower operating costs compared to fibrous filters. The ability to operate effectively at temperatures up to 650˚C further enhances their versatility. Moreover, electrostatic filters excel in handling high gas velocities, adding to their efficiency in various industrial applications [8].

Nonetheless, scientists are currently addressing three significant challenges related to electrostatic precipitators, namely back-corona discharge, sub-micrometer particle removal, and particle reattainment. The primary focus of this paper is to explore diverse parameters influencing the collection efficiency of electrostatic precipitators, and provide a comprehensive review of prior studies on this subject [9].

II. RELATED WORKS

In 2016, Yogesh et.al. [10] An investigation into various sensors intended to track ecological characteristics such as temperature, humidity, and soil humidity, with an emphasis on coordinating them with wireless technologies to meet certain end-use scenarios. According to the research, an autonomous irrigation system that operates wirelessly can be a practical solution, optimizing the use of resources, and lowering labour costs. The device also makes it possible to remotely monitor the field's current environmental conditions in real time, which improves overall operating efficiency.

In 2016, Mohammad et.al. When it comes to magnetic resonant coupling (MRC) devices that used in multi-input multi-output (MIMO) wireless power transfer (WPT), more transmitters (TXs) are used to increase the effectiveness of simultaneous power transfer to different receivers (RXs). The process known as "magnetic beamforming" which is used to deliberately combine the induced magnetic fields in order to achieve this enhancement [11].

In 2018, Tomohiro et.al. Improving Wireless Power Transfer (WPT) entails making the most of using several transmitter coils to send power to a single receiver. WPT's basic idea is based on inductive coupling, which is the process of driving current in a transmitter coil by applying an AC voltage. This then causes a receiver coil to produce current, which powers a resistive load [12].

In 2019, Altun & Kilic Introducing the need for a healthy and comfortable indoor environment, this paper addresses the growing importance of indoor air quality. While ventilation systems play a crucial role in enhancing indoor air quality, it is imperative to address the presence of particulates, microorganisms, and pollutant gases in outdoor air before it enters indoor spaces. Electrostatic precipitators serve as a common solution for particle collection, particularly in industrial settings. This research paper offers a comprehensive review of electrostatic filtration technology, delving into theoretical and technical advancements of electrostatic precipitators. Additionally, it explores design parameters influencing filtering performance, while also discussing the advantages, challenges, and limitations associated with this technology [6].

In 2019, Bongsang et.al. An actuator, and sensor network with resilience (R-WSAN) is intended to maintain control stability for several plants in the face of spatiotemporal changes in the wireless network. A hierarchical cluster-based network is used by the proposed joint architectural protocol to collect the distributed controllers of control systems. It includes resource allocation, clustering, and a control task participation method for wireless networks [13].

In 2019, Fabian et.al. introducing a wireless embedded system, that is intended to reduce jitter, and message loss, two types of faults that reduce control efficiency. In addition, a control architecture makes use of this device's inherent capabilities to offer concrete proof of closed-loop reliability for linear time-invariant dynamics in physical processes. Updating every 20 to 50 milliseconds, the system is able to describe, and evaluate feedback control, and coordination over wireless multi-hop networks, which is a first for the field. This assessment is based on observations made on a cyber-physical test bed with several cart-pole systems, and 20 wireless nodes [14].

In 2019, Mobasshir Mahbub, An Arduino Uno R3, and a nRF24L01 wireless transceiver module are used to create a control unit that makes it easier to handle several devices. This adaptable controller is used in a variety of situations, such as light control, DC motor control, and servo motor manipulation in a multipurpose radio-controlled car, or quadcopter. The Arduino Uno R3 and nRF24L01 are integrated into the controller, which consists of a transmitter, and a receiver unit.

Based on the positional data it got from the transmitter, the receiver unit controls the equipment that is connected [15].

III. ESP ROLE IN CEMENT INDUSTRY

In the cement industry, Electrostatic Precipitators (ESPs) play a crucial role in controlling particulate emissions. These devices are typically located at specific points in the cement manufacturing process to capture, and remove particulate matter from flue gases before they are released into the atmosphere [16]. ESPs are often strategically placed in the flue gas stack of key processes such as the raw mill, and rotary kiln. These stationary emission sources, including the stacks attached to the raw mill, rotary kiln, coal mill, grate cooler, and cement mill, may release particulate matter during various stages of cement production [17]. The ESP, through its electrostatic charging and collection mechanism, helps to mitigate the environmental and health risks that associated with particulate emissions from cement plants. The exact location and specifications of the ESP can vary among cement plants but are typically integrated into the overall emission control system to ensure compliance with environmental regulations, and standards. Figure (1) shows the general structure of Cement industry [16].

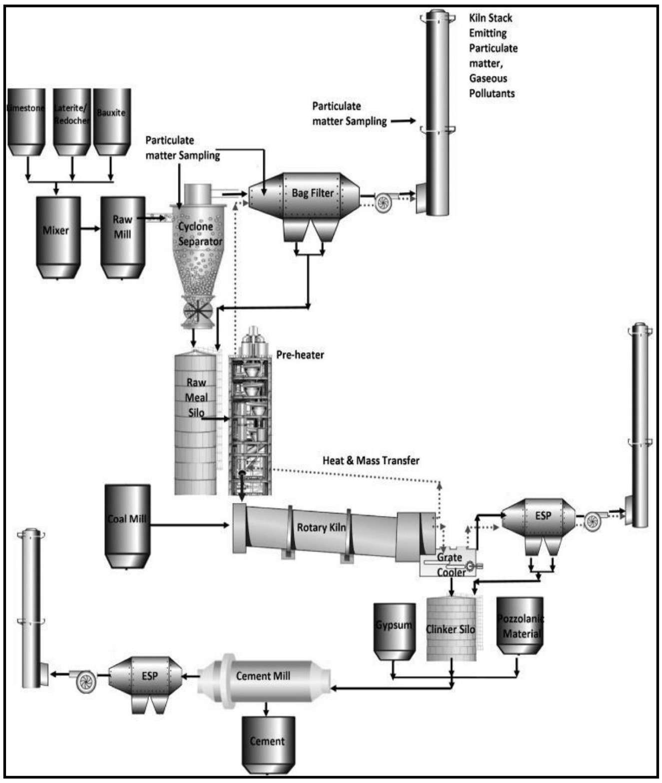

Figure 1: General structure of Cement industry [16]

There are five key phases in the operation of electrostatic precipitators, [18]. Corona discharge, which starts the process by applying a high voltage to the corona electrode, and charging the suspended dust particles, which is the first step in the process. The charged particles then go through additional charging in order to get them ready for the next stages [17].

The charged particles travel in the direction of the grounded collecting electrodes under the influence of drag, and electrostatic forces. The charged dust particles land on these electrodes because of the electrostatic forces at work. To finish the electrostatic precipitation process, the settled dust must be removed from the collecting electrodes [19].

IV. GARY WOLF OPTIMAL CONTROL (OPTIMAL CONTROLLER)

Feature extraction using the Grey Wolf Algorithm is a relatively new approach aimed at enhancing the feature selection process in machine learning. This algorithm is a metaheuristic inspired by the natural behavior of grey wolves in hunting their prey, and relies on the cooperation between individual wolves. Grey wolves are social animals, leading to complex hierarchical behavior consisting of four levels: the leader known as Alpha (α), who heads the pack, followed by Beta (β), the assisting individuals who support Alpha's decisions. The third level is Delta (Δ), responsible for executing the orders of Alpha and Beta. The final level is Omega (ω), which has no power but engages in social activities, as illustrated in Figure (2.) [20].

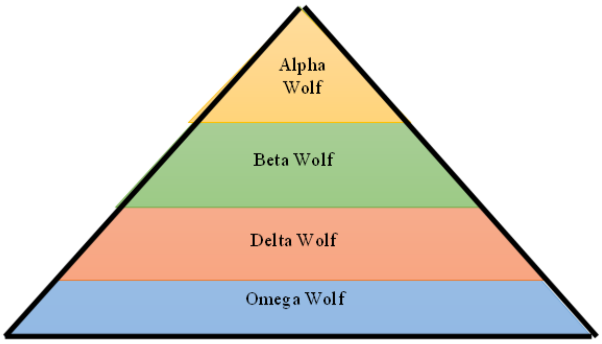

Figure 2: Hierarchical behavior of GWO

V. METHODOLOGY

5.1 System Design and Components

The essential parameters for electric power transmission lines in substations are crucial for determining energy efficiency, and diagnosing faults that may impact critical equipment in substations. Therefore, a control, and monitoring system based on the Internet of Things (IoT) has been proposed, and designed for an electrical distribution station[21].

In this system, devices, and software such as programmable logic controllers, sensors, and operating systems are utilized to execute specific tasks. Additionally, the data is uploaded to the IoT platform, allowing the monitoring of the IoT system anytime, and anywhere online, as depicted in Figure (3). The proposed system consists of three components:

1) Microcontrollers, and Sensors: Responsible for executing specific tasks and collecting data.
2) Operating System: Manages the overall operation of the system.
3) User Interface and Database: Displays real-time data through a C# program, and stores it in an SQL database.

This integrated system enables effective control, monitoring, and data management for electric distribution stations, enhancing overall efficiency, and facilitating remote monitoring through the IoT platform.

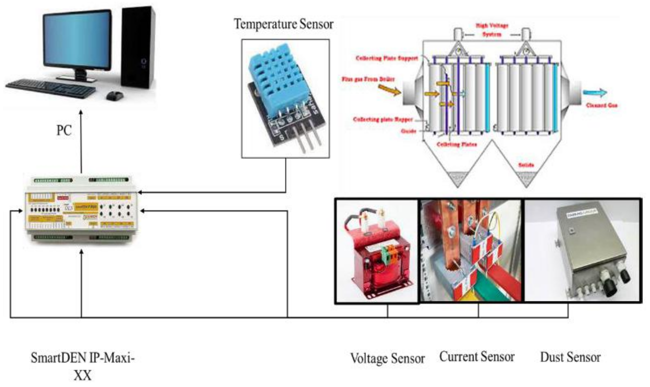

Figure 3: Designed System Components

5.2 Integrated System

An intelligent way to keep an eye on, and control the amount of dust produced by the precipitator is to integrate a dust sensor into an electrostatic precipitator system. A responsive, and adaptive system is made possible by the real-time data on dust levels provided by the dust sensor. The electrostatic precipitator's performance is influenced by the dust sensor readings in a feedback loop used by the system. The system's ability to adapt to variations in dust concentration is ensured by this dynamic interaction, which also allows the system to operate at its best given the actual environmental conditions.

A PLC (Programmable Logic Controller) of the Denkovi type is used to enable communication between the dust sensor, and the control system. By gathering data from the dust sensor, and sending it to the precipitator controller panel, the PLC serves as a mediator. The system's automation, and control capabilities are improved by this integration, enabling effective decision-making based on real-time data.

A voltage divider is used to bridge the signal compatibility gap between the precipitator controller panel, and the PLC controller. The voltage divider facilitates smooth communication between the two components by adjusting, and balancing the signal levels. For the data transmission process to continue with precision, and signal integrity, an intermediate step is required.

All things considered, this integrated method incorporating the voltage divider, PLC device, dust sensor, and electrostatic precipitator system demonstrates a complex system design intended to maximize the precipitator's performance in response to changing dust levels.

In industrial, or controlled settings, the integration of automation and real-time data feedback enhances operating efficiency, and improves environmental management. Figure (4) describe the model block diagram.

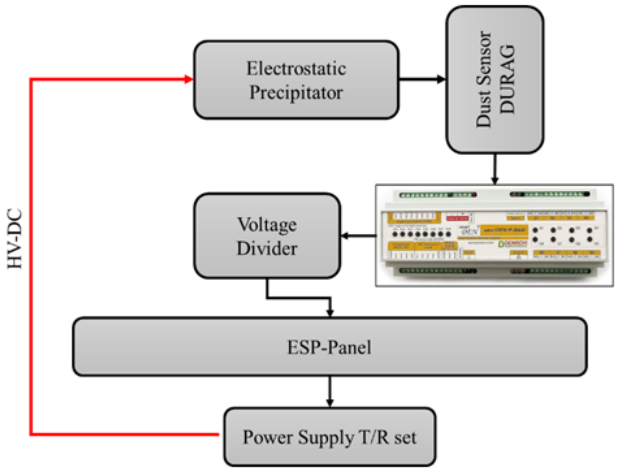

Figure 4: Model Block Diagram

5.3 Tahady System Transfer Function calculation

5.3.1 No Load State

The relationship between "ESP Voltage (KV-DC)", and "Leakage Current (mA)" for an electrostatic precipitator (ESP) running without a load is shown in the accompanying Table (1). This situation suggests that the ESP is not actively gathering dust particles, which permits an analysis of its behavior free from outside interference.

In the first section of the table, there is a discernible rise in the "Leakage Current" in tandem with the "ESP Voltage" as it grows gradually. This straight proportionality points to a common behavior in insulating systems, where current leakage increases with increasing voltage levels. These findings align with the ESP's intrinsic dielectric and capacitance characteristics.

The critical point, which marks a significant change, is indicated at 42 KV-DC. There is a noticeable spike in the

"Leakage Current" to 420 mA, which suggests that the ESP has failed. This breakdown threshold is important because it indicates that there is a breach in the insulation system, which could be brought on by contaminants, deterioration of the insulating materials, or the presence of other variables.

Table 1: L No Load State

Leakage Current (mA)	ESP Voltage (KV-DC)
0	0
0	3
0	6
0	9
0	11
0	15
0	20
10	24
13	27
16	30
18	35
18.5	37
20	39
22	40
25	41
420 (Break Down)	42

5.3.2 Load Operation Measurements

When the electrostatic precipitator (ESP) is loaded, the relationship between "Leakage Current (mA)", and "ESP Voltage (KV-DC)" is more evident, and even at lower voltages, the current increases significantly in comparison to the no-load state. When the load is applied, the breakdown voltage (42 KV-DC) is less than the breakdown point at 470 KV-DC, which yields a leakage current of 420 mA. This higher breakdown voltage highlights the robustness of the ESP, by indicating a greater ability to withstand high voltages under load.

The analysis emphasizes how vulnerable the ESP is to electrical stress when there is a load on it, and how careful monitoring is necessary to guarantee safe operating settings, and avoid putting too much strain on the insulating system. These observations support the creation of customized safety margins that ensure the ESP operates at its best, and lasts for a variety of operating loads. Table (2) Describe results.

Table 2: Load State Measurements

Leakage Current (mA)	ESP Voltage (KV-DC)
0	0
0	4
8	10
10	15
13	20
15	25
18	30
19	35
20	40
25	41
470 (Break Down)	42

5.3.3 DURAG 290AW Operation Curve with ESP voltage Measurements

The dataset that is being presented shows how the "ESP voltage (KV)", and the "DUST Sensor (mV)" in an electrostatic precipitator (ESP) system relate dynamically. The gradual voltage increase that follows corresponds positively with growing dust sensor data, starting with zero ESP voltage, or 0 mV. This implies that the dust sensor reacts to the electrostatic field being activated, suggesting that the concentration of dust particles may have increased. At 42 KV, there is a significant change shown by a "DUST Sensor" measurement of 680 mV, which denotes a critical threshold, or ESP system breakdown point.

The measurements show a nonlinear relationship that operators can be utilized to set operational thresholds and put effective control techniques in place. This relationship is represented by an operational curve. With the use of this dataset, operators can evaluate the effectiveness of dust particle removal in real-time, and take appropriate action in the event that there are any problems, or departures from the defined operational curve. Table (3) shows measurements.

Table 3: DURAG 290AW Operation Curve with ESP voltage

DUST Sensor (mV)	ESP voltage (KV)
0	0
13	0
28	1
43	2
52	3
71	4
86	5
93	6
118	7
145	8
163	10
209	12
245	14
281	16
334	20
450	25
524	31
568	33
631	36

642	37
650	38
655	39
667	40
673	41
680	42 (Break Down)

5.4 Transfer Function Identification using MATLAB

Transfer function identification in MATLAB involves the process of determining the mathematical representation of a system's input-output relationship. This typically begins with collecting input-output data from the system under study. MATLAB offers various tools and functions for system identification, such as System Identification Toolbox. These tools enable users to preprocess the data, select appropriate model structures (such as ARX, ARMAX, or state-space models), and estimate model parameters using techniques like least squares or maximum likelihood estimation. Additionally, MATLAB provides functions for model validation, enabling users to assess the accuracy of the identified model. Overall, MATLAB's system identification capabilities streamline the process of extracting transfer functions from empirical data, facilitating the analysis and control of dynamic systems.

VI. RESULTS

The incorporation of a Bode plot in Figure (5) further enriches the analysis, by offering a frequency domain perspective. This plot illustrates the magnitude of the DUST sensor's output voltage across varying frequencies, aiding in the identification of dominant frequency components. Analyzing the generated curve entails a qualitative examination of trends, and distinctive features, providing valuable insights into the DUST sensor's response characteristics under different ESP Voltage conditions.

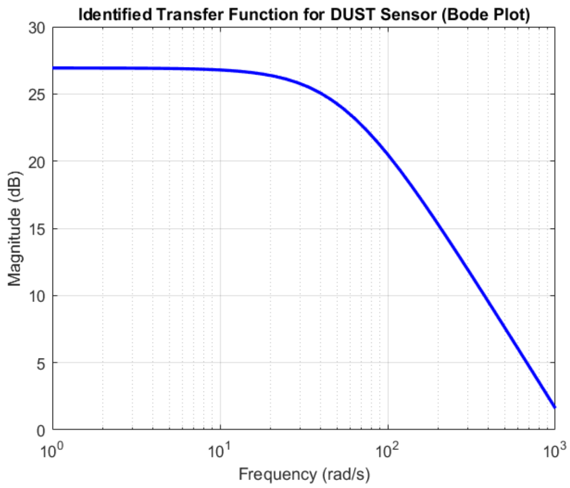

Figure 5: Identification Transfer Function for Dust State

Additionally, the displayed transfer function coefficients furnish a quantitative foundation for comprehending the identified transfer function's parameters. Parameters such as gain and time constant play a pivotal role in shaping the dynamic response of the DUST sensor. The alignment of these coefficients with the observed behavior in the plotted curve enhances our understanding of the intricacies involved in how the DUST sensor responds, to changes in ESP Voltage. Ultimately, this integrated approach, combining visualization, and system identification, affords a holistic understanding of the interplay between ESP Voltage, and the DUST sensor's output voltage, offering valuable insights for system optimization and analysis.

MATLAB code used for a closed-loop control system designed for tuning Proportional-Integral-Derivative (PID) parameters using the Grey Wolf Optimizer (GWO) algorithm. The system is represented by a transfer function G(s), where the numerator coefficients (ns), and denominator coefficients (ds) define its dynamics. The GWO algorithm is employed to optimize the PID controller parameters, namely the proportional gain (kp), integral gain (ki), and derivative gain (kd), with the objective of minimizing the Integral of Time-weighted Absolute Error (ITAE). The optimization process involves initializing a population of potential PID parameter sets, simulating the closed-loop system for each set, and evaluating the ITAE as an objective function.

The GWO algorithm iteratively updates the PID parameters based on the performance of each solution, aiming to converge towards an optimal set of parameters that minimizes the ITAE. The steady-state response of the tuned system is subsequently checked for accuracy, and the entire optimization process is visualized through the plotting of the ITAE over iterations. This model provides a systematic approach for optimizing PID controllers for a given dynamic system using an evolutionary algorithm. Table (4) shows the Grey Wolf Optimizer (GWO) for PID Controller Tuning.

Table 4: Grey Wolf Optimizer (GWO) for PID Controller Tuning

Parameter	Value
Transfer Function (G)	Defined by ns and ds
Number of Iterations	200
Population Size	100
GWO Alpha	10
Number of Variables	3 (Kp, Ki, Kd)
Search Space Bounds	0 to 1000

The flowchart in Figure (6) presented outlines a comprehensive, and systematic approach to the optimization process using the Grey Wolf Optimizer (GWO) for tuning Proportional-Integral-Derivative (PID) controllers. This

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method is designed to identify the optimal values of PID parameters, namely Kp, Ki, and Kd, for a given dynamic system represented by a transfer function. The process begins with the initialization of GWO parameters, defining crucial aspects such as the number of iterations, population size, and search space bounds. Subsequently, the GWO algorithm is employed in a loop, iteratively exploring, and exploiting the parameter space.

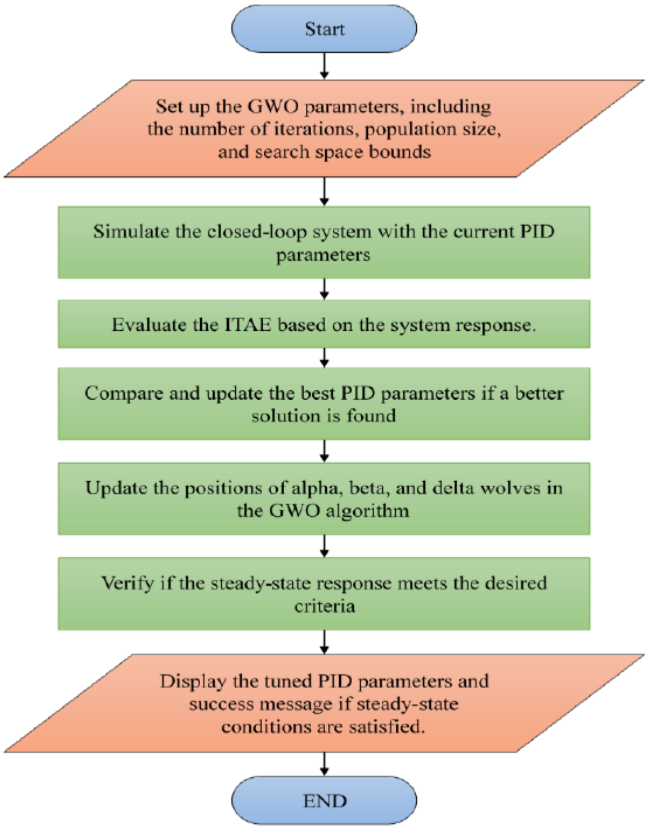

Figure 6: GWO-PID Flowchart

Within each iteration, the PID simulation is executed to assess the performance of the current parameter set. “The Integral of Time-weighted Absolute Error” (ITAE) is then calculated as an objective function, representing the system's response. An update mechanism is in place to track, and store the best solution encountered during the optimization. The GWO algorithm adjusts the positions of alpha, beta, and delta wolves, enhancing the exploration of the search space. Iterations are monitored, ensuring the optimization process continues until the specified number is reached.

A critical check is conducted to verify if the steady-state response of the system meets the desired criteria. If the conditions are satisfied, the final tuned PID parameters will be displayed, along with a success message. To aid in the analysis of the optimization process, a visualization step follows, where the convergence of the ITAE over iterations is plotted. The flowchart concludes the optimization process, providing a structured, and efficient methodology for achieving optimal PID controller tuning.

In the MATLAB Simulink simulation, a PID controller was designed based on the tuned parameters obtained from the optimization process. The resulting PID controller has the following parameters:

- Proportional Gain (Kp): 988
- Integral Gain (Ki): 37.7
- Derivative Gain (Kd): 885

The transfer function of the PID controller, denoted as Gc(s), is expressed as:

$$Gc(S) = \frac{K_p + K_i S + K_d S}{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where (Kp = 988), (Ki = 37.7), and (Kd = 885). This controller is applied to the closed-loop system, represented by the transfer function G(s), to regulate the overall system performance. By incorporating this tuned PID controller, the simulation aims to achieve an optimized closed-loop response with minimized Integral of Time-weighted Absolute Error (ITAE). The Simulink simulation allows for a thorough evaluation of the system's behavior, providing insights into the effectiveness of the optimized PID parameters in achieving the desired control objectives. Figure (7) shows the designed system using MATLAB Simulink.

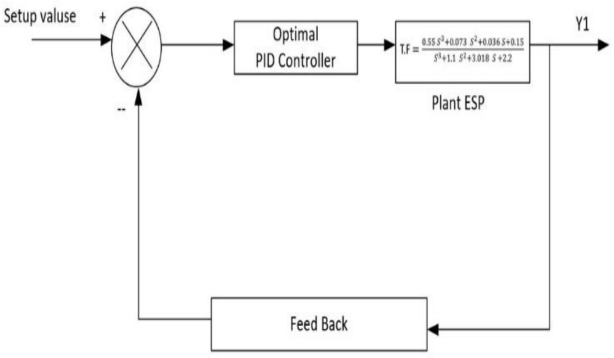

Figure 7: System Design

VII. CONCLUSIONS

In conclusion, the presented work outlines a comprehensive approach for tuning Proportional-Integral-Derivative (PID) controllers using the Grey Wolf Optimizer (GWO) algorithm. The optimization process involves defining the transfer function of the system, initializing GWO parameters, and iteratively updating PID parameters to minimize the Integral of Time-weighted Absolute Error (ITAE). The flowchart provides a systematic methodology for exploring, and exploiting the parameter space, ensuring convergence towards optimal PID values. The MATLAB Simulink simulation incorporates the tuned PID parameters (Kp = 988, Ki = 37.7, Kd = 88.5) into the closed-loop system, represented by the transfer function G(s)c. The simulation aims to achieve an optimized closed-loop response with minimized ITAE, showcasing the effectiveness of the tuned PID parameters.

The step response analysis demonstrates system stability with zero phase, indicating the successful design, and tuning of the PID controller. Overall, this systematic approach offers a structured methodology for PID controller design, and optimization, contributing to enhance control performance in dynamic systems.

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REFERENCES

[1] T. M. Mata, G. M. Oliveira, H. Monteiro, G. V. Silva, N. S. Caetano, and A. A. Martins, “Indoor air quality improvement using nature-based solutions: Design proposals to greener cities,” *Int. J. Environ. Res. Public Health*, vol. 18, no. 16, 2021, doi: 10.3390/ijerph18168472.

[2] T. W. Oo *et al.*, “Assessment of respiratory dust exposure and lung functions among workers in textile mill (Thamine), Myanmar: a cross-sectional study,” *BMC Public Health*, vol. 21, no. 1, pp. 1–10, 2021, doi: 10.1186/s12889-021-10712-0.

[3] J. Pizzorno and W. Crinnion, “Particulate matter is a surprisingly common contributor to disease,” *Integr. Med.*, vol. 16, no. 4, pp. 8–12, 2017.

[4] P. Thangavel, D. Park, and Y. C. Lee, “Recent Insights into Particulate Matter (PM2.5)-Mediated Toxicity in Humans: An Overview,” *Int. J. Environ. Res. Public Health*, vol. 19, no. 12, 2022, doi: 10.3390/ijerph19127511.

[5] Y. Wang *et al.*, “Effects of air purification of indoor PM 2.5 on the cardiorespiratory biomarkers in young healthy adults,” *Indoor Air*, vol. 31, Mar. 2021, doi: 10.1111/ina.12815.

[6] A. F. Altun and M. Kilic, “Utilization of electrostatic precipitators for healthy indoor environments,” *E3S Web Conf.*, vol. 111, no. May, 2019, doi: 10.1051/e3sconf/201911102020.

[7] C. Li, L. Huangfu, J. Li, S. Gao, G. Xu, and J. Yu, “Recent advances in catalytic filters for integrated removal of dust and NOx from flue gas: fundamentals and applications,” *Resour. Chem. Mater.*, vol. 1, no. 3–4, pp. 275–289, 2022, doi: 10.1016/j.recm.2022.06.002.

[8] F. N. H. Karabulut, G. Höfler, N. A. Chand, and G. W. Beckermann, “Electrospun nanofibre filtration media to protect against biological or nonbiological airborne particles,” *Polymers (Basel).*, vol. 13, no. 19, 2021, doi: 10.3390/polym13193257.

[9] E. Tian, J. Mo, Z. Long, H. Luo, and Y. Zhang, “Experimental study of a compact electrostatically assisted air coarse filter for efficient particle removal: Synergistic particle charging and filter polarizing,” *Build. Environ.*, vol. 135, Mar. 2018, doi: 10.1016/j.buildenv.2018.03.002.

[10] A. H. Roy, “Automatic Water Conserving Irrigation System,” *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 6, no. 5, pp. 2661–2664, 2018, doi: 10.22214/ijraset.2018.5435.

[11] G. Cao, H. Zhou, H. Zhang, J. Xu, P. Yang, and X. Y. Li, “Requirement-driven magnetic beamforming for MIMO wireless power transfer optimization,” *2018 15th Annu. IEEE Int. Conf. Sensing, Commun. Networking, SECON 2018*, no. June, pp. 1–9, 2018, doi: 10.1109/SAHCN.2018.8397139.

[12] T. Arakawa *et al.*, “Optimizing Wireless Power Transfer from Multiple Transmit Coils,” *IEEE Access*, vol. 6, pp. 23828–23838, 2018, doi: 10.1109/ACCESS.2018.2825290.

[13] H. G. C. R. Laksiri, J. V Wijayakulasooriya, and H. A. C. Dharmagunawardhana, “Design and Development of an IoT Based Intelligent Controller for Smart Irrigation,” *Am. J. Electr. Electron. Eng.*, vol. 7, no. 4, pp. 105–115, Jan. 2024, [Online]. Available: http://pubs.sciepub.com/

[14] F. Mager, D. Baumann, R. Jacob, L. Thiele, S. Trimpe, and M. Zimmerling, “Feedback control goes wireless: Guaranteed stability over low-power multi-hop networks,” *ICCPS 2019 - Proc. 2019 ACM/IEEE Int. Conf. Cyber-Physical Syst.*, no. April, pp. 97–108, 2019, doi: 10.1145/3302509.3311046.

[15] M. Mahbub, “Design and Implementation of Multipurpose Radio Controller Unit Using nRF24L01 Wireless Transceiver Module and Arduino as MCU,” *Int. J. Digit. Inf. Wirel. Commun.*, vol. 9, no. 2, pp. 61–72, 2019, doi: 10.17781/p002598.

[16] R. K. Gupta, D. Majumdar, J. V. Trivedi, and A. D. Bhanarkar, “Particulate matter and elemental emissions from a cement kiln,” *Fuel Process. Technol.*, vol. 104, no. December 2012, pp. 343–351, 2012, doi: 10.1016/j.fuproc.2012.06.007.

[17] I. F. Corporation, “Improving Thermal and Electric Energy Efficiency at Cement Plants,” *Improv. Therm. Electr. Energy Effic. Cem. Plants*, 2017, doi: 10.1596/28304.

[18] D. M. Petković, M. D. Radić, and D. N. Zigar, "Particles Charging in Tubular Electrostatic Precipitators With Polygonal Collection Electrodes," *Work. Living Environ. Prot. Vol.*, vol. 11, pp. 13–21, 2014.

[19] V. Behjat, A. Rezaei-Zare, I. Fofana, and A. Naderian, "Concept design of a high-voltage electrostatic sanitizer to prevent spread of covid-19 coronavirus," *Energies*, vol. 14, no. 22, 2021, doi: 10.3390/en14227808.

[20] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey Wolf Optimizer," *Adv. Eng. Softw.*, vol. 69, pp. 46–61, 2014, doi: https://doi.org/10.1016/j.advengsoft.2013.12.007.

[21] A. Swain, E. Abdellatif, A. Mousa, and P. W. T. Pong, "Sensor Technologies for Transmission and Distribution Systems: A Review of the Latest Developments," *Energies*, vol. 15, no. 19, 2022, doi: 10.3390/en15197339.

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