RESEARCH ARTICLE OPEN ACCESS

Design Control Algorithm Used To Optimize the Maximum Power Extraction from a Hydropower Generator

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ABSTRACT:
Non-renewable energy sources are the primary source of power generation. As a result, environmental issues become a barrier for all nations. Furthermore, there is an issue with the use of nonrenewable resources since they eventually become extinct due to constant use. Therefore, in order to prevent these issues, power grids should work with both renewable and non-renewable sources. It is difficult to integrate renewable energy sources into the electrical system. Issues such as the power system's decreased inertia, frequency stability, and the output system's weak grid characteristics could restrict the ability to supply renewable energy. The suggested frequency control methodology, or phase difference method, can effectively address these issues in the motor-generator pair (MGP) system. The purpose of the MATLAB simulation is to evaluate the viability of the frequency feedback control approach.

Keywords: Non-renewable energy; Power grid; Maximum power extraction.

Date of Submission: 23-04-2025 Date of acceptance: 03-05-2025

I. Introduction

The growing need for electricity has led to a daily growth in power generation, production, and delivery. Coal and other fossil fuels are the primary sources of electrical power generation. The primary issue resulting from the use of coal is the environmental impact. This ushers in a new era of electricity generation, one that combines non-renewable and renewable sources. There are existing hydroelectric plants that generate electricity, but the grid's integration with solar cells, wind turbines, and other sources has been evolving. Many research approaches have been put up for such an implementation. The installation of a small 800 kVA hydropower plant in an area with a high concentration of industrial consumers leads to a high voltage power quality issue. Many companies use advanced technology in their manufacturing, necessitating high power quality and power supply dependability. For these consumers, even minor issues with electricity quality might have major technical and financial repercussions. [1]. Regardless of any voltage fluctuations generated by the hydro generator [squirrel cage induction generator (SCIG)], a series power active filter (SEPAF) is utilized to guarantee a constant and basic voltage magnitude across loads. Additionally, by resolving a number of problems such reactive power, current harmonics, current unbalancing, and power factor, a shunt power active filter (SHPAF) of the UPQC raises the PQ of source terminals. [2].

HTRS state space model with surge tank and explicit formula for dimensionless turbine rotation speed using system decoupling with the Jordan canonical form of the state matrix[3]. The performance of the group predictive generator control algorithms. The research has revealed that the use of a DC link and a small HPP with group predictive voltage and frequency controllers has a noticeable effect on the improvement of power quality [4]. the problems with power quality in distributed generation systems that use renewable energy sources like wind and solar. This is a comprehensive examination of the power quality problems. This document first discusses the problems with power quality before moving on to basic criteria. This research does a thorough analysis of power quality in power systems, including those that use dc and renewable energy sources. [5]. By adding renewable energy systems to the network, distributed generating resources (DGs) have become more significant. Power quality issues in low voltage and medium voltage distribution systems have emerged as a key area of research due to the growing network penetration of renewable energy sources. [6]. Analysis of power quality issues with renewable DG system grid integration and the state of related mitigation technique research. The first goal of this paper is to theoretically illustrate all of the important power quality issues related to grid integration of renewable energy. Secondly, a comprehensive overview of all PQI techniques that have been introduced to date is provided, along with opportunities for further research. [7]. A higher power factor and more efficient electric vehicle (EV) battery charger based on a bridgeless (BL) CUK converter is designed and developed. [8]. By incorporating diverse renewable energy sources into energy storage systems, researchers and industry professionals have worked on a variety of energy storage methods. The authors of this article have taken into consideration a variety of energy storage technologies due to the vast array of advancements in this field, including battery, thermochemical, thermal, pumped energy storage, compressed air, hydrogen, chemical, magnetic, and a few more. [9]. The widespread usage of these technologies presents new problems for power systems, including problems with voltage management, protective device settings, power quality (PQ), and optimal placement. [10].

The combined system (including WHRPGS and CPS) was described using a new, simplified model. The energy process of the integrated system was thoroughly examined by integrating the techniques of pinch analysis and energy analysis.[11]. Technologies for energy-efficient desalination and water treatment are essential for boosting freshwater supply without unduly taxing already scarce energy supplies. Membrane distillation (MD), a crucial aspect of the water-energy nexus, has the potential to enhance sustainable water production by desalinating high-salinity waters utilizing low-grade or waste heat. [12]. innovative control method to increase the PQ in WECS by using a Distribution Static Compensator (DSTATCOM) based on Artificial Neural Networks (ANN). Our suggested method generates the DSTATCOM's gate pulses using an online learning-based ANN Back Propagation (BP) model, which reduces the grid side harmonics. [13].

Thanks to advancements in technology, declining costs, a track record of success, and increased awareness of their advantages, microgrids are gradually making their way from lab benches and pilot demonstration sites into commercial markets. Their applications include enhancing electrical grid resilience and dependability, controlling the integration of distributed clean energy sources such as solar photovoltaic (PV) and wind power to cut down on emissions from fossil fuels, and supplying electricity to places without centralized electrical infrastructure. [14]. intends to analyze photovoltaic systems, focusing on their vital components—design, operation, and maintenance. The design includes revisions to the system's essential components and their own layout. [15]. There are strategies for peak load shaving. There has been extensive discussion of the effects of the three main peak load shaving strategies: demand side management (DSM), energy storage system (ESS) integration, and electric vehicle (EV) grid integration. [16].

The most frequent characteristic that distinguishes MGP from a conventional thermal power plant is the synchronous generator's loss. When evaluating the prime mover under 50% normal rating, the cost and efficiency for each will be different. Since a de-rated operation has no effect on the conversion from wind to electricity, MGP's overall efficiency and cost will increase as a result of the energy conversion. Virtual Synchronous Generators (VSG) require a large-scale energy storage system to supply sufficient inertia energy when compared to Motor Generator Pairs (MGP) in terms of increased penetration of renewable energy. Because it doesn't require pricey battery storage devices to provide the same inertia energy, the MGP will be far less expensive.

II. Various Control Strategies

a. MGP System with PI Controller

Because it can retain a precise set point, PI control is growing in popularity. The goal of this chapter is to establish the design and implementation of typical PI controllers at different operating points, where the controller is exposed to different input voltage disturbances and load variations. The proportional and integral modes combine to form the proportional-integral controller mode. Certain advantages of both control actions can be obtained from this mode. This mode is also called as the proportional plus reset action controller. Combining the equations for the integral and proportional modes yields the following analytic statement for this mode:

$P = K_p\, e_p + K_p\, K_t \int e_p dt + p_{t(0)}$……

Where,

$p_{t(0)}$ = Integral term value at t = 0 (initial value)

By design, the proportional gain also modifies the net integration mode gain; however, the integration gain is separately adjustable. The proportional offset is known to have happened when a load change necessitated a new nominal controller output, which could only be supplied by a fixed error from the set point. In the current mode, the error can be zero following a load shift because the integral function supplies the necessary new controller output. After the load modification, the integral feature essentially offers a "reset" of the zero-error output. The error arises from a change in load at time t1. It takes a fresh controller output to accommodate the new load state. The total of proportional and integral actions provides the controller output, which ultimately leaves the error at zero. Clearly, the proportional portion is merely an illustration of the mistake.

- The controller output is locked at the value that the integral term had when the error is zero. Just by choosing to define the time at which observation begins as t = 0, we are able to obtain this output using pt(0).
- The integral term starts to raise or lower the cumulative value [initial pt(0)] based on the sign of the error and its direct or reverse direction, while the proportional term provides a correction if the error is not zero. If the error and the action attempt to drive the area to a net negative value, the integral term will saturate at zero since it cannot become negative.
- The transfer function is given by $K_p+(K_I/s)$

The integral time T1 (=KI) is the integral action adjustment. The time for proportional action is the integral time, also known as the reset time, for a step deviation "e." The number of times per minute that the proportionate piece of the response is repeated is known as the "reset rate." As the inverse of integral type, reset rate is sometimes known as "repeats per minute." In order to develop the PI controller for the buck and boost converter, a closed loop operation is required. Line and load interruptions have no effect on the open loop operation. This operation is hence ineffectual. This leads to the selection of the closed loop procedure. The closed loop control system employs an output voltage as the intended value or set point, a feedback signal from the process, and a control system that compares the two to produce an error signal. In an attempt to lower the error, the converter is then controlled by the processed error signal. System delays can make handling error signals extremely complicated. A proportional-integral (PI) controller is typically used to process the error signal; the parameters of this controller can be changed to maximize system stability and performance. Very accurate and efficient control is possible after a system is stable and set up.

b. MGP System with Fuzzy Logic with PI Controller

Numerous control applications successfully employ fuzzy logic. Fuzzy control is included in practically every consumer product. Examples include using an air conditioner to regulate the temperature of your room, anti-braking systems in cars, traffic light controls, washing machines, big economic systems, etc. A control system is a configuration of physical elements intended to modify another physical system in order to make it display specific desired properties. The use of fuzzy logic in control systems has the following justifications.

- When using classical control, one must be familiar with the model and the precisely specified goal function. In many situations, this makes application quite challenging.
- We can leverage human expertise and experience in controller design by implementing fuzzy logic.
- The best way to create a controller is to use fuzzy control rules, which are essentially IF-THEN rules.

The main elements of the FLC, as depicted in the above image, are as follows: −

- Fuzzifier − the role of fuzzifier is to convert the crisp input values into fuzzy values.
- Knowledge Base for Fuzzy It keeps track of all the fuzzy relationships between input and output. Additionally, it features a membership function that specifies the output variables for the controlled plant and the input variables for the fuzzy rule base.
- Fuzzy Rule Base: It contains information on how the domain process works.
- The inference engine functions as any FLC's kernel. In essence, it uses approximation reasoning to mimic human decision-making.
- Defuzzifier: The defuzzifier's job is to transform fuzzy values from fuzzy inference engines into crisp values.

The Fuzzifier transforms input from real-world data into appropriate language values. An FLC accepts an input value, also referred to as the fuzzy variable, and fuzzifies it by analyzing it using Membership Functions, which are user-defined charts. In this case, the input values are always precise numbers. With the aid of their MFs, the inputs are first taken and their degree of belonging to each of the relevant fuzzy sets is ascertained. The degree of membership that corresponds to its numerical value as determined by the qualifying linguistic set is the result of the fuzzification procedure. Area control error e(k) and change in area control error ce(k) are the two inputs to the controller that we have examined in this work. DelPc, the speed changer setting change, is the output. The degree of membership, which is determined by the qualifying linguistic set, is the result of the fuzzification process. This work examines two controller inputs: the change in area control error ce(k) and the area control error e(k). The output is the change in the speed changer setting, or delPc. . The range of the output variable was 0 to 0.02. The rulebase and inference engine constitute the second component of an FLC. Rule-based decision-making provides reasoning. We obtain the output values in terms of membership functions for different combinations of the input membership functions. Here, the linguistic inputs are e(k) and ce(k), and the linguistic output is delPc. The controller has seven membership functions and up to 49 rules. Below is a table that displays the rules. According to the regulations, if e(k) is NB and ce(k) is NS, then delPc is S for the area control error e(k) and change in error ce(k). Both input and output use triangular membership functions.

III. Results and Discussions

a. Results of MGP System with Convectional PI Controller:

At the beginning of the simulation, the MGP system's reference power transfer value (Pg) is 500MW. In the initial state, the power reference value (Pref) is 1000 MW, as illustrated in fig. 2 above. The MGP system's reference power transmission value (Pg) in the simulation is 500MW at startup. As seen in fig. 2 above, the reference power value (Pref) is set to 1000 MW under beginning conditions. The inverter modifies the output voltage phase in response to changes in the MGP system's reference value by using the grid voltage as a guide. The power angle (delta) in the simulation results fluctuates according to the MGP system's power reference value, indicating that the phase angle difference method is used to regulate the power transmission. The controller sets the speed to 1500 rpm, as seen in figures 3 and 4 above. Trial and error is used to obtain the PI controller's values, which are as follows: K-P.=0.14 and K-I.=0.01.

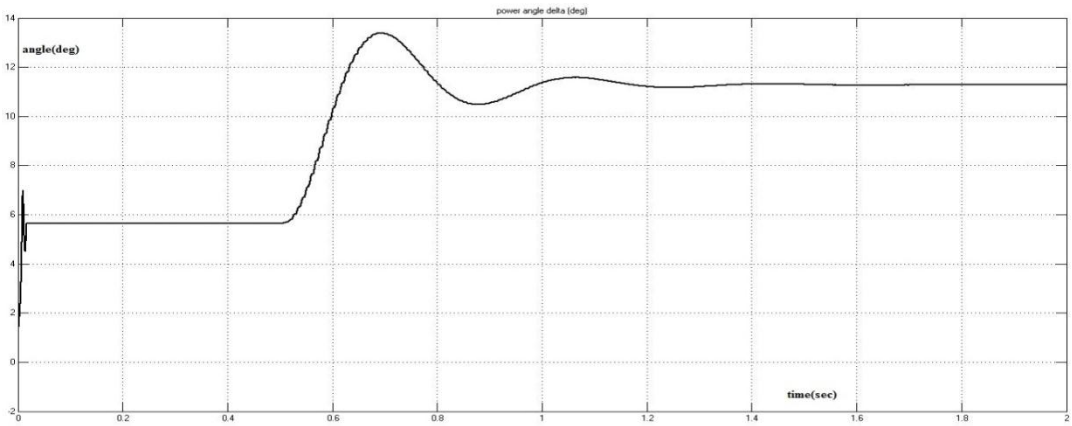

Fig.1: Maximum Power angle with PI Controller

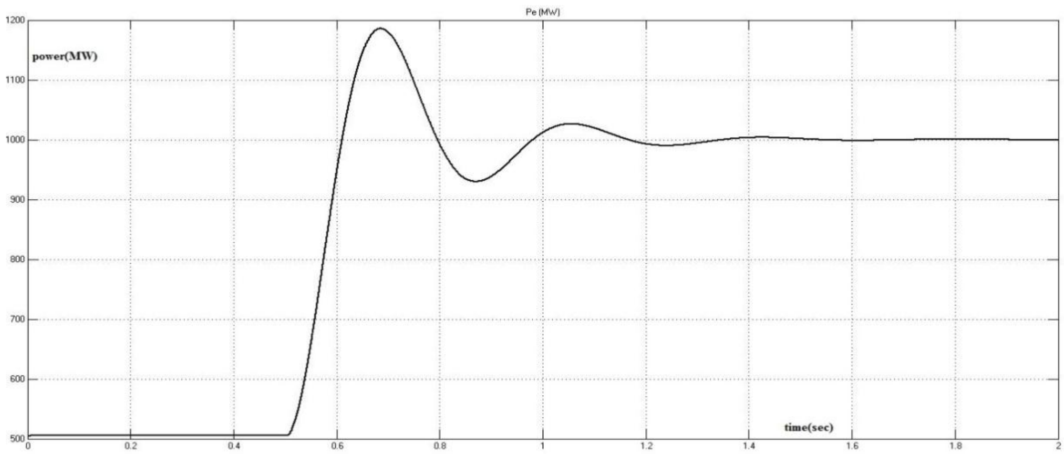

Fig.2: Maximum Power with PI Controller

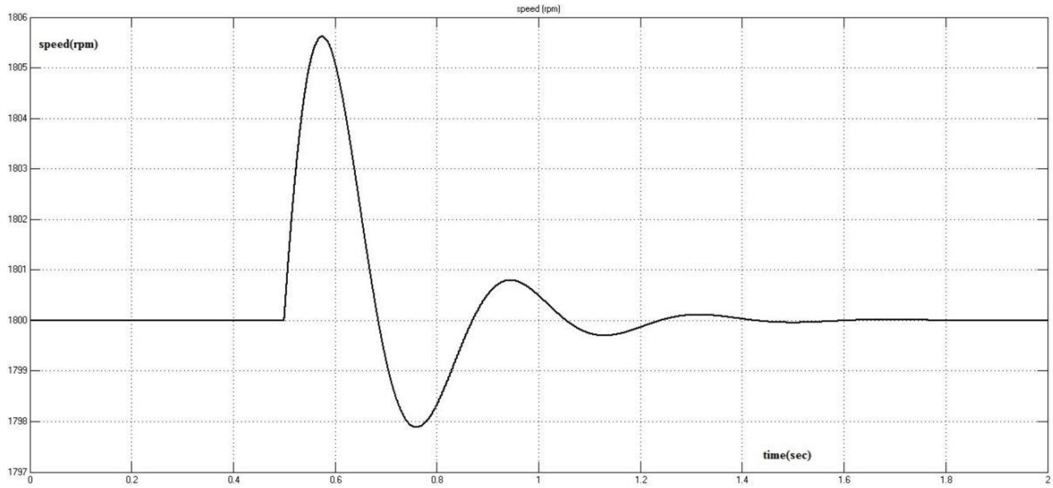

Fig.3: Maximum Speed with PI Controller

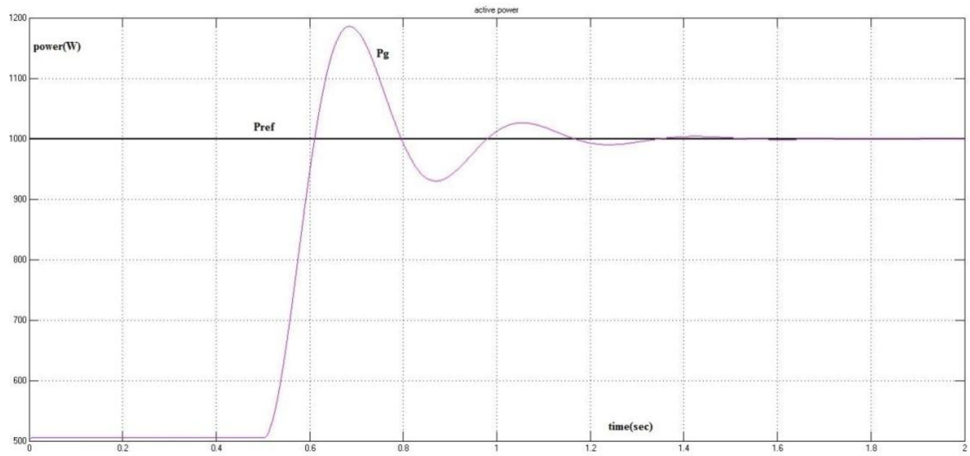

Fig.4: Active power with PI Controller

b. Results of MGP System With Fuzzy Logic PI Controller:

At the beginning of the simulation, the MGP system's reference power transfer value (Pg) is 500MW. In the initial situation, the power reference value (Pref) is 1000 MW, as illustrated in figure 8 above. As seen in figures 5 and 6 above, the simulation's findings demonstrate that power transmission is carried out steadily in accordance with the specified power reference value. The inverter modifies the output voltage phase in response to changes in the MGP system's reference value by using the grid voltage as a guide. The power angle (delta) in the simulation results fluctuates according to the MGP system's power reference value, indicating that the phase angle difference method is used to regulate the power transmission. As seen in fig. 7 above, the controller sets the speed to 1500 rpm.

According to the results of the simulations, fuzzy logic controllers perform better than convectional PI controllers. While fuzzy controllers are based on rules, convectional PI controllers have one equation. Implementing fuzzy controllers is simple, but fine-tuning them—that is, determining what membership functions to use, how to configure their parameters, etc.—can be challenging. When properly built, fuzzy logic controllers can function similarly to a collection of linear PID controllers or even as a nonlinear controller, depending on the inputs or stimuli. Any control system with a strong non-linear plant, where even a slight alteration in the manipulated value might alter the plant's characteristics or even its dynamics, can benefit from fuzzy controllers.

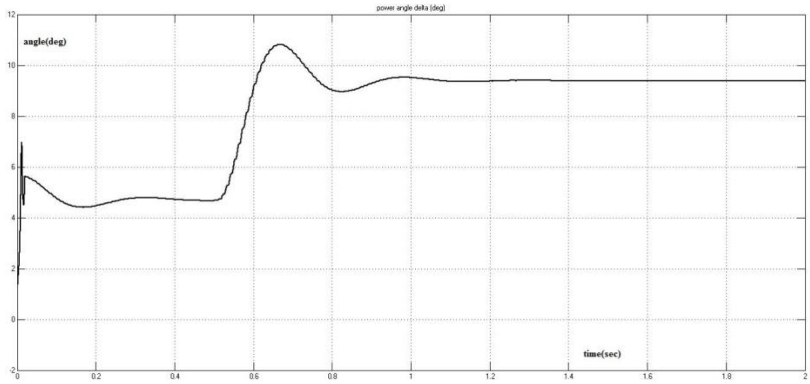

Fig.5: Maximum Power angle with FGPI Controller

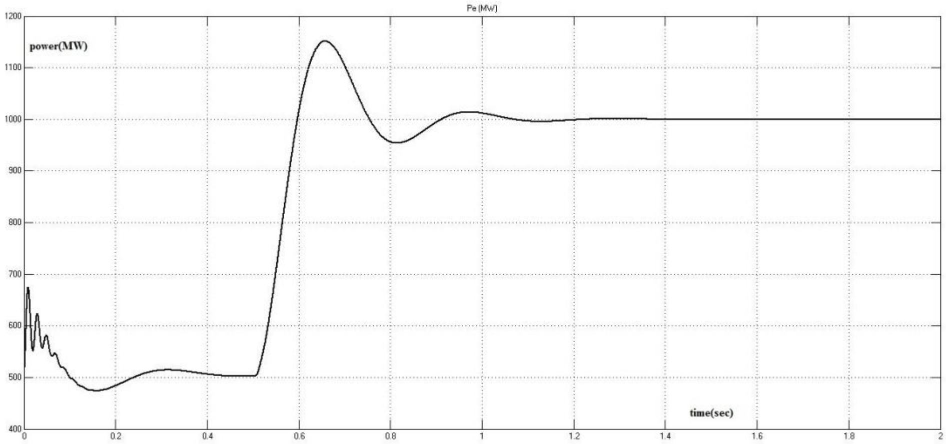

Fig.6: Maximum Power with FGPI Controller

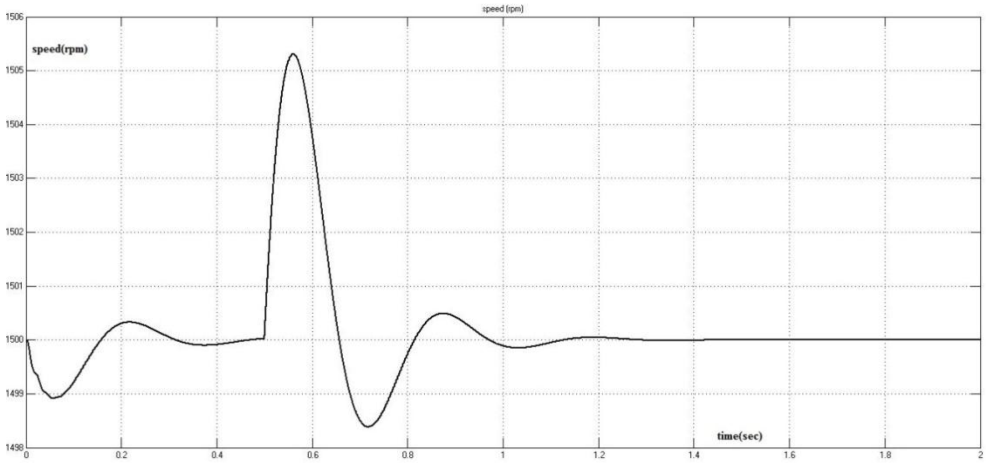

Fig.7: Maximum Speed with FGPI Controller

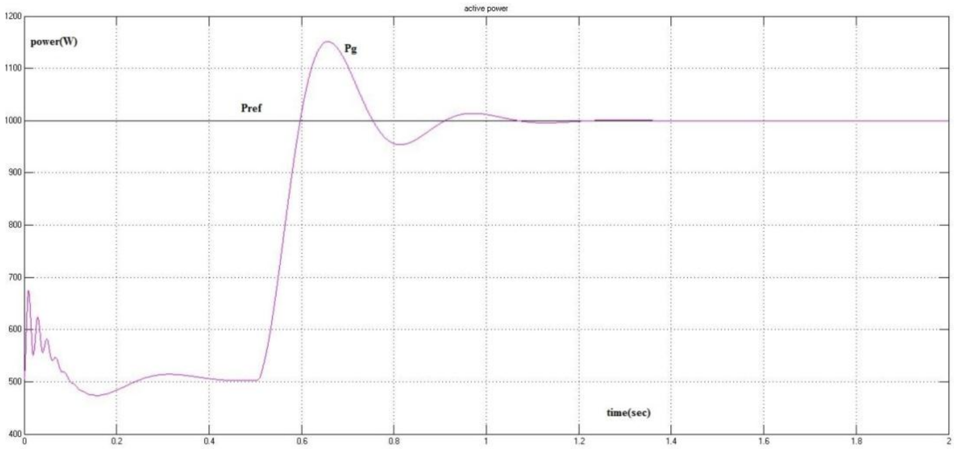

Fig.8: Maximum Speed with FGPI Controller

Based on expert knowledge, fuzzy logic is the foundation of fuzzy logic controllers, which translate linguistic control strategy values into automatic control strategies. In contrast to fuzzy logic controllers, convectional PI controllers generate responses with short rise and delay times. Because of its oscillating behavior during the transient phase, convectional PI provides a longer settling time than fuzzy logic controllers. As the accompanying table illustrates, the fuzzy logic controller reduces oscillatory behavior.

IV. Conclusion

This paper compares the fuzzy logic PI controller with the convectional PI controller. The simulation findings also confirm the variation of the load in one location and many areas. Both fuzzy logic controllers and convectional PI do not alter the parameter values. According to the results of the simulations, fuzzy logic controllers perform better than convectional PI controllers While fuzzy controllers are based on rules, convectional PI controllers have one equation. Implementing fuzzy controllers is simple, but fine-tuning them—that is, determining what membership functions to use, how to configure their parameters, etc.—can be challenging. When properly built, fuzzy logic controllers can function similarly to a collection of linear PID controllers or even as a nonlinear controller, depending on the inputs or stimuli. Any control system with a strong non-linear plant, where even a slight alteration in the manipulated value might alter the plant's characteristics or even its dynamics, can benefit from fuzzy controllers.

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