DUAL AXIS SOLAR TRACKER METHOD USING INTERNAL MODEL CONTROL BASED PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER

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Abstract - Dual axis solar tracker is an electromagnetic device used for tracking the sun's apparent position in both horizontal and vertical axis. However, it suffers from external disturbances like wind, sun intensity and direction which limit its stability. Conventional Proportional Integral Derivative (PID) controller previously used in turning methods such as Ziegler-Nichols (ZN), Chien-Hones-Reswick (CHR) and Tyreus-Luyben(TL) was characterized with inadequate poor tuning of its control parameters. In this work, the dual axis solar tracker method using internal model control based proportional integral derivative controller was carried out. The dual-axis solar tracker comprises DC motor coupled with solar panel was developed using Permanent Magnet Direct Current (PMDC) motor equation. Internal Model Control-based PID controller (IMC-PID) was used to control the developed model. The developed IMC-PID-based system was simulated in Matrix Laboratory 2013aversion. The performance of the simulated IMC-PID-based solar tracker was evaluated in Reference Tracking Mode (RTM), Input Disturbance Rejection Mode (IDRM), Output Disturbance Rejection Mode (ODRM) and Controller Effort Mode (CEM) using rise time, settling time and overshoot as performance metrics. The performance of the IMC-PID based system was compared with Chien-Hones-Reswick (CHR-PID), Ziegler-Nichols (ZN-PID) and Tyreus-Luyben (TL-PID) tuning methods. The simulation results of IMC-PID based dual axis solar tracker gave the rise time of 1.2s, 0.5s, 1.8s and 1.8s for CEM, IDRM, ODRM and RTM respectively. The settling time of 4.7s, 7.2s, 1.7s and 5.5s for CEM, IDRM, ODRM and RTM respectively were obtained. While the poorest settling times obtained were 26.9s, 12.4s, 10.1s and 10.1s for ZN-PID at CEM, CHR-PID at IDRM, TL-PID at ODRM and TL-PID at RTM. Also, poorest rise time results obtained were 15.9s, 10.3s, 9.3s and 7.0s for ZN-PID at ODRM, TL-PID at CEM, TL-PID at RTM and ZN-PID at IDRM. The overshoot simulation results reflected that IMC tuning method gave the best overshoot of 1% at IDRM and ODRM respectively, while other tuning methods gave higher results at different modes. The developed IMC-PID based dual axis solar tracker gave the best performance in terms of rise time, settling time and percentage overshoot over ZN-PID and TL-PID tuning Methods therefore, the developed IMC-PID based dual axis solar tracker in solar powered Electricity generating companies can be used to improve the quantity of energy harnessed from the sun.

Keywords - Axis, Controller, Tracker, Solar.

I. INTRODUCTION

Solar radiations are absorbed most efficiently when they strikes the photovoltaic cells at a perpendicular angle. For this reason it is important to position the solar panel in a way it would collect maximum energy (Rohit,Gurmohan and Marjit 2013). Currently majority of solar panels are permanently fixed towards a direction in the sky and do not turn to follow the sun's path. Solar tracking is required in order to increase the surface area being illuminated on the solar panel. (Huang, Zhang, Wu and Yu, 2007). Solar tracking system is an electromechanical device that turns the solar devices to face the sun as it moves across the sky. Tracking the sunaccurately effectively increases the incident solar radiation collected by the solar panel. (Rohitet al, 2013). To extract maximum power in solar systems three tracking techniques can be employed namely active tracking (fixed control algorithm) technique, passive tracking (dynamic tracking) technique and the combination of both techniques. Any of these techniques need a particular controller to control its operation (Tse, Ho, Chung and Hui, 2002). The proportional-Integral-Derivative (PID) controller has been implemented successfully in various engineering system and is the most widely used in feedback control of industrial processes.

The impact of external disturbances and nonlinearities on the dual axis tracker is a risk to the stability of the closed loop system. The solar tracker control using the conventional PID controllers have been used in the past, but the result proved inadequate. Although, a PID controller has only three adjustable parameters, finding appropriate settings for effective control performance is not simple. Therefore there is the need to use a more effective tuning control approach for the PID controller in order to overcome these difficulties. The work was aimed at developing an internal model control based proportional integral derivative controller for dual axis solar tracker. The specific objectives of this work are todevelop a model for the dual axis solar tracking system using Permanent Magnet Direct Current (PMDC) motor equation, employ IMC-PID controller to control the developed model, simulate the developed control technique using MATLAB software package, perform a comparative analysis of the developed control technique with

Ziegler Nichols, ChienHronesReswick and Tyreus-LuybenPID Controllers based on rise time, settling time and overshoot as performance matrices.

II. REVIEW OF RELATED WORKS

Abdallah and Nijmeh, (2004) designed a two axesPLC controlled solartracking system Acomparism study of single axes, dual axis and fixed solar panel power output level was also carried out. The results showed that the power output from tracked panel issignificantly greater than that on a fixed panel. The dual axes tracking panel gave better result. Specifically an increase of 41.34% when compared with fixed panel. Sarkeret al, (2010) presented the design, construction and also investigated an experimental study of a two axis (azimuth and Polar) automatic controlled solar tracker. The system is meant to track solar panel in a dual axis. The circuit employed sensor and Microcontroller with an in built analogue to digital converter operated control circuits which would drive the motor with control software. Also installed is a gear- bearing arrangements with mountingsand supports. The effect of using dual axis tracker on electrical generation of a photovoltaic system was carried out and the result compared with fixed axis. The result indicated an increase in output energy of 30% to 45% in a dual axis panel. El-mogany and Hamed, (2012) designed and implementedsun tracking generating power system in real time. The system mechanism was composed of photovoltaic module, stepper motor, sensors and expert Fuzzy Logic Controller implemented on PIC.The system can track the sun to place the solar cells at 90 degrees to the sun radiation. The solar tracking controller was implemented using Matlab/Simulink softwareand the results revealed a good response by the controller. Rahul (2013) designed a single axis solar tracker, and performed a stability analysis using convectional PID controllers to control the solar tracking systemwith the aim of increasing the speed of response with littleor no overshoot. Frequency response andtime responseanalysis were carried out using different tuning methods.The results showed that IMC controller provided the best performance in both the speed of response and stability. It overcame the limitations of conventional PID controller and feedback plus feed-forward controller. This demonstrated a high percentage improvement in the speed of response and overshoot of the developed system. Abdallah and Nijmeh, (2004) designed a two axesPLC controlled solartracking system Acomparism study of single axes, dual axis and fixed solar panel power output level was also carried out. The results showed that the power output from tracked panel issignificantly greater than that on a fixed panel. The dual axes tracking panel gave better result. Specifically an increase of 41.34% when compared with fixed panel. Sarkeret al, (2010) presented the design, construction and also investigated an experimental study of a two axis (azimuth and Polar) automatic controlled solar tracker. The system is meant to track solar panel in a dual axis. The circuit employed sensor and Microcontroller with an in built analogue to digital converter operated control circuits which would drive the motor with control software. Also installed is a gear- bearing arrangements with mountingsand supports. The effect of using dual axis tracker on electrical generation of a photovoltaic system was carried out and the result compared with fixed axis. The result indicated an increase in output energy of 30% to 45% in a dual axis panel. El-mogany and Hamed, (2012) designed and implementedsun tracking generating power system in real time. The system mechanism was composed of photovoltaic module, stepper motor, sensors and expert Fuzzy Logic Controller implemented on PIC.The system can track the sun to place the solar cells at 90 degrees to the sun radiation. The solar tracking controller was implemented using Matlab/Simulink softwareand the results revealed a good response by the controller. Rahul (2013) designed a single axis solar tracker, and performed a stability analysis using convectional PID controllers to control the solar tracking system with the aim of increasing the speed of response with littleor no overshoot. Frequency response andtime response analysis were carried out using different tuning methods.The results showed that IMC controller provided the best performance in both the speed of response and stability. It overcame the limitations of conventional PID controller and feedback plus feed-forward controller. This demonstrated a high percentage improvement in the speed of response and overshoot of the developed system.

III. METHODOLOGY

A. Conceptual framework

The solar tracker system requires movement in different directions, and uses electric motors as prime mover, based on this; solar tracker system motor control is simplified to an electric motor motion control. In the tracking operation, the LDR sensor will measure the sunlight intensity as a reference input signal. The error voltage which would be generated in the comparator is proportional to the difference between the sunlight location (reference input signal) and the PV panel location. The controller (IMC – PID) attempts to minimize the error by adjusting the process through the use of manipulated variables. If the output goes high or low, the motor drives will be activated so as to rotate the dual axis (azimuth and elevation) tracking motor and bring the PV panel to face the sun. Figure 1 is representing the solar tracking control architecture for one direction only. If this figure is representing the vertical control architecture, the horizontal control architecture is the same as this figure.

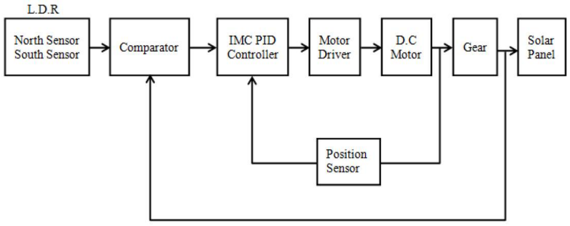

Figure 1 Simplified block diagram of a dual axis solar tracker

B. Modeling the Solar Tracker

Mathematical modeling of the Solar Tracking system involves modeling the DC motor with load coupled by gear. The load in this regard is the solar panel.The mathematical model of the system was derived from the true behavior of the system for various inputs.The schematic diagram of a DC motor with external load (solar panel) coupled to the motor spindle through a gear train is shown in Figure 2 The magnetic flux φ between the stator and the rotor is given by the linear relation.

$$\varphi = k_f I_f \qquad 1$$

Where k_f is a constant and I_f is the stator current. The torque T_m developed by the motor is given by the relation:

$$T_m = k_m i_a \varphi \qquad 2$$

where k_m is the armature coil constant and i_m is a constant armature current.

Substituting (1) into (2), the torque now has the form

$$T_m = k_a i_a \qquad 3$$

where.

$$k_a = k_f k_m I_f$$

The Kirchhoff's law of voltages for the rotor network is

$$v_a = L_a \frac{di_a}{dt} + R_a i_a + v_b \qquad 4$$

The voltage v_b is proportional to the motor speed, i.e.

$$v_b = k_b \frac{d\theta_m}{dt} = k_b \omega_m \qquad 5$$

where k_b is the back emf constant, θ_m is the angular position or displacement, and ω_m is the angular velocity of the motor. Applying the Laplace transform to (4) with zero initial conditions, the armature current is

$$I_a = \frac{V_a - V_b}{L_a s + R_a} = \frac{V_a - k_b s\theta_m}{L_a s + R_a} \qquad 6$$

Since, the shaft torque T_m is used for driving load against the inertial and frictional torque, therefore,

$$T_m = J_m \frac{d^2\theta_m}{dt^2} + B_m \frac{d\theta_m}{dt} = k_a i_a$$

where J_m is the torque inertial and B_m is the coefficient of friction. Applying Laplace transform to equation (7) would yield 8

$$I_a = \frac{J_m s^2 \theta_m + B_m s\theta_m}{k_a}$$

Substitute for I_a in equation (3.8), we obtain:

$$K_a V_a - K_a K_b S\theta_m = (L_a S + R_a)(J_m S + B_m) S\theta_m \qquad 9$$

$$V_a = \frac{(L_a S + R_a)(J_m S + B_m) S\theta_m + K_a K_b S\theta_m}{K_a} \qquad 10$$

$$\frac{\theta_m}{V_a} = \frac{K_a}{[(L_a S + R_a)(J_m S + B_m) + K_a K_b] S} \qquad 11$$

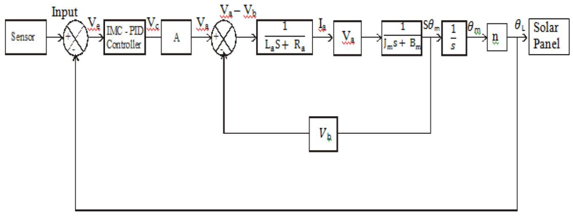

Figure 2: Equivalent block diagram of the DC motor with external load (solar panel) coupled by gear

C. IMC-PID Controller

To develop an IMC-PID controller for the solar tracker we employ the transfer function of the PID controller, transfer function of the process and the IMC function.

The ideal PID transfer function is expressed as

$$C(s) = K_P \left(1 + \frac{1}{\tau_I s} + \tau_D s \right) \qquad 12$$

Where K_P = proportional gain

τ_I = integral time

τ_D = Derivative Time

From figure 3 showing the equivalent block diagram of internal model controller the following equations are deduced.

$$C(s) = \frac{G_c(s)}{1 - G_p(s) G_p(s)} \qquad 13$$

$$G_c(s) = \frac{C(s)}{1 + G_p(s) G_p(s)} \qquad 14$$

The IMC controller is designed thus

$$G_c(s) = \tilde{G}_p^{-1}(s) F(s) \qquad 15$$

where

$$F(s) = \frac{1}{\lambda s + 1} \qquad 16$$

And

$$G_P S = \frac{k_a n}{[(L_a s + R_a)(J_O s + B_O) + k_a k_b] s} \qquad 17$$

Equation 13 can be rewritten as equation 18

$$C(s) = K_P \left(1 + \frac{1}{\tau_I s} + \tau_D s \right), \qquad 18$$

Substitute equations 15 and 17 into equation 13and according to equation 18, IMC-PID tuning parameters were given as in equation 13.

In equation 13 the values $K_p, K_I\ and K_D$ were then generated from mathematical manipulations Therefore,

$$K_p = \frac{R_a J_0 + L_a B_0}{K_a \lambda} \qquad 19$$

$$K_I = \frac{R_a B_0 + K_a K_b}{K_a \lambda} \qquad 20$$

$$K_D = \frac{L_a J_0}{K_a \lambda} \qquad 21$$

The specific values from the model parameters are substituted in equations 19, 20 and 21 for calculating $K_p, K_I, and\ K_D$ respectively and the values are used as the controller parameter forthe MATLAB simulink model.

IV. COMPARISON OF RESULT OF IMC-PID WITH CHIEN HRONES RESWICK ,ZIEGLER NICHOLS AND TYRUS LUYBEN TUNING METHODS.

The controller setting for CHR is based on dead time (d), apparent time constant (τ_m) and gain (K_m) respectively.A step response experiment was performed on the system model and the values for d, τ_m, and K_m were arrived at to calculate the parameters for CHR as indicated in table 1.The controller setting for bothZN and TL are based on the variables ultimate gain (k_u) and period (p_u). Afrequency response test was performed on the system model and the values k_u and p_u were found and used to calculate the parameters for ZN and TL as indicated in table 1.

METHOD	CONTROLLER	K_c	τ_I	τ_D
IMC	PID	2.431	0.863	0.2155
CHR	PID	125.80	0.3244	0.06812
ZN	PID	1.4211	6.36	0.08
TL	PID	10.9818	3.4375	1.0158

Table 1: summary parameter values for various tuning methods

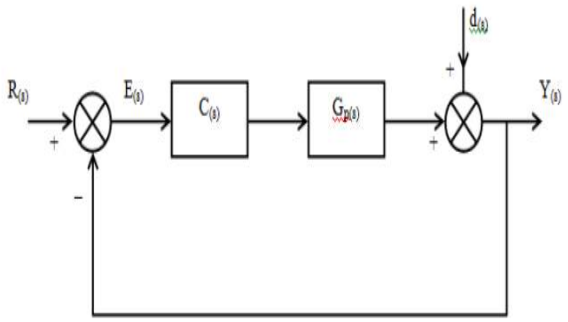

Figure 3 Equivalent Block Diagram of IMC

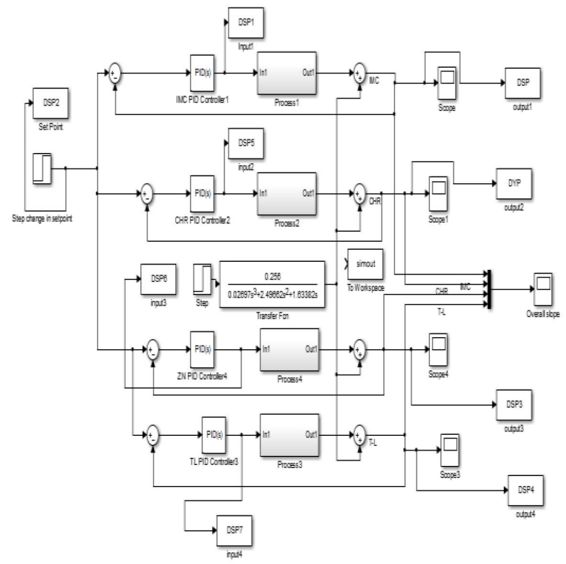

Figure 4: simulink model for response of PID controller comparing IMC tuning with CHR, ZN and TL.

RESULTS AND DISCUSSION

The simulation result in figure 5 shows the step response of IMC tuned PID controller for set point change. The IMC tuned PID controller showed a very fast response by crossing the steady statelevel after 1.65 seconds with an initial well damped oscillating effect complete stability was achieved at around 5 seconds.

The simulation result in figure 6 shows the step response of CHR tuned PID controller for set point change. The CHR tuned PID controller produced a slow response and crossed the steady state level at 7 seconds. The system was unstable until after 17 seconds when it became stable. The simulation result in figure 7 shows the step response of ZN tuned PID controller for set point change. The ZN tuned PID controller gave a very slow response and crossed the steady state level at 8 seconds. Stability was attained around 19 seconds. The simulation result in figure 8 shows the step response of TL tuned PID controller for set point change. TL tuned controller showed a fast response with a damped oscillating effect, it crossed the steady state level at 3 seconds. The response also gave a high overshoot and stability was only attained after 20 seconds. Figure 9 shows the simulation result of the step response of PID controller for set point change using IMC, CHR, ZN and TL turning methods. Considering the four response on the same axis IMC tuned PID controller gave the fastest response and attained stability earlier than the other three controllers. IMC is closely followed by TL in terms of response. CHR gave a slow response and ZN gave a slower response. In terms of stability IMC tuned PID attained a stable sate at the earliest time of 5 seconds; this is followed by 17 seconds, 19 seconds and 20 seconds for CHR, ZN and TL respectively.

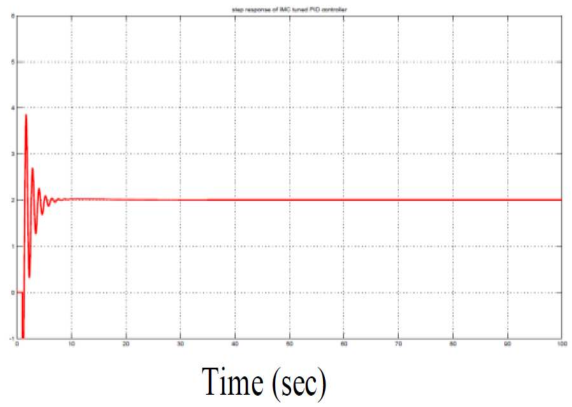

Figure 4.1: step response of IMC tuned PID controller

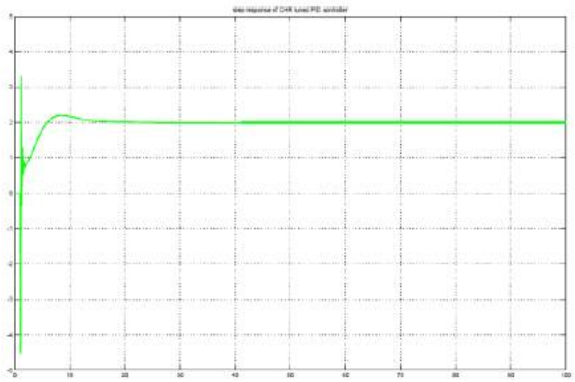

Figure 6: step response of CHR tuned PID controller

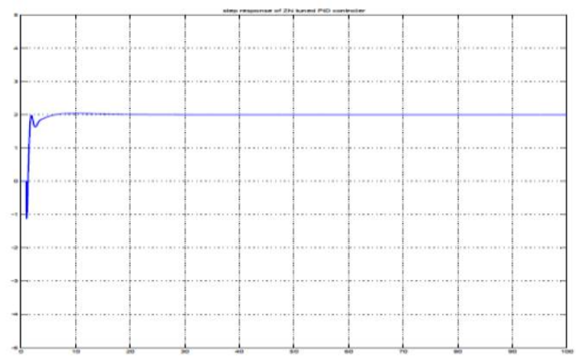

Figure 7: step response of ZN tuned PID controller

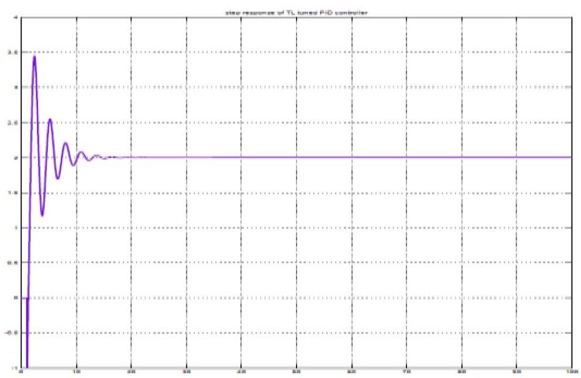

Figure 8: step response of TL tuned PID controller

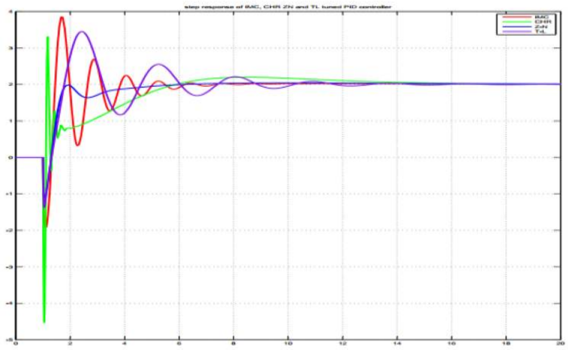

Figure 9: step response of IMC, CHR ZN and TL tuned PID controller

Figure 10 shows the simulation result for the system rise time and settling time in a reference tracking mode for IMC, CHR, ZN and TL controllers. The fastest rise time was 1.8 seconds for the IMC tuned controller; this was followed by 4.0 seconds, 6.4 seconds and 9.3 seconds for CHR, ZN and TL controllers respectively. For settling time IMC tuned PID equally gave the fastest settling time at 5.5 seconds followed by 5.6 seconds, 6.9 seconds and 10.1 seconds for CHR, ZN and TL controllers respectively. Figure 11 shows the simulation results for the system rise time and settling time at input disturbance rejection mode for IMC, CHR, ZN and TL controller tuning methods. IMC – PID gave the fastest rise time at 0.5 seconds other values are 5 seconds, 7 seconds and 4 seconds for CHR, ZN and TL respectively. For settling time IMC-PID was the fastest at 7.2 seconds, other values are 11 seconds for ZN in second place, 11.4 seconds for TL and CHR comes last at 12.4 seconds.

Figure 12 shows the simulation result for rise time and settling time at output disturbance rejection mode for IMC, CHR, ZN and TL controller tuning methods. The result reveals that IMC-PID was having the fastest rise time at 1.8 seconds and ZN presented the lowest at 15.9 seconds while CHR and TL presented 12.6 seconds and 10.3 seconds respectively.

Figure 13 shows simulation result for rise time and settling time in controller effort mode for IMC, CHR, ZN and TL tuning methods. The result for rise time are IMC 1.2 seconds, CHR 6.0 seconds, ZN 8.4 seconds and TL 10.3 seconds in ascending order. The result also shows that IMC have the fastest rise time of the four. For settling time, the results are 4.7 seconds, 15.6 seconds, 26.9 seconds and 10.1 seconds for IMC, CHR, ZN and TL tuning methods respectively. Of the four controller modes, IMC PID gave the fastest rise time and settling time at 0.5 seconds and 1.7 seconds respectively. The effect of this is a very fast response of the controller, less overshoot and attainment of stability early enough. Figure 14 shows the simulation result of controller overshoot in reference tracking, input disturbance rejection, output disturbance rejection and controller effort modes for IMC, CHR, ZN and TL tuning methods. It would be seen from the result that IMC-PID gave the lowest overshoot at 1% for input disturbance rejection mode. We also have 5.8% and 7.8% for reference tracking and controller effort modes respectively. It would be seen that IMC-PID controller was able to achieve the least overshoot under the two disturbance rejection modes. This feat does not repeat itself under other controller methods used. Highest and lowest percentage overshoot results recorded are for CHR-PID controller highest is 63.4% (reference tracking mode) lowest is 13.4% (controller effort). For ZN highest percentage overshoot is 90% (output disturbance rejection) lowest is 10% (controller effort mode). TL–PID, highest percentage overshoot is 69.7% (reference tracking mode) and lowest percentage overshoot is 19.7% (controller effort mode) it was observed that for the other three controllers CHR, ZN and TL all presented their lowest percentage overshoot at controller effort modes, whereas IMC–PID controller presented its highest overshoot at controller effort mode.

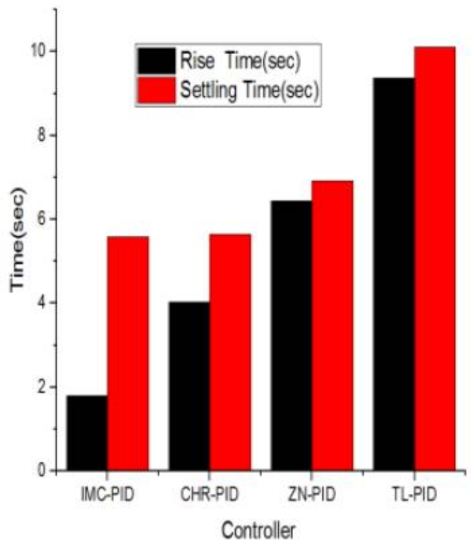

Figure 10: simulation result for the rise time and settling time for reference tracking mode

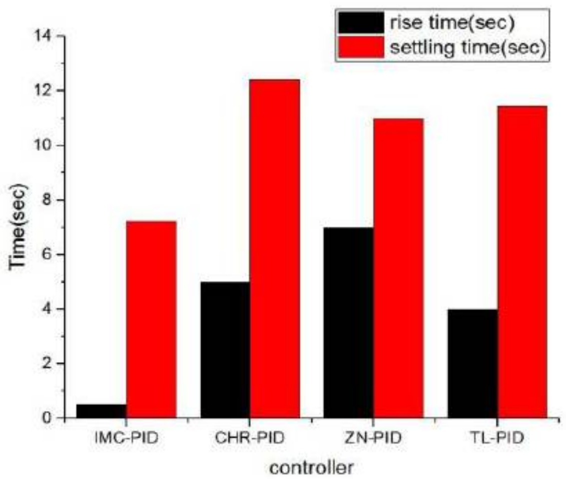

Figure 11: simulation result for the Rise Time and Settling Time for input disturbance rejection mode

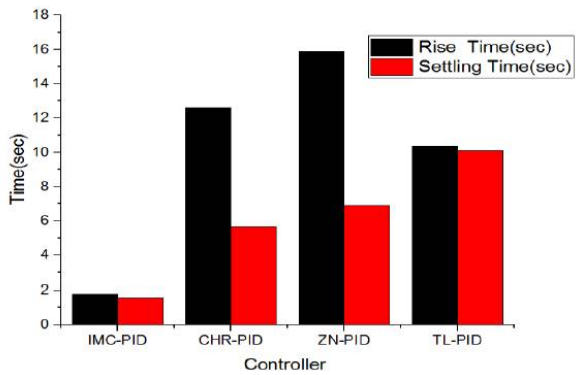

Figure 12: Simulation result for the Rise Time and Settling Time at output disturbance rejection mode

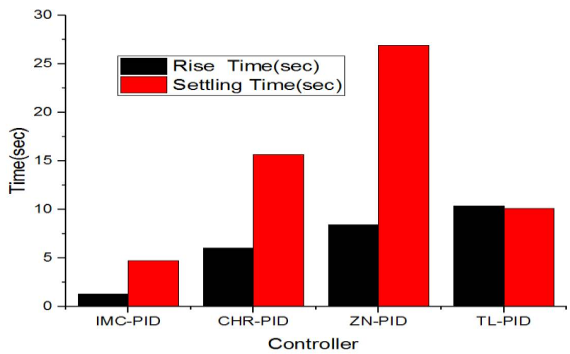

Figure 13: Simulation result for the Rise Time and Settling Time in controller Effort Mode

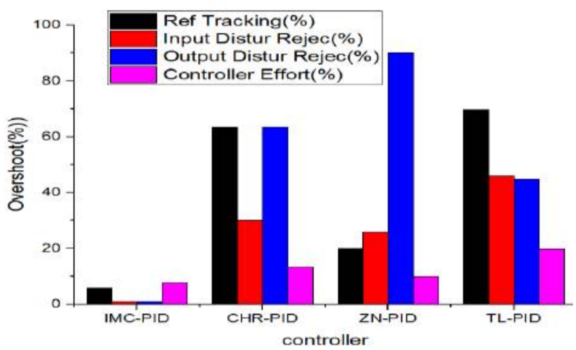

Figure 14: Simulation Result of Overshoot in Reference Tracking, Input Disturbance, Output Disturbance Rejection and Controller Effort modes

CONCLUSION

The results showed that IMC tuned PID controller step response crossed the steady state level earlier than the other tuning methods at 1.65 secondsand it also attained the level of stability earlier at 5 seconds. IMC–PID controller also presented the lowest overshoot among the controllers. It is hereby affirmed that IMC tuned PID for a dual axis solar tracker gave the best response, stability and lowest overshoot.

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