Monitoring of Hydrogen Fuel Cell Modeling with Boost Converter

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Abstract. Energy plays a very important role in human life. Every year, the demand for energy needs continues to increase and the majority of energy generation uses fossil fuels. So we need an energy source that is environmentally friendly. One of the environmentally friendly energy sources is a fuel cell. Fuel cells can produce electrical energy at a lower cost than the electrical energy generated by conventional power grids. In making a fuel cell system, a modeling is needed so that the fuel cell system can work properly and in accordance with the desired specifications. One method for modeling a fuel cell system is to use MATLAB. The use of a DC-DC boost converter with a properly designed closed loop PID controller has a very important role in regulating the PWM of the DC-DC boost converter switch and plays a very important role in controlling power regulation. In this research, a modeling analysis of NEXATM 1.2 kW hydrogen fuel cell with a DC-DC boost converter controlled by a PID controller was carried out for a compact Power Conditioning Unit (PCU) design. The purpose of this research is to model and analyze the characteristics of the performance of the hydrogen fuel cell system and the performance of the PID controller in regulating the DC-DC boost converter output voltage on the hydrogen fuel cell. The results showed that the performance of the hydrogen fuel cell was influenced by the pressure of oxygen gas, hydrogen, and temperature. The greater the value of oxygen gas pressure, hydrogen gas pressure, and temperature on the fuel cell, the greater the voltage and current output of the fuel cell. The simulation results show the fuel cell output voltage is 47.89 V with an error percentage of 4.22\%, and the fuel cell output current is 23.94 A with an error percentage of 0.25\%, and the fuel cell output power is 1147 W with an error percentage of 4.12\%. The performance of the PID controller with the DC-DC boost converter in regulating the fuel cell output voltage is very good. This is indicated by the results of the response curve for the fuel cell output current, namely the value of rise time (tr) of 4 seconds, delay time (td) of 0.2 seconds, peak time (tp) of 4 seconds, settling time (ts) of 4 seconds, and a maximum overshoot (Mp) of 0\%. For output voltage, the value of rise time (tr) is 4 seconds, delay time (td) is 0.2 seconds, peak time (tp) is 4 seconds, settling time (ts) is 4 seconds, and maximum overshoot (Mp) is 0\% with the parameter value Proportional (P) of 0.001, Integral (I) of 10, and Derivative (D) of 0.
1. Introduction

Energy plays a very important role in human life. For example for industrial processes, lighting, and many other equipment that require energy to work. Most of the energy production comes from fossil energy sources in the form of oil and natural gas. Based on data from the International Energy Agency (IEA), in 2018 world energy production was 14,421 Mtoe [1]. Much of this is driven by generation from fossil fuels of 370 Mtoe. Energy production from renewable and nuclear energy has also increased, by 60 Mtoe and 19 Mtoe, respectively. Fossil fuels ultimately accounted for more than 81% of energy production in 2018 [1].

Conventional use of energy resources is increasingly limited due to inefficient and untidy operations. The private and utility sectors are currently concentrating on renewable energy technologies with increasing benefits due to cleanliness, modularity and reliability [2]. Among various renewable energies such as wind power, solar photovoltaic, micro turbines, and fuel cell, distributed generation based on fuel cell is considered as one of the most promising technologies due to its high operating efficiency of 40% - 60%, reliability, and potential capabilities. higher [3][4]. A fuel cell is an electrochemical device that generates electricity using hydrogen gas and oxygen gas as fuel. Of all types of fuel cells, PEMFC (Proton Exchange Membrane Fuel Cell) has become an attractive choice due to its high efficiency, low operating temperature in the $40^\circ C$ to $100^\circ C$ range, zero emissions, high power density and long life. long stack [5].

In recent research, modeling has become one of the main steps to develop a fuel cell [6]. Electro-chemical fuel cell modeling is used to simulate and test the entire system as closely as possible to the effective fuel cell working conditions [6]. Fuel cell modeling is basically done using three approaches, namely analytical, empirical or semi-empirical [6]. The analytic approach will help achieve the required mathematical model more accurately than using the empirical approach. MATLAB is a better platform for the implementation of mathematical models and faster processing [6].

The fuel cell operates at a low voltage so the output voltage must be increased. One of the electronic devices that can increase the voltage is the DC-DC boost converter. The DC- DC boost converter design and its controller play a very important role in controlling power regulation, especially for the DC bus in general. DC-DC boost converter offers higher efficiency and fewer components compared to other DC-DC converter topologies [2].

The purpose of the DC-DC boost converter design is to regulate the output voltage which will remain within a certain range when a disturbance occurs [7]. To achieve this goal, a negative feedback control loop is inserted to automatically adjust the PWM duty cycle to have a constant output voltage. PID controllers have been widely used to compensate for errors caused by the difference between the reference voltage (set point voltage) and the feedback voltage in power converter designs due to their simplicity and effectiveness [7].

Based on this background, the authors are interested in researching hydrogen fuel
cell modeling studies with a DC-DC boost converter controlled by a PID controller. The purpose of this research is to model and analyze the characteristics of the hydrogen fuel cell system performance and the PID controller performance in regulating the DC-DC boost converter output voltage on the hydrogen fuel cell.

2. Basic Theory

2.1. Proton Exchange Membrane Fuel Cell (PEMFC)

PEMFC is an electrochemical device that can generate electrical energy by converting the chemical energy of hydrogen and oxygen with the help of an electro-catalyst [8]. Here is the chemical equation of a fuel cell [9]:

Anode :

\[ 2H_2 \rightarrow 4H^+ + 4e^- \]  

\[ O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \]  

\[ 2H_2 + O_2 \rightarrow 2H_2O + \text{Panas} \]  

2.2. PEMFC Electrochemical Equations

The output voltage of one PEMFC cell is defined in equation 4 [10].

\[ V_{FC} = E_{Nernst} + V_{act}V_{Ohmic} + V_{Con} \]  

In the above equation, \( E_{Nernst} \) is the thermodynamic voltage of the fuel cell and represents the reversible voltage, also known as the open-circuit voltage. \( V_{act} \) is the voltage drop caused by activation of the anode and cathode (also known as over-activation voltage). The \( V_{act} \) also shows the voltage drop value associated with the electrodes. \( V_{Ohmic} \) is the drop in ohmic voltage (also known as ohmic excess voltage). \( V_{Ohmic} \) also shows the drop in ohmic voltage that results from the conduction resistance of protons through solid electrolytes and electrons. \( V_{Con} \) is the voltage drop caused by the displacement of reactant gases.

2.3. Nernst’s Equations for PEMFC Reversible Voltage

The reversible voltage of the fuel cell (\( E_{Nernst} \)) is the voltage generated from one fuel cell when it is open circuit. The following is the \( E_{Nernst} \) equation to calculate the reversible voltage of a fuel cell [11].

\[ E_{Nernst} = 1.229 - \left[ 0.85 \times 10^{-3} (T - 298.15) \right] + \left[ 4.3085 \times 10^{-5} T \ln(P_{H2}) + 0.5P_{O2} \right] \]  

Where : \( T \) = fuel cell temperature (°K), \( P \) (H2) = partial pressure of hydrogen gas (atm), \( P \) (O2) = partial pressure of oxygen gas (atm). The effectiveness of the partial pressure on each surface needs to be calculated. The calculation is to find the
partial pressure on other sectors. The following is an equation for calculating the partial pressure at each electrode of the fuel cell [8].

\[ P_{H2O} = 10^{-X} \]  

\[ X = -2.1974 + 0.02953.T_{ref} - 9.1837 \times 10^{-5}.T_{ref}^2 + 1.4454 \times 10^{-7}T_{ref}^3 \]  

\[ P_{O2} = \frac{P_{Udara}}{4.192 \times 10^{-14} + 0.00286 + (0.0002 \times \ln A) + (4.5 \times 10^{-5}) \times \ln C_{H2}} \]  

\[ P_{H2} = \frac{e^{0.5 \times P_{Udara}}}{e(1.653 \times 10^{-10} \times T_{303})} \]  

Where :  
- \( P_{H2O} \) = Partial pressure of water (atm),  
- \( P_{O2} \) = Partial pressure of oxygen gas (atm),  
- \( P_{H2} \) = Partial pressure of hydrogen gas (atm),  
- \( P_{Udara} \) = Partial pressure of air (atm),  
- \( T_{ref} \) = Reference temperature (298 °K),  
- \( T \) = Temperature of fuel cell (°K).  

### 2.4. PEMFC Activation Drop Voltage

The equation for the activation voltage drop is represented in equation 2.11. The activation voltage drop equation is also referred to as the Tafel Equation [12].

\[ V_{ACT} = -[\xi_1 + \xi_2 \times T + \xi_3 \times T \ln(C_{O2}) + \xi_4 \times T \ln(I_{FC})] \]  

\[ \xi_2 = 0.00286 + (0.0002 \times \ln A) + (4.5 \times 10^{-5}) \times \ln C_{H2} \]  

Where :  
- \( V_{ACT} \) = Activation Drop Voltage (V),  
- \( \xi_1, \xi_2, \xi_3, \xi_4 \) = Empirical parameters,  
- \( T \) = Fuel cell temperature (°K),  
- \( I_{FC} \) = Fuel cell current,  
- \( C_{O2} \) = Concentration of oxygen gas.

The oxygen gas concentration is determined in equation [12].

\[ C_{O2} = \frac{P_{O2}}{5.08 \times 10^6(e^{-4.49})} \]  

Where :  
- \( C_{O2} \) = Concentration of oxygen gas (mol/cm3),  
- \( P_{O2} \) = Partial pressure of oxygen gas (atm),  
- \( T \) = Fuel cell temperature (°K).  

### 2.5. Ohmic Voltage PEMFC

Ohmic voltage is the voltage that is lost due to resistance when the protons move. The following is the ohmic voltage equation [12].

\[ V_{Ohmic} = I_{FC} \times (R_M + R_C) \]  

\[ R_M = \frac{P_M^{X\lambda}}{A} \]  

\[ P_M \times 181.6[1 + (0.03 \times \frac{I_{FC}}{A}) + 0.062 \times (\frac{T_{303}}{2.3}) \times (\frac{I_{FC}}{A})^{2.5}] \times \left[ \psi - 0.634 - 3 \times (\frac{I_{FC}}{A}) \times e^{[4.18 \times (\frac{T_{303}}{2.3})]} \right] \]  

Where :  
- \( V_{Ohmic} \) = Ohmic voltage (V),  
- \( I_{FC} \) = Fuel cell current (A),  
- \( R_M \) = Membrane resistance (Ω),  
- \( R_C \) = Constant resistance (Ω),  
- \( P_M \) = Membrane resistivity to electron exchange (Ω),  
- \( \lambda \) = Membrane thickness (cm),  
- \( A \) = Area of each cell (cm²),  
- \( T \) = Fuel cell temperature (°K),  
- \( \psi \) = Water content of the membrane.
2.6. Voltage Drop of PEMFC Concentration

The concentration drop stress occurs because of a change in the amount of concentration. The formula for the concentration drop stress is shown in equation 16 [12].

\[ V_{con} = -Bx\ln(1 - \frac{J}{J_{max}}) \]  \hspace{1cm} (16)

Where: \( V_{con} \) = Voltage drop concentration (V), \( B \) = constant (V), \( J \) = actual current density of fuel cell (A/cm\(^2\)), \( J_{max} \) = maximum current density of fuel cell (A/cm\(^2\)).

2.7. DC-DC Boost Converter

DC-DC boost converter is a DC-DC converter that produces an output voltage that is greater than the source voltage. The DC-DC boost converter is also referred to as a step-up converter. The following is a circuit form of a DC-DC boost converter [12].

\[ D = 1 - \frac{V_{in}}{V_{out}} \]  \hspace{1cm} (17)

Where: \( D \) = Duty ratio, \( V_{in} \) = Input voltage (V).

\[ R_{load} = \frac{V_{in}}{I_{out}} \]  \hspace{1cm} (18)

Where: \( R_{load} \) = Load resistance (Ω), \( V_{out} \) = Output voltage (V), \( I_{out} \) = Output current (A).

\[ C = \frac{D}{R_{load}x f_s x \Delta V_{out}} \]  \hspace{1cm} (19)

Where: \( C \) = Capacitance (F), \( \Delta V_{out} \) = Ripple voltage (5% of \( V_{out} \))(%), \( R_{load} \) = Load resistance (Ω), \( f_s \) = Switching frequency (Hz), \( D \) = Duty ratio.

\[ L = \frac{R_{load}x D x (1 - D)^2}{2x f_s} \]  \hspace{1cm} (20)

Where: \( L \) = Inductance (H), \( V_{in} \) = Input voltage (V), \( R_{load} \) = Load resistance (Ω), \( f_s \) = Switching frequency (Hz), \( D \) = Duty ratio.
2.8. PID Controller

One of the simplest and most widely used controller types is the PID controller [11].

The PID controller can be expressed as follows [14]:

\[ u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \] (21)

Where: \( K_P \) = Proportional gain, \( K_I \) = Integral gain, \( K_D \) = Derivative gain, \( e(\tau) = SP - PV(t) \) is error, \( SP \) = Set point, \( PV(t) \) = Process variable, \( t \) = Time, \( \tau \) = Integration variable (current value \( t = 0 \) to current \( t \) present).

2.9. Transient Response

The shape of the transient response is depicted in Figure 3.

Order 2 control system is the most widely used approach with a specification of the quality of the transient response as follows [15]:

1. Rise Time (\( tr \)) is a measure of time measured when the response starts from \( t = 0 \) until the response crosses the first steady state axis.
2. Settling Time (\( ts \)) is a measure of time which states the response has entered by 2% or 5% or 0.5% of the steady state response.
3. Delay Time (\( td \)) is a time measure which states the delay factor in the output response to the input response measured when \( t = 0 \) until the response reaches 50% of the steady state response.
4. Overshoot (\( Mp \)) is a relative value which states the ratio of the maximum response price that exceeds the steady state price compared to the steady state value.
2.10. Percentage of Error

The percentage of error can be calculated using equation 22

\[
\%outputvoltageerror = \left| \frac{data_{model} - simulationresults}{data_{model}} \right| \times 100\% \quad (22)
\]

3. RESEARCH METHODOLOGY

![Research flow diagram.](image)

Figure 4. shows a flow chart of the research conducted. The stages taken in carrying out this research are as follows: conducting a literature study of relevant research, collecting data for research support, namely data on global hydrogen fuel cell parameters, designing and modeling a DC-connected hydrogen fuel cell system. -DC boost converter using MATLAB R2019b software, performs performance analysis of the hydrogen fuel cell system and the performance of the PID controller against the DC-DC boost converter through the MATLAB R2019b software, conducts literature studies of relevant research, collects data. To support the research, namely data on hydrogen fuel cell parameters globally, designing and modeling the hydrogen fuel cell system using the MATLAB R2019b software, analyzing the performance of the hydrogen fuel cell through the MATLAB R2019b software.

3.1. Designing a Hydrogen Fuel Cell System Simulation

Data collection is carried out by collecting data on hydrogen fuel cell system parameters with global standards from several journals and literature studies [16][17]. The hydrogen
Table 1. Hydrogen Fuel Cell System Parameters.

| Parameters | Value                  |
|------------|------------------------|
| A          | 62.05 cm\(^2\)        |
| T          | 323.15 °K              |
| B          | 0.0179                 |
| R\(_c\)    | 0.00028 Ω              |
| ξ\(_1\)    | -0.289                 |
| ξ\(_2\)    | *Equation              |
| ξ\(_3\)    | 8.210 X\(^{-5}\)      |
| ξ\(_4\)    | -1.5810 X\(^{-4}\)    |
| J\(_{max}\)| 1.537 A/cm\(^{-2}\)   |
| P\(_{O2}\)| 1 atm                  |
| P\(_{H2}\)| 1 atm                  |
| ψ          | 23.06                  |
| λ          | 131 μm                 |
| N\(_{cell}\)| 34                    |
| l          | 89 μm                  |

The fuel cell used is NexaTM 1.2 kW. By using the parameters in table 1.

Figure 5. MATLAB / Simulink Hydrogen Fuel Cell.

Figure 6. DC-DC Boost Converter System Design with PID Controller.

4. RESULTS AND DISCUSSION

The parametric effect on the voltage and current characteristics of the fuel cell will be analyzed using the different operating parameter values. The parameters to be analyzed are the effect of changes in temperature, hydrogen gas pressure, oxygen gas pressure on fuel cell current and voltage as well as the characteristics of the Enernst, Vohm, Vcon, Vfc, and Vact polarization curves. To regulate the fuel cell output voltage and improve the performance of the fuel cell system, a DC-DC boost converter with a PID controller is connected to the fuel cell. The simulation results of the fuel cell output voltage and current are compared with the fuel cell data model. The performance of the PID
Table 2. DC-DC Boost Converter Specifications.

| Parameters | Value |
|------------|-------|
| D          | 0.4   |
| R_{Load}   | 5.58 Ω |
| C          | 1200 × 10^{-6} F |
| L          | 4 × 10^{-6} H |
| V_{IN}     | 47.89 V |
| V_{OUT}    | 80 V   |
| I_{OUT}    | 14.33 A |
| P_{OUT}    | 1200 W |
| ΔV_{OUT}   | 5 %    |
| ΔI_{OUT}   | 5 %    |

controller with the DC-DC boost converter in regulating the fuel cell output voltage is shown by the output response curve analysis.

Figure 7. Polarization characteristics of a fuel cell.

Figure 8. Characteristics of temperature changes to the fuel cell voltage and current.

Figure 9. Characteristics of hydrogen gas pressure on the fuel cell voltage and current.
Figure 10. Characteristics of oxygen gas pressure to fuel cell voltage.

Figure 11. Fuel cell output voltage.

Figure 12. Fuel cell output current.

Figure 13. Fuel cell output power.

\[
\%\text{outputvoltageerror} = \left| \frac{\text{datamodel} - \text{simulationresult}}{\text{datamodel}} \right| \times 100\%
\]

\[
= \left| \frac{50 - 47.89}{50} \right| \times 100\% = 4.22\%
\]

\[
\%\text{outputvoltageerror} = \left| \frac{\text{datamodel} - \text{simulationresult}}{\text{datamodel}} \right| \times 100\%
\]

\[
= \left| \frac{24 - 23.94}{24} \right| \times 100\% = 0.25\%
\]

\[
\%\text{outputvoltageerror} = \left| \frac{\text{datamodel} - \text{simulationresult}}{\text{datamodel}} \right| \times 100\%
\]

\[
= \left| \frac{1200 - 1147}{1200} \right| \times 100\% = 4.12\%
\]
Based on the calculation results, it can be seen that the percentage error for the output voltage is 4.22%, the percentage error for the output current is 0.25%, and the percentage error for the output power is 4.12%. The highest error percentage is in the output voltage, because it is in accordance with equation 2.4, that there is a voltage loss caused by Nernst voltage ($E_{\text{Nernst}}$), ohmic voltage ($V_{\text{Ohm}}$), activation voltage ($V_{\text{Act}}$), and concentration voltage ($V_{\text{Con}}$). When electrical energy is generated from the fuel cell, the actual voltage on the fuel cell decreases relative to the theoretical voltage in the fuel cell. This is due to the losses during the reaction mechanism in the fuel cell. These losses are defined as Nernst voltage ($E_{\text{Nernst}}$), ohmic voltage ($V_{\text{Ohm}}$), activation voltage ($V_{\text{Act}}$), and concentration voltage ($V_{\text{Con}}$). The electrochemical reaction controls the rate at which energy is produced from the fuel cell and is a major cause of loss of activation voltage. Activation stress is the stress loss due to a chemical reaction to overcome the activation barrier of the catalyst to convert the products into reactants. This type of voltage loss is complex because it involves gaseous fuels, solid metal catalysts, and electrolytes. The catalyst reduces the height of the activation barrier, but stress losses persist due to the slow oxygen reaction. Transfer of charge during electrochemical reactions through the fuel cell membrane layer by conduction. Therefore, ohmic voltage loss occurs due to lack of proper reaction contact by the gas diffusion layer, bipolar plate, cooling plate, contacts, and interconnects. However, the greatest ohmic voltage loss occurs during the transport of ions through the membrane. To reduce ion losses through the membrane, the membrane needs to be made more conductive or thinner. Electrochemical reactions in the catalyst layer can cause thinning of the reactant layer which can affect the fuel cell performance through loss of concentration ($V_{\text{Con}}$). The difference between the catalyst layer reactants and the product concentration determines the rate of loss of concentration.

![Current response curve and output voltage on the DC-DC boost converter](image)

**Figure 14.** Current response curve and output voltage on the DC-DC boost converter with values of $P = 0.001$, $I = 10$, and $D = 0$.

Based on Figure 4.14, it can be seen that the response of the current and output voltage on the DC-DC boost converter is very stable at values 13.2 A and 80 V. The performance of the PID controller with the DC-DC boost converter for the output current is indicated by the value of the rise time ($t_r$) of 4 seconds, delay time ($t_d$) of 0.2 seconds, peak time ($t_p$) of 4 seconds, settling time ($t_s$) of 4 seconds, and maximum overshoot ($MP$) of 0%. Performance of the PID controller with DC-DC boost converter for output voltage, rise time ($t_r$) value of 4 seconds, delay time ($t_d$) of 0.2 seconds, peak
Table 3. Configuration of PID Controller and PID Controller Performance with DC-DC Boost Converter for Output Current.

| Konfigurasi PID Controller | Hasil Unjuk Kerja |
|----------------------------|-------------------|
|                           | P     | I    | D    | rise Time (tr) | delay Time (td) | peak Time (tp) | setling Time (ts) | max. over-shoot (Mp) | Arus Keluar (A) |
|---------------------------|-------|------|------|---------------|-----------------|----------------|-------------------|-------------------|-----------------|
| Percobaan 1               | 0     | 5    | 0    | 7s            | 0.2s            | 7s             | 7s                | 0%                | 13.2            |
| Percobaan 2               | 0.001 | 5    | 0    | 8s            | 0.2s            | 8s             | 8s                | 0%                | 13.2            |
| Percobaan 3               | 0.001 | 10   | 0    | 4s            | 0.2s            | 4s             | 4s                | 0%                | 13.2            |

Table 4. PID Controller Configuration and PID Controller Performance with DC-DC Boost Converter for Output Voltage.

| Konfigurasi PID Controller | Hasil Unjuk Kerja |
|----------------------------|-------------------|
|                           | P     | I    | D    | rise Time (tr) | delay Time (td) | peak Time (tp) | setling Time (ts) | max. over-shoot (Mp) | Tegangan Keluar (V) |
|---------------------------|-------|------|------|---------------|-----------------|----------------|-------------------|-------------------|-------------------|
| Percobaan 1               | 0     | 5    | 0    | 7s            | 0.2s            | 7s             | 7s                | 0%                | 80   |
| Percobaan 2               | 0.001 | 5    | 0    | 8s            | 0.2s            | 8s             | 8s                | 0%                | 80   |
| Percobaan 3               | 0.001 | 10   | 0    | 4s            | 0.2s            | 4s             | 4s                | 0%                | 80   |

The response time (tp) of 4 seconds, settling time (ts) of 4 seconds, and a maximum overshoot (Mp) of 0%. PID controller with DC-DC boost converter is proven to provide fast response time with a value of less than 10 seconds, stable at a value of 80 V for voltage and 13.2 A for current, and reduces the effect of overshoot on currents and voltages. Overshoot at voltage and current must be reduced, because it will result in a reduced life of the equipment connected to the DC-DC boost converter output. The parameters for the response curve in accordance with the desired criteria are the Proportional (P) value of 0.001, Integral (I) of 10, and Derivative (D) of 0.

5. CONCLUSIONS

Based on the results of the research that has been done, the following conclusions can be drawn:

1. The performance of hydrogen fuel cell is affected by oxygen gas pressure, hydrogen, and temperature. The greater the value of oxygen gas pressure, hydrogen gas pressure, and temperature on the fuel cell, the greater the voltage and current.
output of the fuel cell. The simulation results show the fuel cell output voltage is 47.89 V with an error percentage of 4.22%, and the fuel cell output current is 23.94 A with an error percentage of 0.25%, and the fuel cell output power is 1147 W with an error percentage of 4.12%.

2 The performance of the PID controller with DC-DC boost converter in regulating the fuel cell output voltage is very good. This is indicated by the results of the response to the fuel cell output current, namely the value of rise time (tr) of 4 seconds, delay time (td) of 0.2 seconds, peak time (tp) of 4 seconds, settling time (ts) of 4 seconds, and Maximum overshoot (Mp) of 0%. For output voltage, the value of rise time (tr) is 4 seconds, delay time (td) is 0.2 seconds, peak time (tp) is 4 seconds, settling time (ts) is 4 seconds, and maximum overshoot (Mp) is 0% with a Proportional (P) value parameter of 0.001, Integral (I) of 10, and Derivative (D) of 0.

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