



# Direct Adaptive Fuzzy PI Strategy for a Smooth MPPT of Variable Speed Wind Turbines

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**Abstract.** For this generation, life is too complex without sufficient energy. Due to the increase demand of energy from time to time, several researchers are too eager on renewable energy sources to have good enough, clean and greenhouse effect free energy. Thanks to its cost effectiveness, wind power is the primary focus of professionals on energy area and it is the fastest rising energy source. Adaptive fuzzy proportional integral (AFPI) is proposed here to keep a maximum power of a wind turbine (WT). From various methods of maximum power point tracking (MPPT), tip speed ratio (TSR) is selected here. TSR has the ability to retrieve the optimum desired speed of the generator for every wind speed value. For a WTs, a 1.5 MW permanent magnet synchronous generator (PMSG) is chosen because of its self-excitation property that enables high power factor and efficiency operation. The system efficiency is verified by MATLAB software. After all, the final result with proposed strategy display better performance than the outcome with conventional controller.

**Keywords:** Wind turbine · Permanent magnet synchronous generator · MPPT · Direct adaptive fuzzy proportional integral

## 1 Introduction

In order to produce electrical power, the desire to use renewable energy as a sustainable and readily accessible alternative to fossil fuels is growing dramatically [1]. Increasing energy requirements and the adverse environmental impact of fossil fuels made renewables a very important option, preferable and market competent. Because the world has immense wind energy resources, it is easy to understand wind energy is the world's growing technology with respect to power generation. As per experts, taking around 10–15% of the available wind could supply the world's entire electricity needs [2, 3]. The WTs speed has been set fixed for the past few years. However, the optimum performance of fixed speed turbines is too difficult to achieve the final goal. While it is simple to determine the optimum torque, it is difficult to monitor and achieve instantaneous tracking because of the inertia of the mechanical system, as the wind velocity changes

rapidly. If the established TSR is adopted, this condition becomes too bad when the wind speed is below rated value while the acceleration or deceleration torque is very low. As a consequence, the energy produced is actually slightly less than the full energy available [1, 4, 8, 9]. Therefore, here, a variable speed WT with TSR based MPPT is proposed to solve the above problem.

In this paper, an adaptive fuzzy PI controller is proposed to get maximum energy as well as in order to achieve both economic and technological efficiency. For a wind speed below the rated value, TSR method works to obtain the optimum desired speed of the generator while a pitch angle controller is activated with a speed of a wind greater than the rated value [5–7, 10]. As a WT generator, PMSG is chosen to be beneficial in which its self-excitation as well as high efficiency and power factor activity [1, 3].

Low performance nature is the main weakness of WECS. MPPT algorithm should therefore be used in the partial load field. In [8], proportional derivative (PD) controller dependent maximum power tracking is studied. However, there have been some shortcomings. The way of finding parameters P, I, and D (mostly trial and error) offers an incentive for improperly calibrated control gains, decreasing the precision and dynamic efficiency of the entire system [1]. MPPT via fuzzy is proposed in [4] and [11]. The good side of this works is that they used a fuzzy strategy that can easily eliminate the need for accurate system model. But since one of the controllers fills the void between each other, a blend of the two, that is fuzzy with traditional controller, is better than each alone. In [1], for a maximum power extraction, a phase lag compensator controller is presented. However, for the first min times, the system has highly oscillatory responses and the science is not yet well established.

## 2 System Modelling

### 2.1 Wind Turbine Modelling

Conditions like speed of wind, density of air, blade diameter, altitude and such should be considered strictly to have efficient wind power.

With a speed of a wind,  $V_w$  the kinetic energy,  $KE$ , is given as

$$KE = \frac{1}{2}mV_w^2 \quad (1)$$

$$K_E = \frac{1}{2}\rho\pi R^2dV_w^2 \quad (2)$$

Where  $K_E$  is kinetic energy,  $m$  is mass of wind,  $v$  is speed of wind,  $A$  is the rotor area,  $R$  is the blade length, and  $d$  is the thickness of the air disk. Finally the overall mechanical power  $P_w$ , of wind can be expressed as follows

$$P_w = \frac{\text{Energy}}{\text{Time}} = \frac{K_E}{t}$$

$$P_w = \frac{1}{2} \rho \pi R^2 \left( \frac{d}{t} \right) V_w^2 = \frac{1}{2} \pi R^2 V_w^3 \quad (3)$$

This means that the energy gained from the actual speed of wind is varied with a cube degree [3]. As per Betz law, it is impossible to extract all the available power from wind. So the maximum possible mechanical power that can be gained is given in [12].

$$P_m = \frac{1}{2} \rho C_p(\lambda, \beta) \pi R^2 V_w^3 \quad (4)$$

Where  $p_m$ , is the mechanical power,  $\rho$  is density of air ( $\text{kg/m}^3$ ),  $R$  is radius of the blade in meter,  $V_w$  is speed of wind in meter per second,  $C_p$  is the power coefficient.

In [13], the power coefficient,  $C_p$  is given as

$$C_p(\lambda, \beta) = 0.5176 \left( \frac{116}{i} - 0.4\beta - 5 \right) e^{-\frac{21}{i}} + 0.0068 \quad (5)$$

Where:

$$\frac{1}{\lambda i} = \frac{1}{(\lambda \lambda + 0.08\beta)} - \frac{0.035}{\beta^3 + 1} \text{ and } \lambda = \frac{\omega_m * R}{V_w}$$

## 2.2 PMSG Model

For a WT's application PMSG is very powerful and suitable [1]. Now a day's, due to its benefits such as high energy density, easy control technique, high reliability, low maintenance costs, and its self-excitation nature, PMSG is competent and preferable over DFIG. In this paper, 1.5 MW rated power, 23.5 rpm rated speed, and 26 number of pole pair of PMSG is used. But it is too costly to manufacture permanent magnets and this is the main drawbacks of synchronous permanent magnet generators [14]. In d-q axis the proposed generator is modelled as follows [3]. Diode rectifiers and a multichannel boost converters are the power electronic converters used in this paper.

$$V_d = R_s i_d - \omega_e L_q i_q + \frac{d}{dt} L_d i_d \quad (6)$$

$$V_q = R_s I_q + \omega_e L_d i_d + \omega_e \lambda_r + \frac{d}{dt} L_q i_q \quad (7)$$

### 3 Proposed Adaptive Fuzzy PI Controller

Both MPPT and pitch angle of a WT has different control methods. Modern control techniques based on artificial intelligence have now been established. The proposed controller, AFPI is one of these modern controllers. In this work, both MPPT and pitch angles are controlled via adaptive fuzzy PI (AFPI) and offers attractive features such as quick response and excellent smooth power [16].

#### 3.1 Tip Speed Ratio (TSR) Based MPPT Control

In order to preserve the tip speed ratio to the optimum value at which maximum power can be gained, the tip speed ratio (TSR) control method controls the generator's rotational speed. In addition to the knowledge of the optimum tip speed ratio of a WT, this approach needs the wind speed to be calculated to extract all possible power [15]. As stated previously, this work proposes an adaptive fuzzy proportional integral strategy for a TSR control. As a fuzzy logic input, both change in error and error of the speed of the generator from its TSR calculated desired speed are given. The fuzzy logic output directly tunes  $K_p$  and  $K_i$  constants of the proportional integral controller. Which in turn the  $K_p$  and  $K_i$  constants are taken as an inductance current reference,  $i_{L*}$  of the boost converter. The reference,  $i_{L*}$  is then compared with the actual current of the inductor in boost converter. The difference of the currents above feeds to the discrete proportional integral and eventually the discrete conventional controller produces a duty cycle for a PWM which in turn the PWM helps to switch the boost converter IGBT.

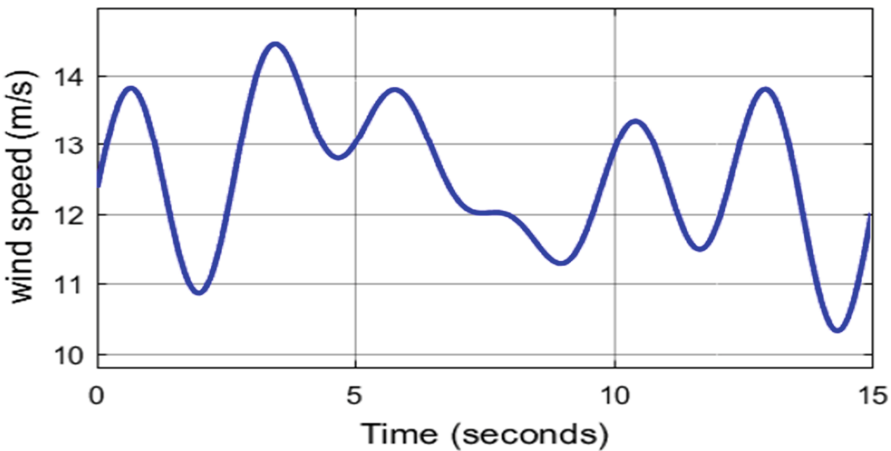


Fig. 1. Wind speed profile

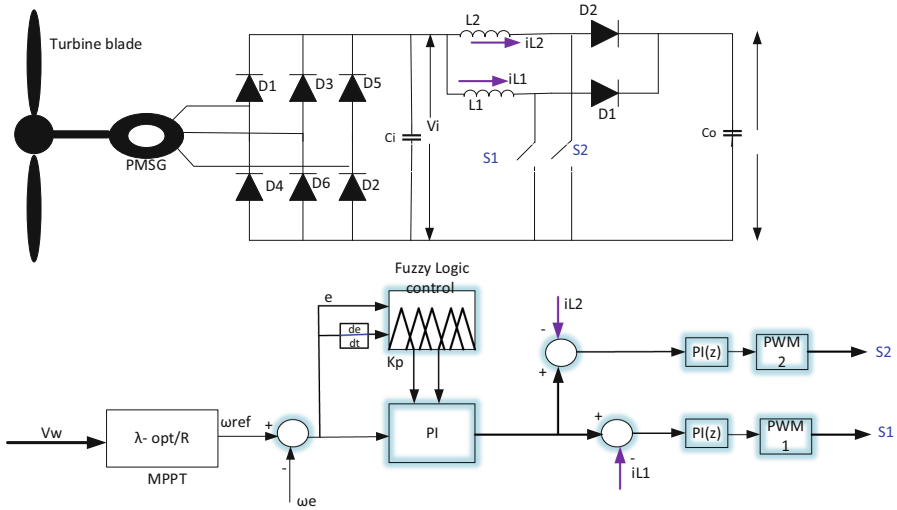


Fig. 2. Block diagram of TSR based MPPT control of an interleaved boost converter.

### 4 Results and Discussions

The system proposed here is a 1.5 MW large scale WT. To show the effectiveness of the proposed system the software tool taken here is MATLAB. With an input of speed of wind in Fig. 1, the outcomes of the speed of generator in both adaptive fuzzy PI and proportional integral alone has a result of shown in Fig. 3. The desire generator speed is calculated through the TSR energy maximization method. For this particular paper, the optimum TSR is selected as  $\lambda_{opt} = 6$ . It is seen from Fig. 3 the reaction with proposed controller has a quick and smooth result than traditional one. Besides to this, the outcome of the proposed one well tracks the speed of the generator as compared to the conventional results. In Fig. 4 the power coefficient  $c_p$  response of the conventional controller is highly oscillatory and the outcome of the proposed controller is more stable and smooth compared to the  $c_p$  reaction of conventional PI controller. We may infer from this that the proposed systems solution is better since the ultimate objective is to obtain maximum smooth electrical power. As it is seen in Fig. 5, one can understand easily the result with proposed system has a fast and an average of maximum power is gained relative to the conventional proportional integral controller. As stated in Eq. 4, the power coefficient variation mainly affects the mechanical power. The variation of the mechanical power is in proportion with the change in power coefficient as expected. In addition to that, it is easy to notice the proposed and PI controller based mechanical power outputs are below the rated value, 1.5 MW.

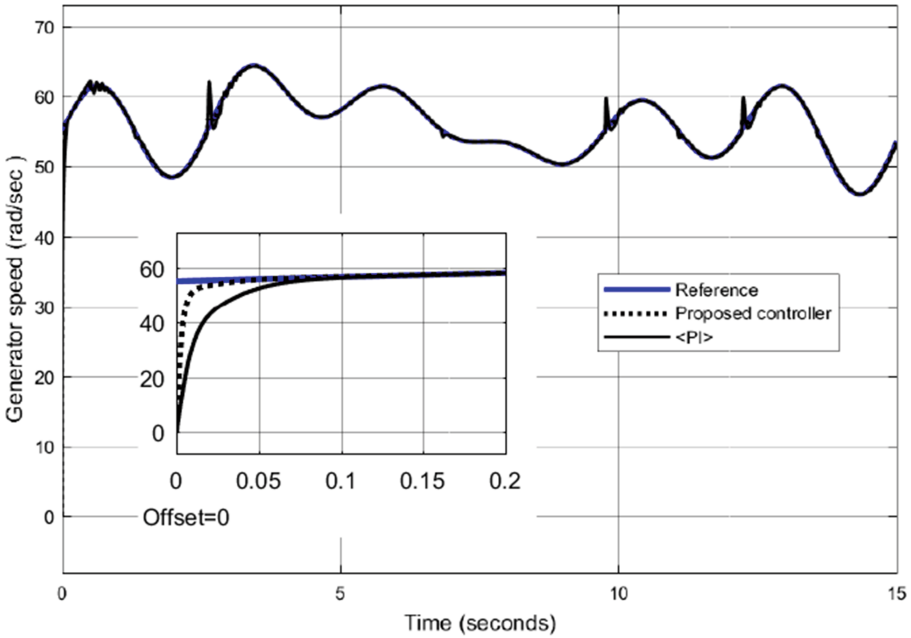


Fig. 3. Generator Speed

However, in the proposed method, an average of maximum smooth power is gained in relative to traditional proportional integral controllers. As the wind speed changes at each instant the output voltage of a WT generator changes in proportion. That is, when a wind speed gets high for a certain instant, the output voltage of the three phase generator also gets high simultaneously. For example, for a time instant 3 to 4 s in Fig. 1, the speed of a wind gets high. With this time interval, the generator output voltage increases directly in proportion. The diode rectifier proposed for this paper gets its input from a PMSG. The uncontrolled diode rectifier then rectifies the output voltage of the generator as such like in Fig. 7. Then, the result of the rectifier is magnified via DC/DC booster circuit after passing through DC link capacitor. To sum up, the proposed interleaved boost converter boosts the rectified voltage and gives an acceptable outcome as shown in Fig. 8.

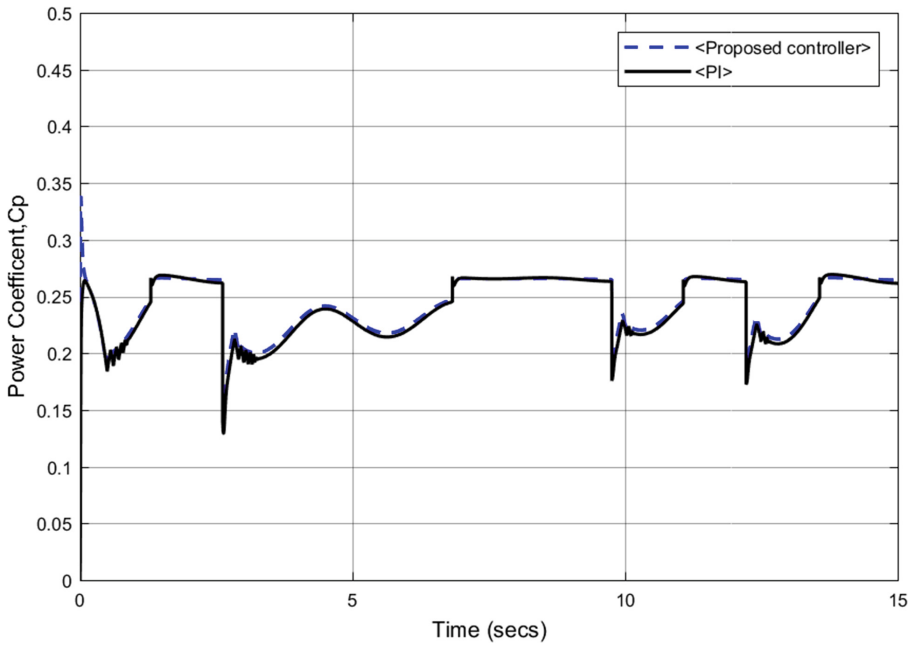


Fig. 4. Power coefficient,  $C_p$

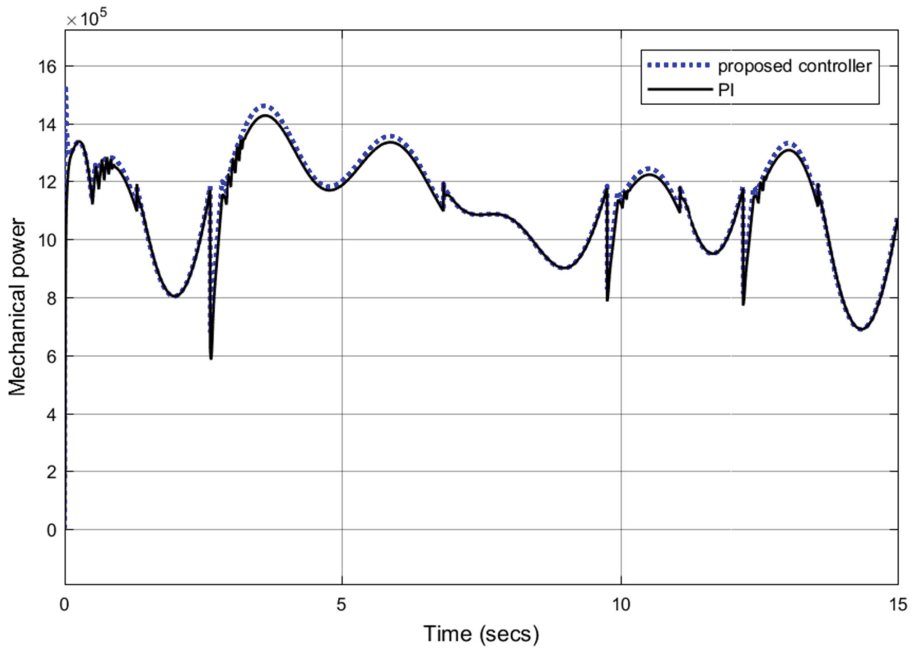
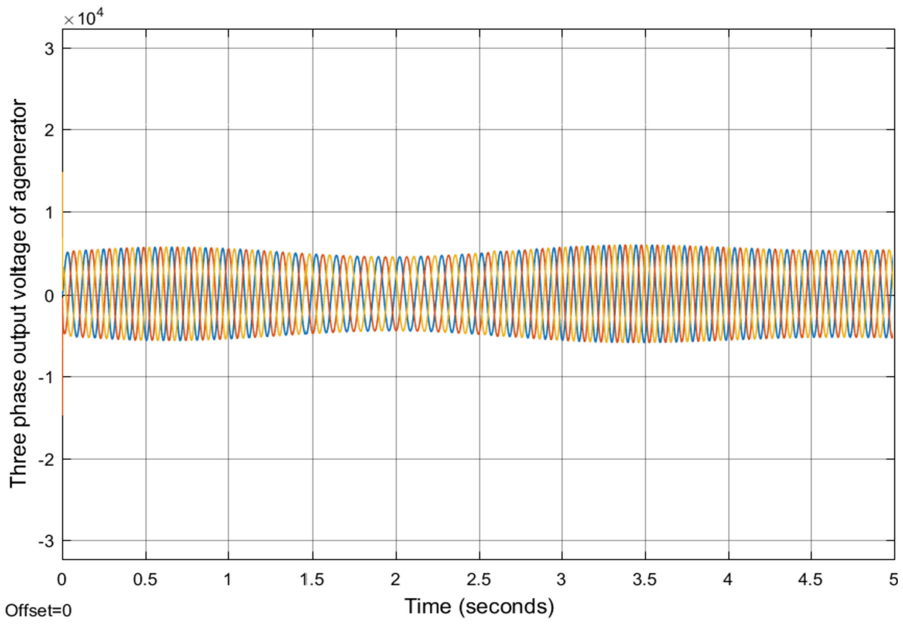
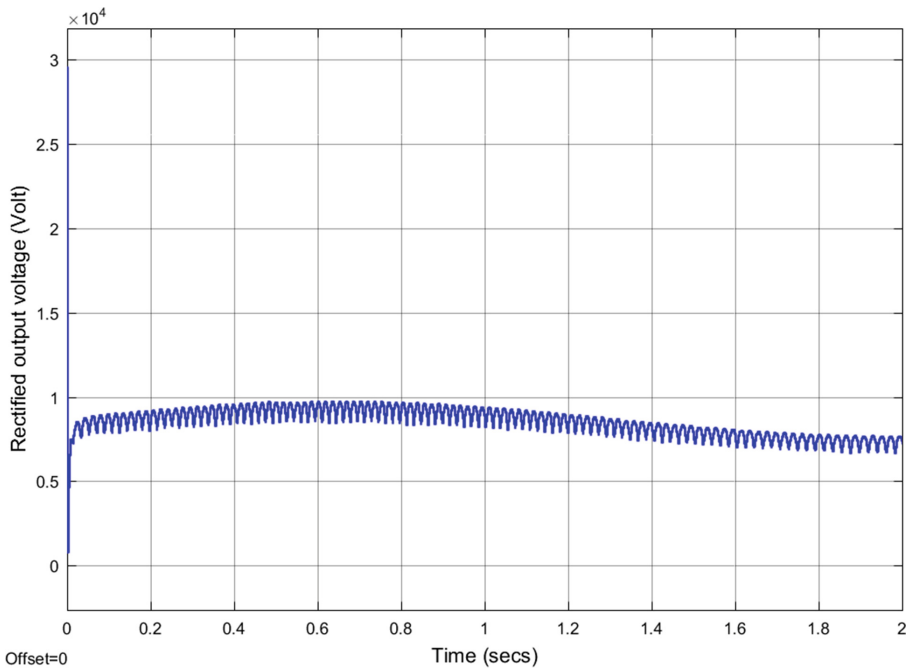


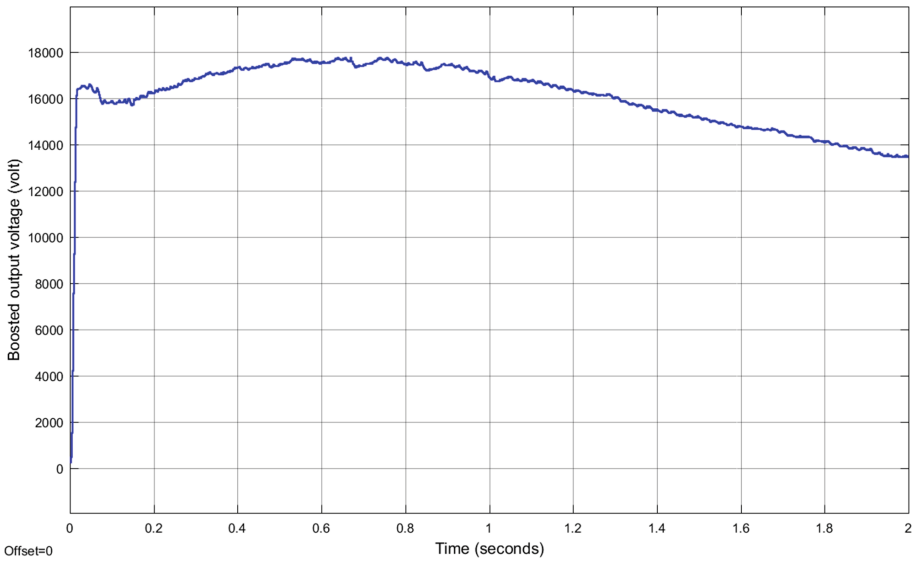
Fig. 5. Mechanical power,  $P_m$



**Fig. 6.** PMSG output voltage



**Fig. 7.** Rectifier output.



**Fig. 8.** Boost converter output.

## 5 Conclusion

For a WECS proposed here a MATLAB software tool has been taken out to check the performance of the proposed controller and evaluate the efficiency of the overall system. In this work, a design of adaptive fuzzy proportional integral controller for a maximum power extraction strategy has been applied. By using the proposed strategy, where the proportional  $K_p$ , and integral  $K_i$ , gains are find out automatically through fuzzy logic concepts, the outcome of the system shows that the proposed design can have the ability to control the TSR based generator speed tracking effectively. The outcome of proposed system and the result with PI controller alone are compared and the effectiveness of the proposed one is shown. Finally, it is possible to infer from the study that adaptive fuzzy PI strategy provides a reasonably fast, smooth and less oscillatory outcome for the given input. By Keeping the rotor as well as generator from injury the proposed strategy provides attractive feature with respect to the goal of the paper compared to the traditional one, which again implies the efficacy of the proposed method. To sum up, the strategy used in this paper gives the expected outcomes and shows better result over PI controller alone.

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