A COMPREHENSIVE REVIEW ON APPLICATION OF AI ALGORITHMS FOR GRID CONNECTED SOLAR PHOTOVOLTAIC SYSTEMS

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ABSTRACT

The preponderance significant renewable energy is solar energy and corporations and governments are investing more in it every year. The most significant issues with PV systems are resolved with Artificial Intelligence (AI). Due to increased processing power, tools, and data collection, artificial intelligence (AI) is becoming more and more prevalent in diverse photovoltaic (PV) system applications. It has been discovered that the methodologies now in use for designing, forecasting, control and maintenance aspects for the solar Photovoltaic business provide findings that are somewhat erroneous. Additionally, applying AI to complete these activities has increased in accuracy and precision and is currently a very intriguing issue. Similar to this, proportional-integral-derivative controllers have unparalleled acceptance and reputation in control systems. PID tuning is still an important area of study, due to its simple structures, robustness to model errors, and easy operations, PID controllers are widely employed in engineering practices. In this context, this paper aims to review the accord among artificial intelligence (AI) applications for photovoltaic (PV) systems and Tunning of PID controllers. This Review paper analyses the appropriate application of AI for designing, maintenance and control of Grid-connected solar Photovoltaic systems as well as advanced control strategies and control algorithms for Tuning PID controller.

I. INTRODUCTION

The ability to employ Artificial Intelligence for research has been expanded tremendous rise of digital data and processing power, due to advancements in AI and ML algorithms. [1] gives the importance of AI which exposed to a much greater urgency in the face of familiar difficulties. The growing accessibility of knowledge, in peculiar threatens the specification and self-determination of b people and country. Artificial intelligence (AI) research is aimed at creating such a computer and expanding our knowledge of intelligence. [2] gives review of artificial intelligence algorithms. Overall, AI tools and approaches are inventive, practical, and beneficial. If these were the only criteria used to assess AI's progress, it would be regarded as one of the most accomplished technical domains. Human mental abilities, on the other hand, are immensely complex and have proven to be extraordinarily difficult to imitate.

Fossil fuel consumption has caused a number of eco-friendly issues, such as the greenhouse effect and global warming. As a result, there is now a greater need for renewable energy sources. Solar photovoltaic (PV) technology is quickly expanding its role in the electrical generation industry. Concerns concerning the synchronization method are brought up by the recent interest in solar Photovoltaic integration into the grid. The modest stand-alone system has been successfully replaced by a grid connected PV system in ongoing research. [3] Investigators progressive efforts have turned the modest stand-alone PV system into a grid-connected. Figure 1 below shows the example of the PV system. The primary goal is to synchronize the utility of PV system to send actual electricity to meet load needs.
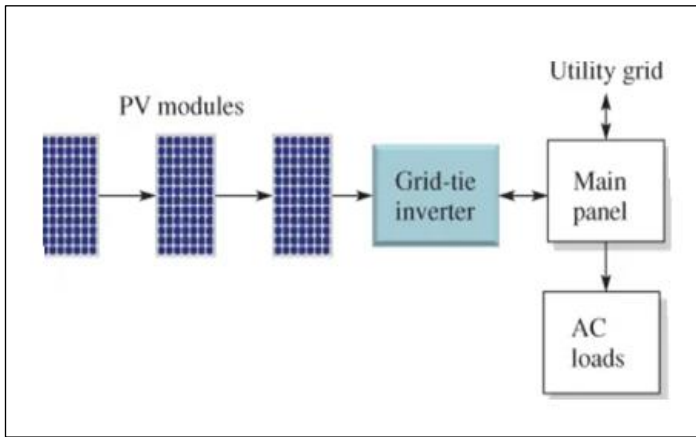
Figure 1: Structure of grid-tied PVs.
Source: Authors, (2024).

Photovoltaic systems are grid-connected satisfy the voltage and frequency standards stated in the IEEE standard for integrating dispersed energy resources with power systems. By giving systems, a set of intricate instructions to follow, it trains them to think, reason, and make judgements much as people do. Both businesses and individuals utilize the technique often in their daily operations. Additionally, it has been determined that the use of AI in the digitalization of power systems has a huge potential to help with enhancing stability, dependability, dynamic reaction, and other crucial developments for the power system network [4]. The qualities of design considerations, forecasting, converter control and maintenance are heavily studied in the literature out of the specified fields of AI use. The components of cybersecurity are evolving and were thought to be the upcoming trends for AI applications in solar energy systems. The development of AI to support the system learning process for enhancing efficiency and lowering reaction time has advanced due to the data availability in the operation of power systems.

In [5] Describes integration of a photovoltaic system utilizing a Marx multilevel inverter under various ecological situations. The P&O MPPT technique is to transition the pulse from the PV panel to the Boost Converter, and grid integration was accomplished utilizing PLL with a closed loop control strategy using the Phase Disposition method. PI parameters pioneered the controller design methodology. [6] A unique grid-connected photovoltaic control mechanism has been developed using boost converter and an L filter. The control objectives are to track the maximum power point of the PV panel, balance the power exchange by regulating the DC link voltage and ensure a unity power factor in the grid.

Proportional Integral Derivative controllers are used significantly and recognized for development control in today's industry due to aspects such as their simplicity, high efficiency and reliability. Tuning of PID control parameter has been a topic of present study. Reduced settling time and low overshoot in the steady state response are the main goals of PID control settings. Ziegler and Nichols (1942) established the first PID controller parameter tuning rules, and numerous further tuning rules were proposed afterwards. [7] investigated the performance of PID while taking the coupling impact of LFC and AVR into account, first utilizing the traditional controller (Z-N) approach to enhance the performance and then applying advanced intelligence techniques to produce more accurate results. Error is the difference in computation between the process value (PV) arriving from the field measurement sensor and the desired process trajectory or setpoint, set by the operator or by sophisticated process control logic. The

controller output moves the final control element and has been computed in accordance with the present and previous error values in order to minimize error. The most efficient control action depends on the PID parameters' ideal values in the PID control algorithm. [8] About 90% of control system applications uses PID controllers.

Various tuning approaches are described in this review study, and observation of existing algorithms tuning method responsiveness is examined. Many methods for adjusting and producing optimized gain factors have been utilized in the past, including the Ziegler-Nichols technique, particle swarm optimization, genetic algorithm and artificial neural network.

Subsequent part of this article is prepared as: Section II explains about AI Frame work for grid connected PV system. Section III gives AI applications in design, forecasting, control and maintenance of PV system. Section IV investigates the modelling of PID controller Tuning. Section V classify the AI algorithms for PID controller tuning. Section VI finally a conclusion is given.

II. AI FRAME WORK FOR GRID CONNECTED PHOTOVOLTAIC SYSTEM

Artificial Intelligence utilizes a variety of approaches to study power system challenges such as architecture, control, monitor, forecast and security. [9] literature divides artificial intelligence into five categories: optimization, data analysis, categorization, regression and clustering. Intelligent PV plants are built in [10], with linear programming-based optimization for scaling PV, energy storage systems and model predictive control. Same optimization technique is used for the designing the storage system as well as operation of the entire IPV power plant to achieve exclusive sizing and control.

Furthermore, with increased access to power system operational data, AI implementation has increased significantly, as has accuracy. In this case, the data collected is used to allow AI-enabled learning methodologies for spotting different difficulties and irregularities in system and suitable action within the time frame is specified. [11] uses irradiance forecasting with LSTM network to estimate the day profile for PV system operation. This information enables the developers to determine the performance of the PV in calculating the lowest, middle and high-power outputs. [12] A data driven strategy for detection of false data injection in system control. According to findings, procedure may be carried out online with the help of reinforcement learning methodologies. AI approaches are used practically scientific sector and business to improve services or solve issues that traditional methods cannot address [13]. We look at how artificial intelligence is being used in the PV industry.

PV systems encounter a variety of issues during installation and operation, because modules are sensitive to unstable climatic conditions. [14] provides a study of the challenges encountered in PV plants; also, module maintenance is critical to ensure maximum production and increase security of the installations. Figure 2 explains about the frame work and also describes about the applications of AI for grid connected solar PV in power systems. Optimization needs expert, decision making and heuristic search approaches for design, forecasting and control. Whereas classification, Regression and Clustering needs learning algorithms for maintenance, control and forecasting.
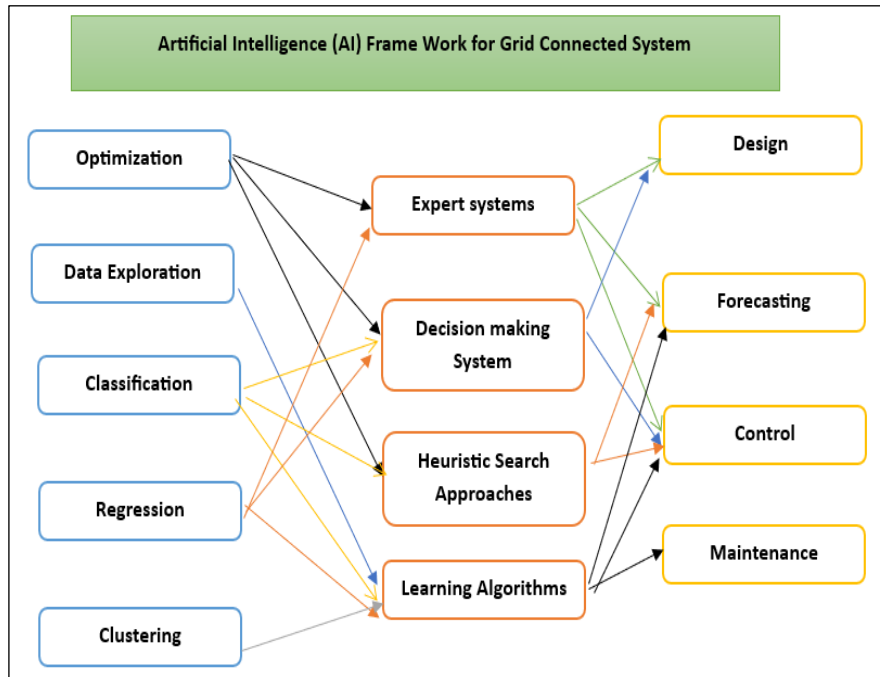
Figure 2: AI frame work for grid connected system.
Source: Authors, (2024).

Renewable energy (RE) supplies have attained peak performance in meeting contemporary energy demands. Among the numerous RE resources, photovoltaic is regarded as sustainable energy. [15] A Re-lift Luo converter is used single-phase grid-integrated solar PV system using chicken swarm optimization method. As PV output is periodic, the converter output varies as well and kept constant by using proportional-integral based closed loop control using optimized CS algorithm and normalized output then sent into grid through voltage source inverter. Furthermore, complexity of the power module construction and the complicated working circumstances for a solar photovoltaic (PV) inverter may damage the dependability of these modules, lowering the functional efficiency of the total grid-connected PV systems [16]. These limits are thought to have a significant influence on the safety and failure cost of GCPIs.

Linearization of a power flow (PF) model is a significant method for simplification and acceleration of power system management, operation, and optimization calculations. [17] Traditional model-based techniques generate linearized PF models by approximating the methodical Power Flow model based on the physical properties of power system. This [18] offers a novel neural network (NN) structure based on gradient descent least squares regression controlling integration of grid to solar PV systems to improve the quality of power. In this case, a neuron structure with single layer is employed to extract the fundamental component from load current. The GDLSR-based NN structure reduces harmonic components, DC offsets and distortions from nonlinear current during FC extraction, hence enhancing power quality in both normal and abnormal grid conditions. The dominance of renewable energy sources with power electronics-interfaced solar photovoltaic systems in recent years has caused grid frequency instability. [19] research offers a new machine learning based virtual inertia synthetization. Artificial intelligence approaches have been widely employed in the previous decade for MPPT in solar power systems under partial shading conditions. [20] A comprehensive fuzzy logic based maximum power tracking controller has been constructed and results demonstrating quick convergence to MPP and low variation in extremely and effectively under specified atmospheric circumstances.

III. AI APPLICATIONS FOR GRID CONNECTED PHOTOVOLTAIC SYSTEM

It is a branch of computer science engineering that concentrates on developing advanced computers, gadgets and systems. [21] characterized a system's capacity to appropriately absorb external information, acquire knowledge, utilize techniques to achieve specific objectives. [22] AI is essentially provision for intelligent that can process information and make judgements in the same manner that humans consider. It is used to make machines intelligent so that they can accomplish complicated tasks effectively.

In [23] investigations-based AI focus on the designing and size of solar photovoltaic, regarded as essential aspects. Solar radiation modelling, prediction, and forecasting is one such extensive use. According to the research released, the Artificial Neural Network is commonly employed approach among the several strategies offered in solar energy literature. [24] Many studies have used Back Propagation Neural Network to forecast solar irradiance, energy, water heating system, daily ambient temperature and maximum power. [25] Artificial Neural Fuzzy Integrated Systems was used to estimate PV power supply, clearness index, radiation prediction and SCPP performance. In certain cases, a mix of methodologies is used to provide the best outcomes in forecasts, estimates and forecasting. [26] Various AI approaches were employed by the writers. The most widely utilized approaches in solar energy were ANN BPNN, ANFIS, and GA. According to the conclusions of this research, these strategies are commonly employed in many types of solar forecasts. ANN stood out as the most effective of these strategies and has distinct benefits in terms of computation speed, accuracy, and generalization capabilities over other modelling approaches. Figure 3 depicts AI applications.
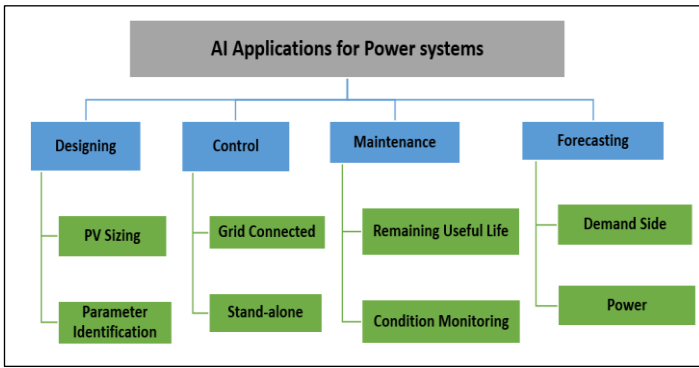
Figure 3: Applications of Artificial Intelligence in Power systems.
Source: Authors, (2024).

III. 1. APPLICATION OF AL FOR DESIGNING

Artificial intelligence techniques are becoming more helpful alternatives than traditional methodologies. It plays a major role in power system designing which involves photovoltaic systems sizing and parameter identification.

Accurate size of a PV solar system is critical for ensuring the quality and stability of power supply, maximizing the economic lifecycle redeem. The major purpose is to provide overview of AI methods for sizing photovoltaic systems, such as stand-alone, grid-connected, and hybrid systems. [27] demonstrates AI's promise as a design tool for optimal PV arrangement. Furthermore, advantage employing AI-based sizing of PV systems delivers effective optimization, particularly in remote places where meteorological data is not always accessible. In this [28] artificial neural network and genetic algorithm are proposed to identify the appropriate size of PV systems, particularly in remote places. The GA-ANN technique has been proved useful for modelling the optimal size coefficient SAPV systems. The advantage of this method is to estimate the PV-array area and battery useable volume using merely geographical coordinates for any place. Generalized regression neural network is utilized in [29]. To adjust the coefficients and assess the possibility of load loss in standalone systems. The created model produces coordination coefficients with a MAE of 0.6%, while the simulation produced a load loss probability of 0.5%.

Parameter identification is critical not just for PV system modelling and simulation, but also for problem detection. The two-parameter identification are single diode and double diode model. Photovoltaic module parameter extraction is recognized as vital issue evaluating the PV energy systems performance. In this [30] the demand for supply-based Optimization Algorithm is used to extract the PV models' specifications. Because of its simplicity of implementation and great optimization capabilities, it is commonly employed to address complex nonlinear problems. In mathematical PV module models, the Triple-Diode Model is widely used. Thus, SDOA regarded as a competitive optimizer in comparison to other strategies documented in current methodologies. The genetic algorithm technique is utilized in [31] double diode solar cell model identification. Suggested method estimates currents and shunt resistance by using diode voltages as a function of temperature. The findings indicate the best experimental I-V curve with high convergence. In this [32], two strong AI approaches, Adaptive Neuro-Fuzzy Inference System and Artificial Neural Network are used to calculate the parameters in differential equations of dynamic systems. Extraction of unknown values of solar cell models are important for PV system performance. [33] demonstrates how to extract parameters from solar cell models

using the symbiotic organisms search efficient metaheuristic method. SOS was stimulated by interaction of symbiotic methods used to improve overall determination in the ecosystem. Advantages such free tuning algorithm for specific parameters, having better balance among investigation and maltreatment.

III. 2. APPLICATION OF AL FOR CONVERTER CONTROL

Based on method of operation, power electronic converter control categorized as Grid connected control and Standalone control

Grid connected Controllers are used to manage the power and frequency on inverter's AC side and decrease harmonics in system. An inverter control algorithm is used to handle the switches. However, AI greatly improves controller performance as well as inverter reaction time to transient faults. A unique cascaded H-bridge inverter with FL control method for PV applications has been suggested in [34]. Its performance meets the requirement for flexible electric power generation while also reducing the impact of disturbances produced by cloud darkening or fluctuations. Because of flexibility, suggested system may be enhanced by increasing the number of tiers, lowering THD even further. An adaptive neuro-fuzzy model using multilevel inverter photovoltaic system was suggested in [35]. The suggested controller's objective is to eliminate the need for an ideal PWM switching. Variations in output of H-bridge cascaded MLI are rigorously prohibited by the suggested technique. The ANFIS has a grid voltage input, a difference voltage, and a control voltage output goal in this technique. The ANFIS sets the rules and has been carefully calibrated using these parameters.

In Standalone control after the DGs are unplugged from the grid, they must continue to run and meet the demand. Distribution grids should address the load-supply balance while simultaneously managing the output in this mode of operation. [36] Traditionally, the inverter's stand-alone mode was examined through SVPWM. Researchers all around the world are concerned about and working to improve the efficiency of distribution generation (DG) inverters. An inverter control mechanism is being developed to alleviate the issue. When operating in grid connected inverters have voltage control and harmonics difficulties. This [37] presents a control technique for DGs that operate in both the conditions. The inverter's GC operation is accomplished through the CC mode, and SA control includes a VC loop capable of overcoming limitations associated with load shedding.

III. 3. APPLICATION OF AL FOR MAINTENANCE

AI may assist to save money and resources by optimizing maintenance schedules, minimizing waste and extending the life of equipment.

Photovoltaic systems have originated as significant renewable energy sources. when PV energy grows, it is critical to investigate defects and degradation of PV systems in order to improve the stability and performance in electrical systems. [38] A fault distribution technique is developed to ensure accurate and early failure detection in PV systems. Batteries play an important part in grid connected PV systems and must give the needed performance. Various diagnostics and prognostics for battery health monitoring, have been investigated. For battery issues, AI-based diagnostic approaches have been investigated. [39] develops a Bayesian regression for remaining useful life estimation in batteries. To calculate the RUL for batteries, electrochemical process method is combined with a statistical model. Furthermore,

relevance vector machine technique is being investigated for analyzing battery health. An adaptive Gaussian mixture model-based battery health monitoring system is proposed.

Condition Investigation in Grid connected systems are generally subjected to demanding and complicated operating conditions. They may experience a variety of fault occurrences, both at the component and system levels. Grid connected PV system safety and dependability are critical to ensuring the system's efficient functioning. Monitoring the state of PV modules is critical for improving power conversion efficiency. Delamination, discoloration, cell fracture, short circuit, glass crack and other problems can occur in PV panels. For defect diagnosis in PV panels, [40] use random forest approaches. The output of voltage and current under various temperature circumstances is acceptable. In [41], a failure diagnostic technique for PV panels is created using probabilistic neural network and radial basis networks. This diagnostic method has been found to be less susceptible to outliers and to have excellent generalization accuracy.

III. 4. APPLICATION OF AL FOR FORECASTING

As the number of Grid connected photovoltaic systems increased in recent years, having accurate projections for electricity generation supplied into the grid has become increasingly crucial. The primary reason for the rise is a reduction in investment expenses. Forecasting methodologies have been widely used by market participants. An overview of energy market systems and the corresponding forecasting needs for intermittent renewable energy sources.

The majority of the research has been on demand side projections rather than distributed energy resource outputs [42], Load projections have been utilized in a number of studies to improve system functioning. [43] provides a study of sun irradiance forecasting strategies utilizing four distinct supervised machine learning and deep learning algorithms. The comparison of the various approaches revealed that the ANN algorithm produces effective performance compared to other methods.

Accurate estimates of PV system output power can help to revealing critical information to control the energy grid more effectively, allowing grid operators to handle rapid fluctuations in power in the grid. A study of solar power forecasting in [44] evaluates several methodologies and approaches to increase prediction model accuracy and minimize uncertainty. According to the review, ANN often employed with ML approaches in prediction of solar power conditions and with a large number of input variables. support vector machines techniques employ supervised modelling methods with input factors such as global horizontal irradiance and other performance specifications. [45] ANN and ensemble techniques are used to forecast power output. Table 1 below gives the summary of the AI methods used for grid-tied Photo voltaic systems.

Table 1: Summary of AI Application techniques for Grid Connected PV systems.

Applications	Method	Algorithm	Advantage	Reference
Designing	PV Sizing	GA-ANN	Efficiently predicts input data	27,28,29
	Parameter Identification	ANN	High accuracy	32,33
Control	Grid connected	AI	Capability to manage multi-inverter grid-connected DG	34,35
	Standalone	Fuzzy	Reliable in Control of System	37
Maintenance	RUL	RVM	Robust and high accuracy	38,39
	Condition Monitoring	RF	Achieve better performance and accuracy	40
Forecasting	Demand	ANN, ML, DL	Efficiently handles the nonlinear data	43
	Power	ANN	High precision and quick response	45

Source: Authors, (2024).

IV. MODELLING OF PROPORTIONAL INTEGRAL AND DERIVATIVE CONTROLLER

This controller has significant role in utility systems due to its serenity of implementation and efficacy of performance in electrical power systems. Most of the industrial applications PID controllers are employed. These controllers date back to the governor design of the 1890s. As per the survey in 1989, 90% of process industries employ them. PIDs are universally used in industry due to simplicity and ease of online re-tuning. For PID tuning, numerous strategies have been used, with the Ziegler Nichols technique being one of the first [46]. Figure 4 below shows Schematic diagram of PID.
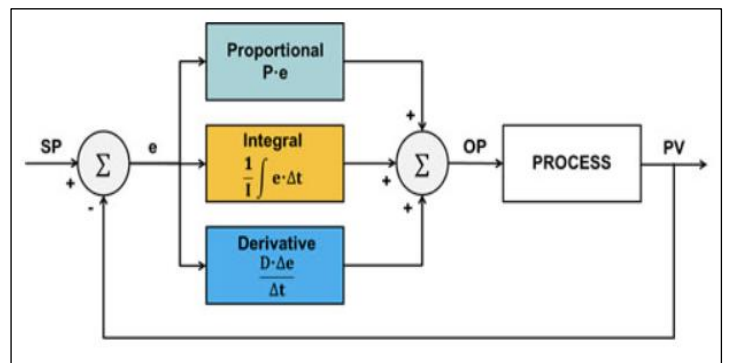

Figure 4: PID controller Schematic representation.
Source: Authors, (2024).

PID controllers use computational models to self-tune or auto-tune. PID controller self-tuning effectively modify the parameters in modelling computational process and comparing the

outputs to check the deviations, in which case the PID settings are reset to obtain the desired response. For tuning of proportional-integral-derivative controller a three-tank system using a mixed optimization approach is presented [47] to acquire optimal controller settings, the unit step response of integral-square-error is reduced.
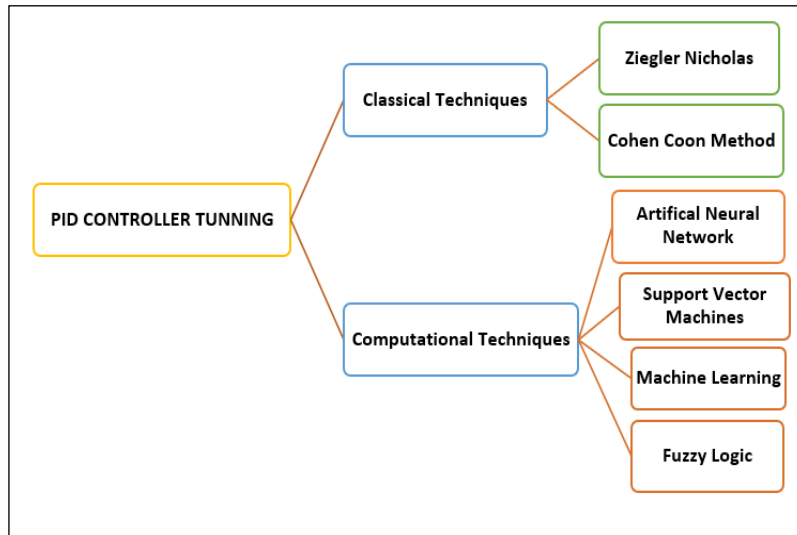

Figure 5: Classification of PID Controller Tunning.
Source: Authors, (2024).

V.1. CLASSICAL TECHNIQUES

Conventional systems estimate the system model to develop controller settings based on these assumptions. The feedback of the systems is measured in order to determine their progress.

V.1.1. Ziegler Nichols Method

The two scientists in 1942 introduced most fundamentally recognized and widely used tuning procedure [48]. Ziegler and Nichols have presented two techniques. PID controllers for spindle motor systems were tuned using the first technique. [49]. The second way is based on previous experience with certain frequencies. The goal is to base the controller settings on the frequencies that are most important for stability. The first strategy, devised by Ziegler and Nichols, is based on certain controller assumptions. Hence controller is destructive, resulting in uncontrolled oscillations.

V.1.2. Cohen Coon Method

In [50] FOLPD model is used to specify PID controller parameters. The fundamental structure requirement is the rejection of load perturbations. Cohen Coon approach produces similar findings to the Ziegler Nichols method.

V.2. COMPUTATIONAL TECHNIQUES

The various intelligent optimization techniques for PID controller tunning are discussed below.

V.2.1. ARTIFICIAL NEURAL NETWORKS

Computations and mathematics are used to replicate human-brain processes in the model. Many of the recent achievements are in the field of artificial intelligence research, such as image and speech recognition, robotics and the use of ANNs. Figure 6 shows the ANN based PID tunning. Though ANN model

V. CLASSIFICATION OF PID CONTROLLERS TUNING

An overview of tuning approaches is shown in Figure 5.

is used for highly nonlinear systems. In [51] neural network control design was specified with inherent drawbacks of ANN theory, in determination of neurons and layers.
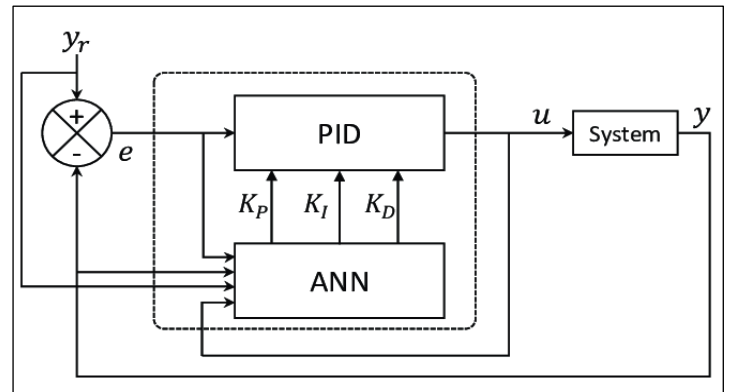

Figure 6: Architecture of ANN based PID
Source: Authors, (2024).

V.2.2. Support Vector Machine

Be concise PID control techniques are commonly used in the majority of chemical processes. However, tuning PID parameters is a critical issue as they have significant impact on adherence of the control system [52]. Support Vector Machine is a set of supervised learning techniques used for classification and regression. layman's words, SVM training algorithm predicts whether a new example belongs in one of two categories given a set of labelled data. In more technical terms, an SVM generates a hyperplane in a high dimension space, which is utilized for classification and regression.

V.2.3. Fuzzy Logic

It is the relationships between control engineering and artificial intelligence. The FLC augments the standard PID by adjusting controller's settings on-line in response to changes in

signal error and error. When compared to the solo Fuzzy, the PID Controller performs well. In the Fuzzy Controller elementary rules are made; whereas in PID Controller based Fuzzy, manifold rules are established for all three Controllers and exhibits improvements quicker, as shown in Figure 7.
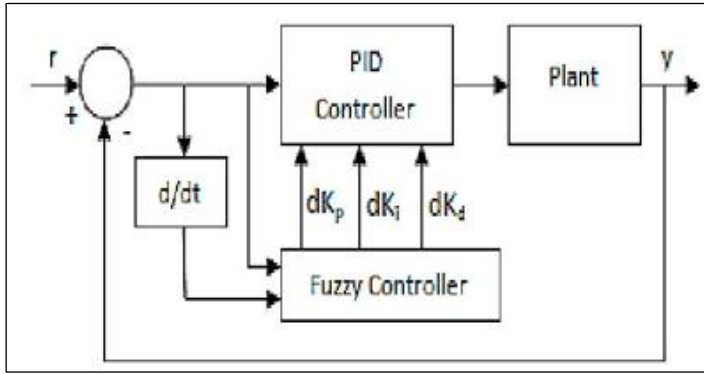

Figure 7: Architecture of Fuzzy based PID.
Source: Authors, (2024).

The rules determined by the system are managed and experienced [53]. Designing integral rule bases may be challenging. As a result, this is an ideal design and additional configurations in which a PI- fuzzy controller and PD-fuzzy controller work together to create a PID- controller.

V.2.3. Machine Learning

Due to its Accuracy and Precision, these algorithms are extensively used industrial control system. However, adjusting PID parameters are not easy, and various approaches have been published in the literature. The purpose [54] study is to demonstrate a machine learning strategy combining gradient descent with multivariate regression and the normal equation as shown in fig 8. As an example, the first order cruise control system is employed, and the results demonstrate effective progress towards autonomous adjustment of PID data using trained data.
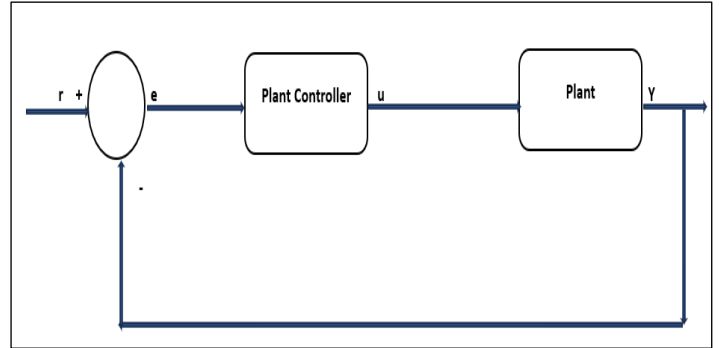

Figure 8: Machine Learning based PID.
Source: Authors, (2024).

Advantages and Disadvantages of all the PID controller Tunning Techniques are given in Table 2 below

Table 2: Summarized Strengths and Weakness of PID Controller Techniques.

Technique	Strengths	Weakness
Ziegler Nichols	Proven and Online Method	Very Aggressive
Cohen Coon	Good process and Offline Method	Good for first order process
Artificial Neural Network	Convergence to Precise Model	Take More Time for Execution
Support vector Machine	Efficient Design Simple control	Low Accuracy
Fuzzy Logic	Simple control structure	Simple Fuzzy Information
Machine Learning	Robustness	Requires data for calculation

Source: Authors, (2024).

VI. CONCLUSION

The First Part of the study undertaken in this work leads to the conclusion that there are several research articles published utilizing different AI algorithms to diverse goals in the combination of solar Grid Connected System. The most often used AI approaches for the Grid Connected Photovoltaic Systems are in Designing, Converter Control, Maintenance and Forecasting have been discussed in brief along with its advantages and applications. Similarly, the second part of the research examined a wide range of strategies for PID tuning. Following a brief overview of the approach, there was an accomplishment in tuning and self-tuning of the controllers applying various control techniques. Applications of these controllers will be encouraged more as computer technology and smart machines advance. As a result, more research into PID algorithms is required. Thus, this article gives a brief description AI application for Grid Connected Photovoltaic systems and PID Controller tunning.

VII. AUTHOR'S CONTRIBUTION

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