O N E

Introduction

ANSWERS TO REVIEW QUESTIONS

1. Guided missiles, automatic gain control in radio receivers, satellite tracking antenna

2. Yes - power gain, remote control, parameter conversion; No - Expense, complexity

3. Motor, low pass filter, inertia supported between two bearings

4. Closed-loop systems compensate for disturbances by measuring the response, comparing it to the input response (the desired output), and then correcting the output response.

5. Under the condition that the feedback element is other than unity

6. Actuating signal

7. Multiple subsystems can time share the controller. Any adjustments to the controller can be implemented with simply software changes.

8. Stability, transient response, and steady-state error

9. Steady-state, transient

10. It follows a growing transient response until the steady-state response is no longer visible. The system will either destroy itself, reach an equilibrium state because of saturation in driving amplifiers, or hit limit stops.

11. Natural response

12. Determine the transient response performance of the system.

13. Determine system parameters to meet the transient response specifications for the system.

14. True

15. Transfer function, state-space, differential equations

16. <u>Transfer function</u> - the Laplace transform of the differential equation

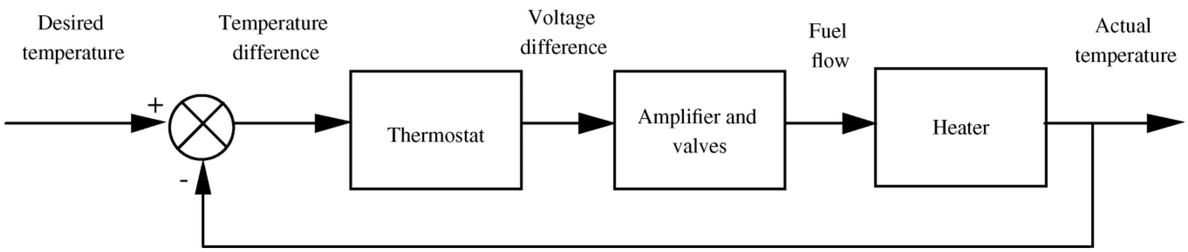
<u>State-space</u> - representation of an nth order differential equation as n simultaneous first-order differential equations

<u>Differential equation</u> - Modeling a system with its differential equation

SOLUTIONS TO PROBLEMS

1. Five turns yields 50 v. Therefore K = $\dfrac{50 \text{ volts}}{5 \text{ x } 2\pi \text{ rad}}$ = 1.59

2.



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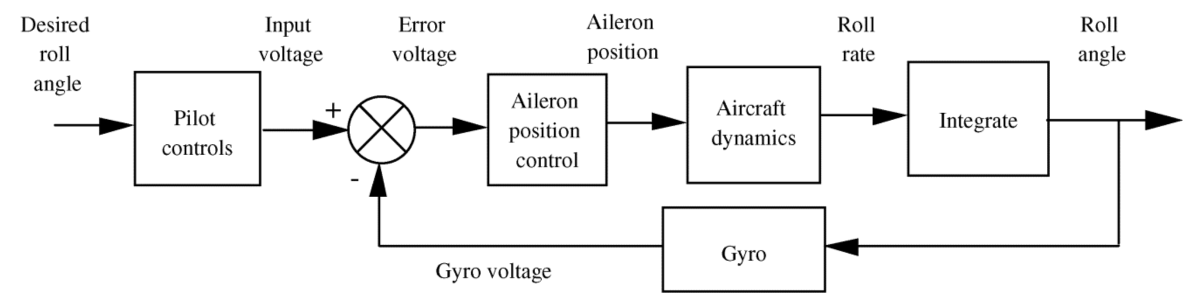

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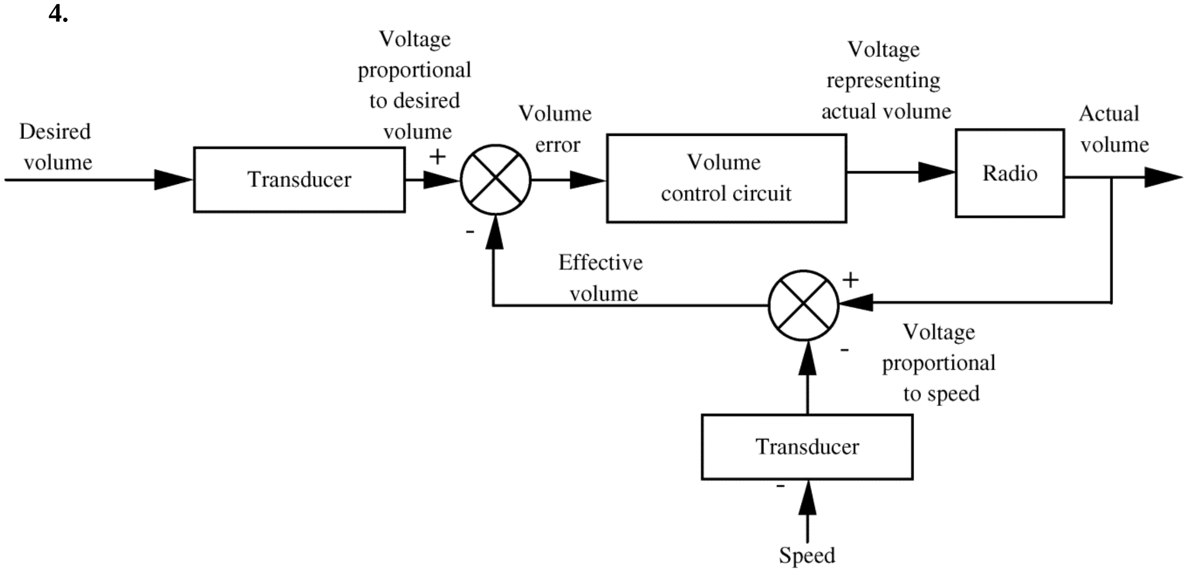

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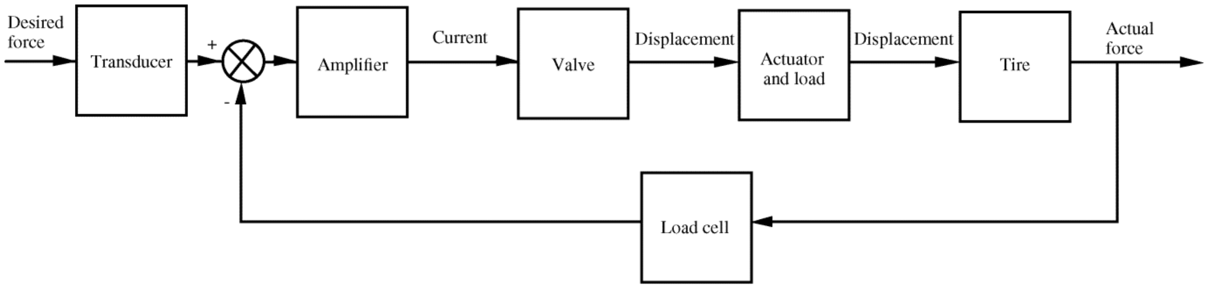
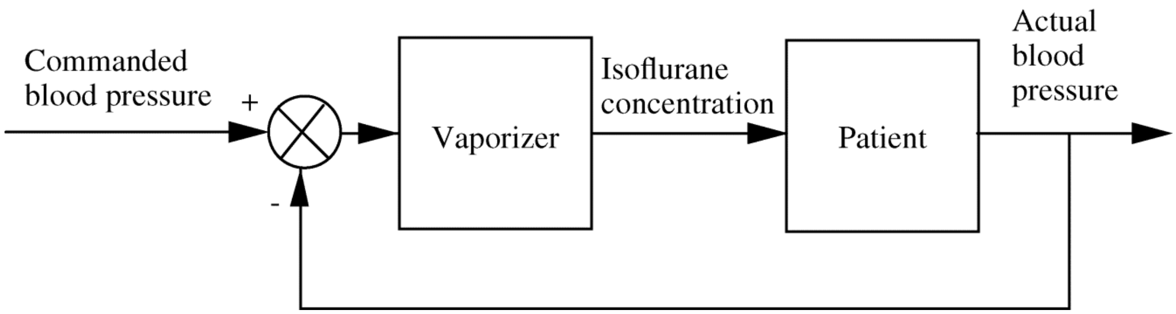
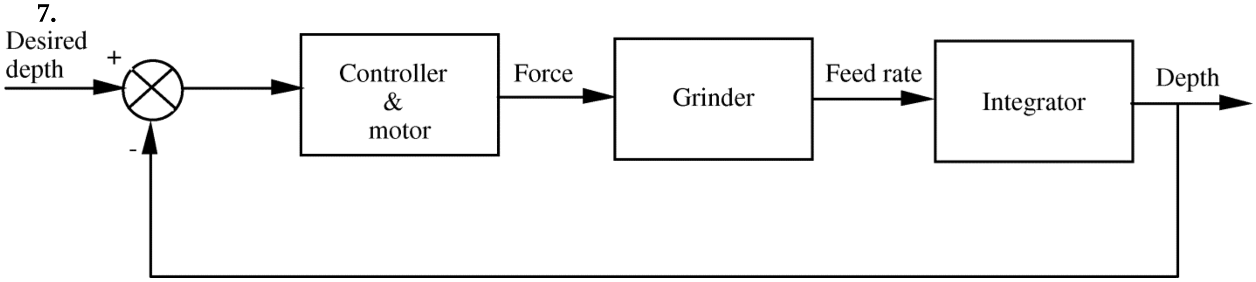

Desired force
Transducer
+
-
Amplifier
Current
Valve
Displacement
Actuator and load
Displacement
Tire
Actual force
Load cell

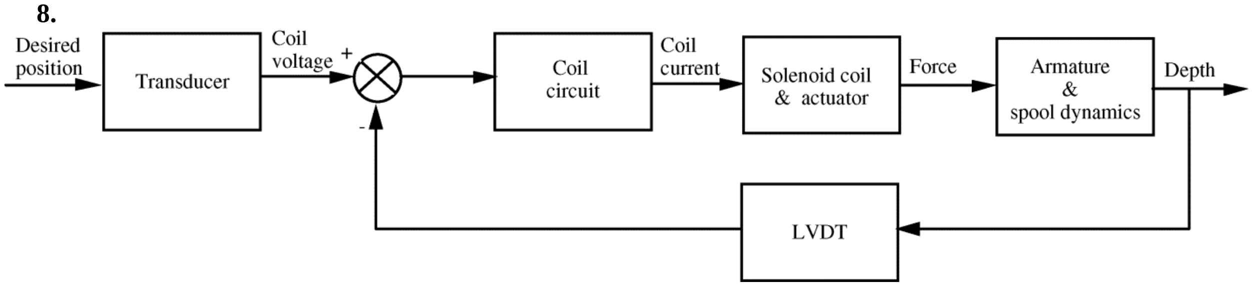
6.


Commanded blood pressure
+
-
Vaporizer
Isoflurane concentration
Patient
Actual blood pressure

7.

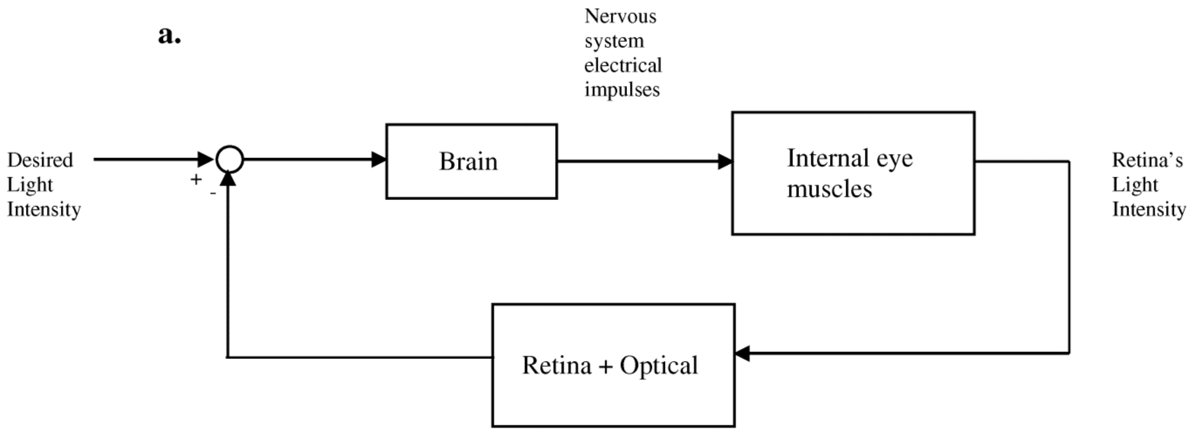

Desired depth
+
-
Controller & motor
Force
Grinder
Feed rate
Integrator
Depth

8.

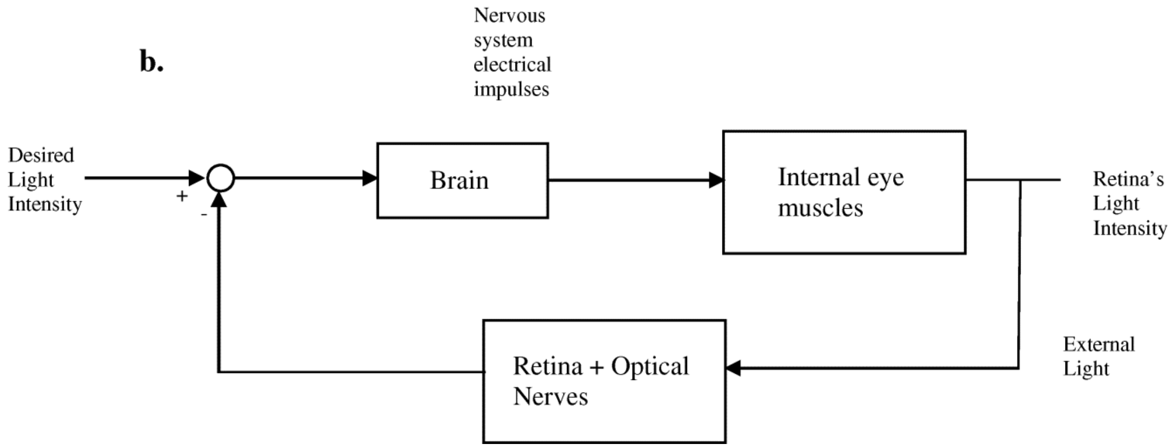

Desired position
Transducer
Coil voltage
+
-
Coil circuit
Coil current
Solenoid coil & actuator
Force
Armature & spool dynamics
Depth
LVDT

9.

a.



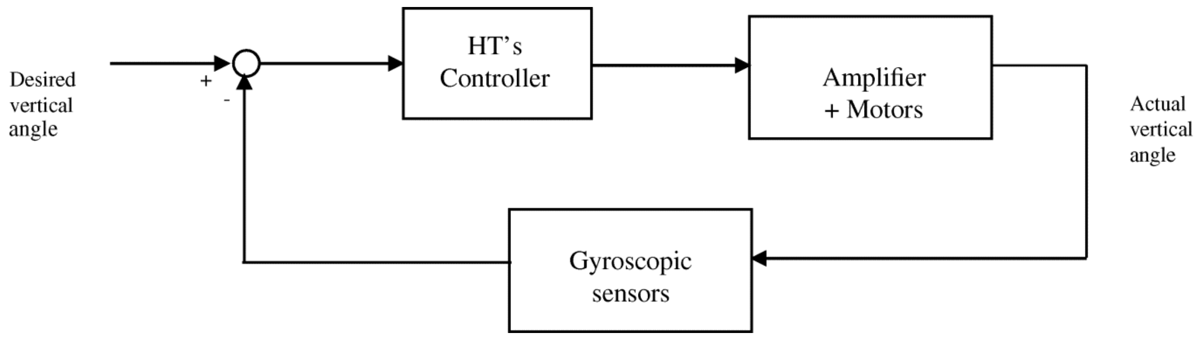
b.



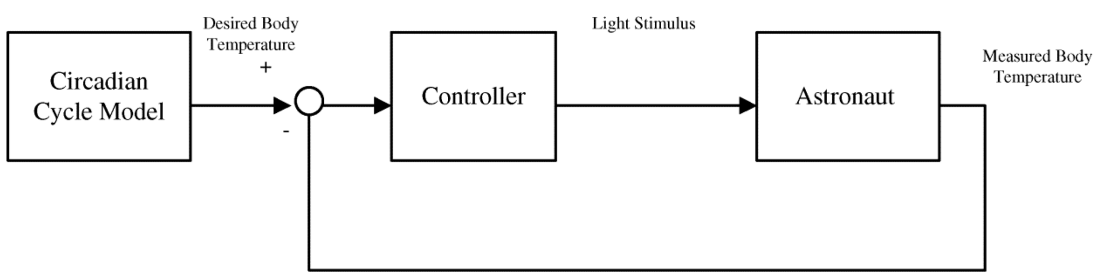
If the narrow light beam is modulated sinusoidally the pupil's diameter will also vary sinusoidally (with a delay see part c) in problem)

c. If the pupil responded with no time delay the pupil would contract only to the point where a small amount of light goes in. Then the pupil would stop contracting and would remain with a fixed diameter.

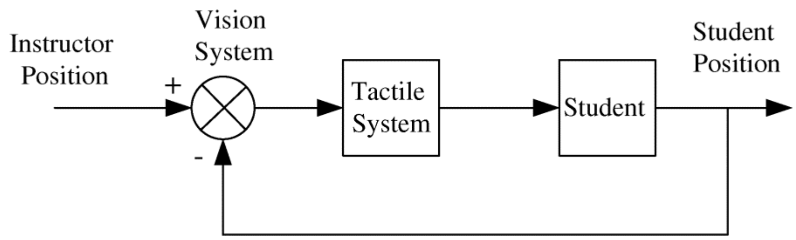
10.


Desired
vertical
angle
+
-
HT's
Controller
Amplifier
+ Motors
Actual
vertical
angle
Gyroscopic
sensors

11.

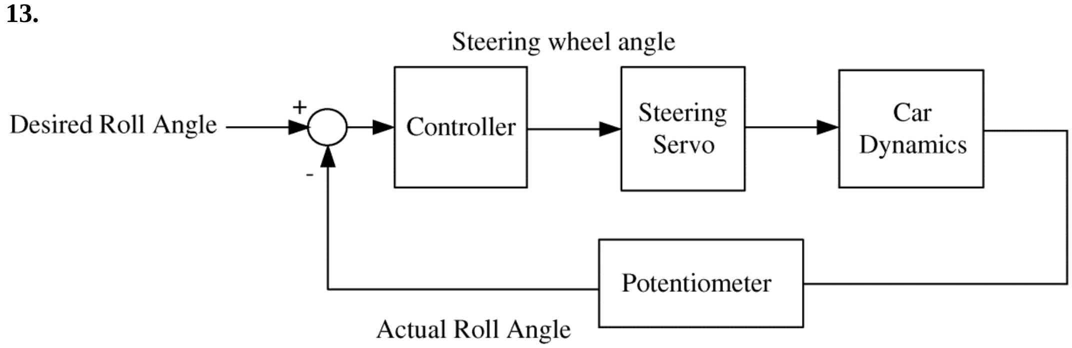

Circadian
Cycle Model
Desired Body
Temperature
+
-
Controller
Light Stimulus
Astronaut
Measured Body
Temperature

12.



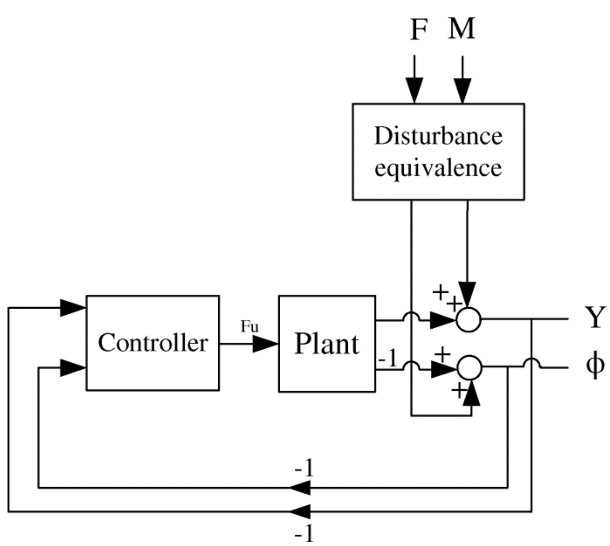
Instructor Position
Vision System
+
-
Tactile System
Student
Student Position

13.



Steering wheel angle
Desired Roll Angle
+
-
Controller
Steering Servo
Car Dynamics
Potentiometer
Actual Roll Angle

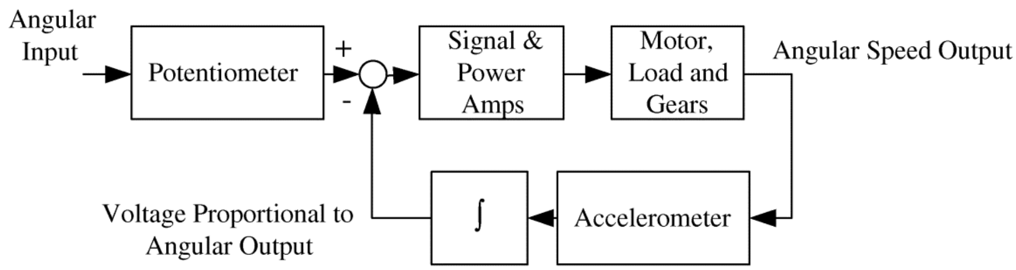
14.



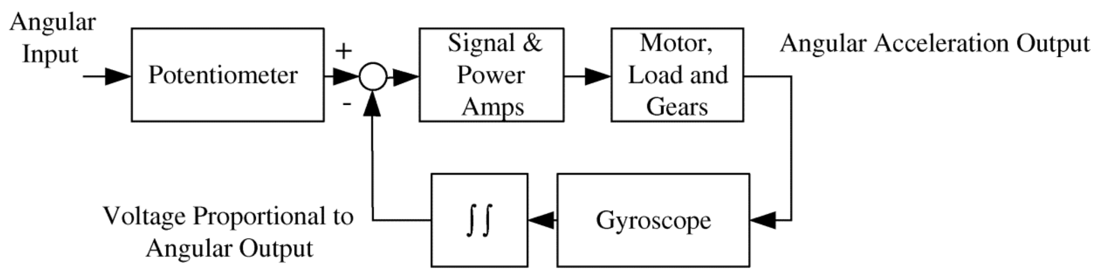
F M
Disturbance equivalence
Controller
Fu
Plant
-1
+
+
Y
ϕ
-1
-1

15.

a.

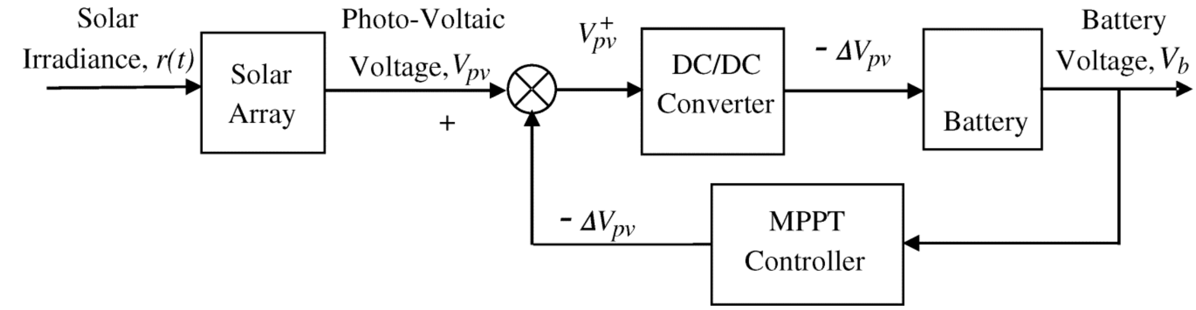

Angular
Input
Potentiometer
+
-
Signal &
Power
Amps
Motor,
Load and
Gears
Angular Speed Output
Voltage Proportional to
Angular Output
∫
Accelerometer

b.

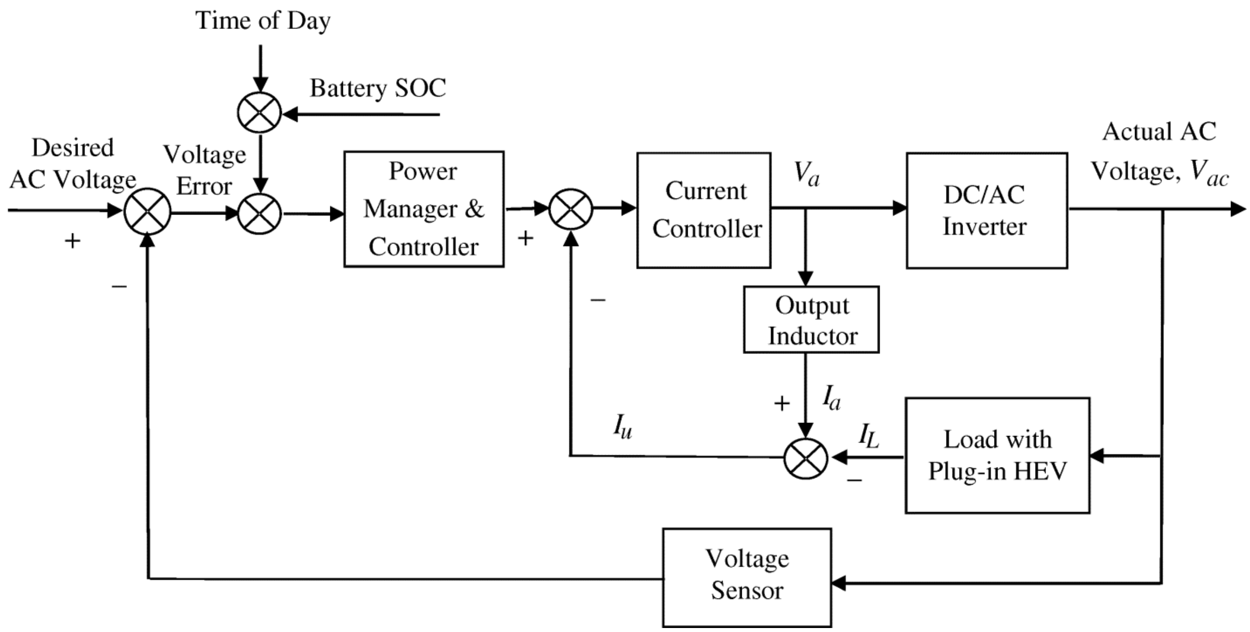

Angular
Input
Potentiometer
+
-
Signal &
Power
Amps
Motor,
Load and
Gears
Angular Acceleration Output
Voltage Proportional to
Angular Output
∫∫
Gyroscope

16.

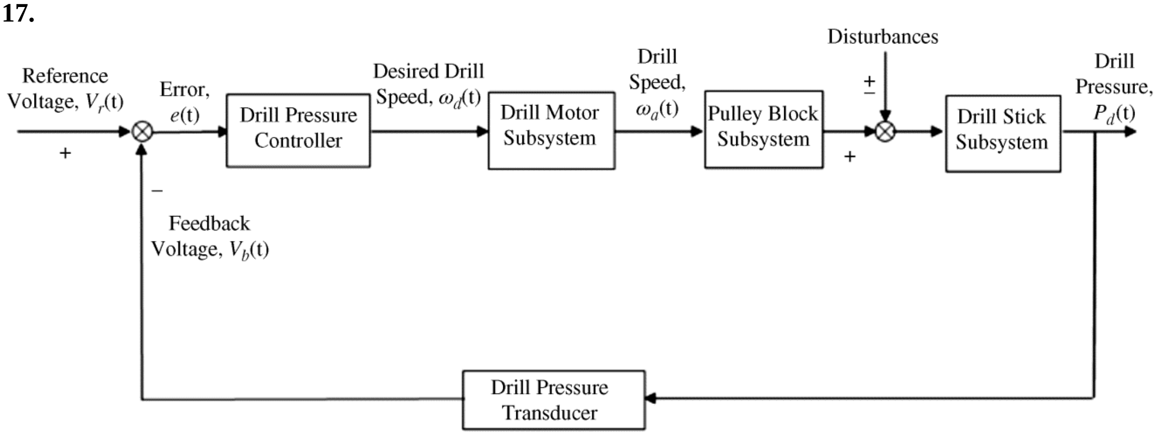
a.


Solar
Irradiance, r(t)
Solar
Array
Photo-Voltaic
Voltage, V_{pv}
+
V_{pv}^{+}
DC/DC
Converter
- ΔV_{pv}
Battery
Battery
Voltage, V_b
MPPT
Controller
- ΔV_{pv}

b.


Time of Day
Battery SOC
Desired
AC Voltage
Voltage
Error
+
–
Power
Manager &
Controller
+
–
Current
Controller
V_a
DC/AC
Inverter
Actual AC
Voltage, V_{ac}
Output
Inductor
+
I_a
I_u
I_L
–
Load with
Plug-in HEV
Voltage
Sensor

17.


Reference
Voltage, V_r(t)
+
Error,
e(t)
–
Drill Pressure
Controller
Desired Drill
Speed, ω_d(t)
Drill Motor
Subsystem
Drill
Speed,
ω_a(t)
Pulley Block
Subsystem
Disturbances
±
+
Drill Stick
Subsystem
Drill
Pressure,
P_d(t)
Feedback
Voltage, V_b(t)
Drill Pressure
Transducer

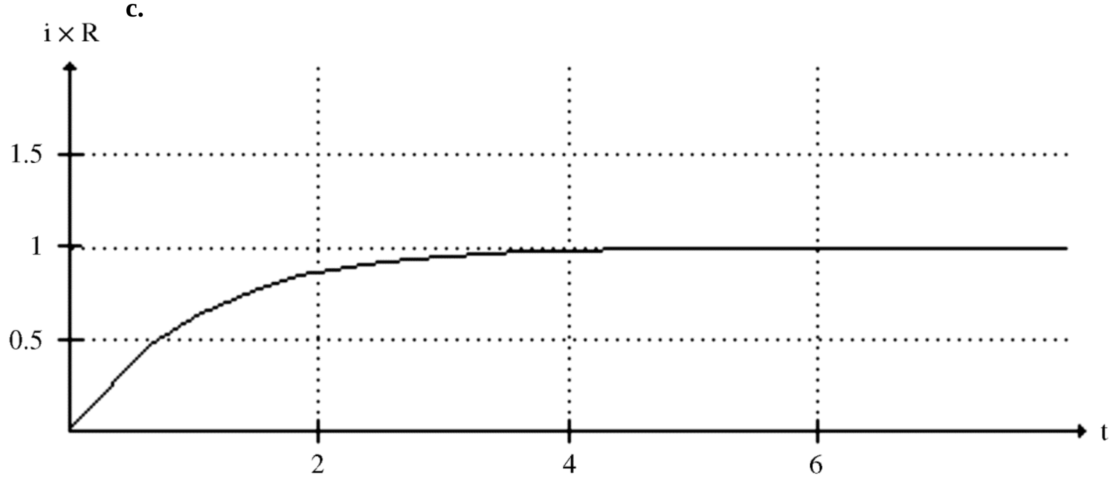
18.

a. L $\frac{di}{dt}$ + Ri = u(t)

b. Assume a steady-state solution i_{SS} = B. Substituting this into the differential equation yields RB = 1,

from which B = $\frac{1}{R}$. The characteristic equation is LM + R = 0, from which M = -$\frac{R}{L}$. Thus, the total solution is $i(t) = Ae^{-(R/L)t} + \frac{1}{R}$. Solving for the arbitrary constants, i(0) = A + $\frac{1}{R}$ = 0. Thus, A = -$\frac{1}{R}$. The final solution is i(t) = $\frac{1}{R}$ -- $\frac{1}{R}e^{-(R/L)t}$ = $\frac{1}{R}(1-e^{-(R/L)t})$.

c.



19.

a. Writing the loop equation, $Ri + L\frac{di}{dt} + \frac{1}{C}\int idt + v_c(0) = v(t)$

b. Differentiating and substituting values, $\frac{d^2i}{dt^2} + 2\frac{di}{dt} + 16i = 0$

Writing the characteristic equation and factoring,

$$M^2 + 2M + 16 = (M + 1 + \sqrt{15}i)(M + 1 - \sqrt{15}i)$$

The general form of the solution and its derivative is

$$i = Ae^{-t}\cos(\sqrt{15}t) + Be^{-t}\sin(\sqrt{15}t)$$

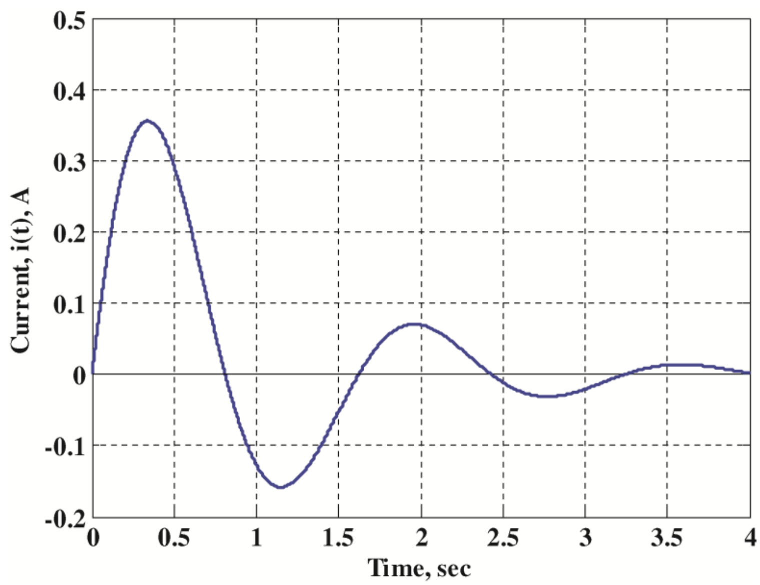
$$\frac{di}{dt} = (-A + \sqrt{15}B)\, e^{-t}\cos(\sqrt{15}t) - (\sqrt{15}A + B)\, e^{-t}\sin(\sqrt{15}t)$$

Using $i(0) = 0$; $\frac{di}{dt}(0) = \frac{v_L(0)}{L} = \frac{1}{L} = 2$

$i(0) = A = 0$ and $\frac{di}{dt}(0) = -A + \sqrt{15}B = 2 \Rightarrow B = \frac{2}{\sqrt{15}}$

The solution is: $$i(t) = \frac{2}{15}\sqrt{15}\ e^{-t}\sin(\sqrt{15}\ t)$$

c.



20.

a. Assume a particular solution of

$$x_p(t) = C\cos(2t) + D\sin(2t)$$

Substitute into the differential equation and obtain

$$(7C + 2D)\cos(2t) + (-2C + 7D)\sin(2t) = 5\cos(2t)$$

Equating like coefficients,

$$7C + 2D = 5$$

$$-2C + 7D = 0$$

From which, C = $\frac{35}{53}$ and D = $\frac{10}{53}$.

The characteristic polynomial is

$$M+7=0$$

Thus, the total solution is

$$x(t)=Ae^{-7t}+\left(\frac{35}{53}\cos[2t]+\frac{10}{53}\sin[2t]\right)$$

Solving for the arbitrary constants, x(0) = A + $\frac{35}{53}$ = 0. Therefore, A = - $\frac{35}{53}$. The final solution is

$$x(t)=\left(-\frac{35}{53}\right)e^{-7t}+\left(\frac{35}{53}\cos[2t]+\frac{10}{53}\sin[2t]\right)$$

b. Assume a particular solution of

$$x_p = A\sin 3t + B\cos 3t$$

Substitute into the differential equation and obtain

$$(18A-B)\cos(3t)-(A+18B)\sin(3t)=5\sin(3t)$$

Therefore, 18A – B = 0 and –(A + 18B) = 5. Solving for A and B we obtain

$$x_p = (-1/65)\sin 3t + (-18/65)\cos 3t$$

The characteristic polynomial is

$$M^2+6M+8=(M+4)(M+2)$$

Thus, the total solution is

$$x=Ce^{-4t}+De^{-2t}+\left(-\frac{18}{65}\cos(3\,t)-\frac{1}{65}\sin(3\,t)\right)$$

Solving for the arbitrary constants, $x(0)=C+D-\frac{18}{65}=0$.

Also, the derivative of the solution is

$$\frac{dx}{dt}=-\frac{3}{65}\cos(3\,t)+\frac{54}{65}\sin(3\,t)-4Ce^{-4t}-2De^{-2t}$$

Solving for the arbitrary constants, $\dot{x}(0)-\frac{3}{65}-4C-2D=0$, or C = $-\frac{3}{10}$ and D = $\frac{15}{26}$.

The final solution is

$$x=-\frac{18}{65}\cos(3\,t)-\frac{1}{65}\sin(3\,t)-\frac{3}{10}e^{-4t}+\frac{15}{26}e^{-2t}$$

c. Assume a particular solution of

$$x_p = A$$

Substitute into the differential equation and obtain 25A = 10, or A = 2/5.

The characteristic polynomial is

$$M^2 + 8M + 25 = (M + 4 + 3i)(M + 4 - 3i)$$

Thus, the total solution is

$$x = \frac{2}{5} + e^{-4t}(B\sin(3t) + C\cos(3t))$$

Solving for the arbitrary constants, x(0) = C + 2/5 = 0. Therefore, C = -2/5. Also, the derivative of the solution is

$$\frac{dx}{dt} = ((3B - 4C)\cos(3t) - (4B + 3C)\sin(3t))e^{-4t}$$

Solving for the arbitrary constants, $\dot{x}(0)$ = 3B – 4C = 0. Therefore, B = -8/15. The final solution is

$$x(t) = \frac{2}{5} - e^{-4t}\left(\frac{8}{15}\sin(3t) + \frac{2}{5}\cos(3t)\right)$$

21.

a. Assume a particular solution of

$$x_p(t) = C\cos(2t) + D\sin(2t)$$

Substitute into the differential equation and obtain

$$-2(C - 2D)\cos(2t) - 4\left(C + \frac{1}{2}D\right)\sin(2t) = \sin(2t)$$

Equating like coefficients,

$$-2(C - 2D) = 0$$

$$-4\left(C + \frac{1}{2}D\right) = 1$$

From which, C = $-\frac{1}{5}$ and D = $-\frac{1}{10}$.

The characteristic polynomial is

$$M^2 + 2M + 2 = (M + 1 + i)(M + 1 - i)$$

Thus, the total solution is

$$x = -\frac{1}{5}\cos(2t) - \frac{1}{10}\sin(2t) + e^{-t}(A\cos[t] + B\sin[t])$$

Solving for the arbitrary constants, x(0) = A - $\frac{1}{5}$ = 2. Therefore, A = $\frac{11}{5}$. Also, the derivative of the solution is

$$\frac{\mathrm{dx}}{\mathrm{dt}}=-\frac{1}{5}\cos(2t)+\frac{2}{5}\sin(2t)+(-A+B)e^{-t}\cos(t)-(A+B)e^{-t}\sin(t)$$

Solving for the arbitrary constants, $\dot{\mathrm{x}}(0)$ = - A + B - 0.2 = -3. Therefore, B = $-\frac{3}{5}$. The final solution

is

$$x(t)=-\frac{1}{5}\cos(2t)-\frac{1}{10}\sin(2t)+e^{-t}\left(\frac{11}{5}\cos(t)-\frac{3}{5}\sin(t)\right)$$

b. Assume a particular solution of

$$x_p = Ce^{-2t} + Dt + E$$

Substitute into the differential equation and obtain

$$Ce^{-2t}+Dt+2D+E=5e^{-2t}+t$$

Equating like coefficients, C = 5, D = 1, and 2D + E = 0.

From which, C = 5, D = 1, and E = - 2.

The characteristic polynomial is

$$M^2+2M+1=(M+1)^2$$

Thus, the total solution is

$$x(t)=Ae^{-t}+Be^{-t}t+5e^{-2t}+t-2$$

Solving for the arbitrary constants, x(0) = A + 5 - 2 = 2 Therefore, A = -1. Also, the derivative of the

solution is

$$\frac{dx}{dt}=(-A+B)e^{-t}-Bte^{-t}-10e^{-2t}+1$$

Solving for the arbitrary constants, $\dot{\mathrm{x}}(0)$ = B - 8 = 1. Therefore, B = 9. The final solution is

$$x(t)=-e^{-t}+9te^{-t}+5e^{-2t}+t-2$$

c. Assume a particular solution of

$$x_p = Ct^2 + Dt + E$$

Substitute into the differential equation and obtain

$$4Ct^2+4Dt+2C+4E=t^2$$

Equating like coefficients, C = $\frac{1}{4}$, D = 0, and 2C + 4E = 0.

From which, C = $\frac{1}{4}$, D = 0, and E = - $\frac{1}{8}$.

The characteristic polynomial is

$$M^2 + 4 = (M + 2i)(M - 2i)$$

Thus, the total solution is

$$x(t) = A\cos(2t) + B\sin(2t) + \frac{1}{4}t^2 - \frac{1}{8}$$

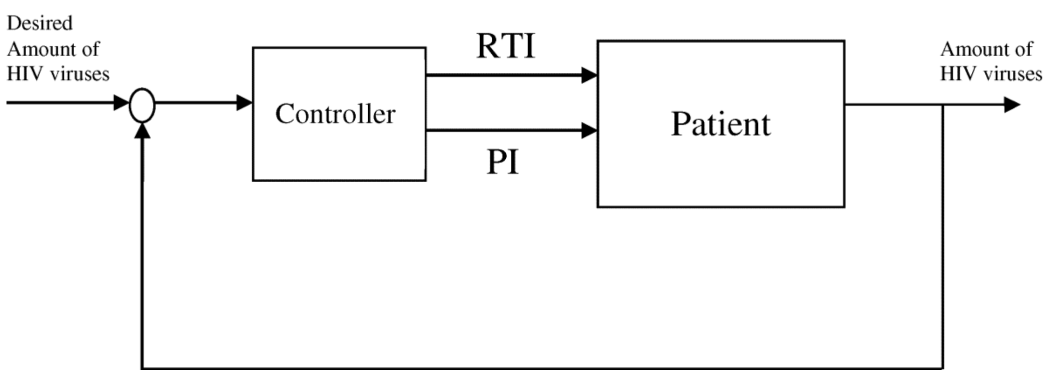
Solving for the arbitrary constants, x(0) = A - $\frac{1}{8}$ = 1 Therefore, A = $\frac{9}{8}$. Also, the derivative of the solution is

$$\frac{dx}{dt} = 2B\cos(2t) - 2A\sin(2t) + \frac{1}{2}t$$

Solving for the arbitrary constants, $\dot{x}(0)$ = 2B = 2. Therefore, B = 1. The final solution is

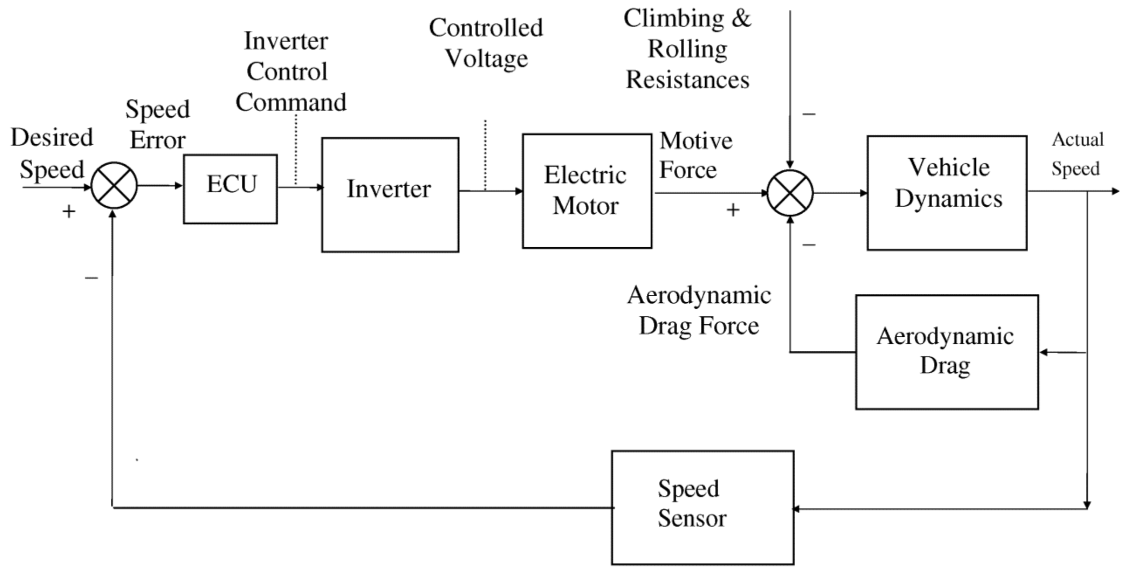
$$x(t) = \frac{9}{8}\cos(2t) + \sin(2t) + \frac{1}{4}t^2 - \frac{1}{8}$$

22.

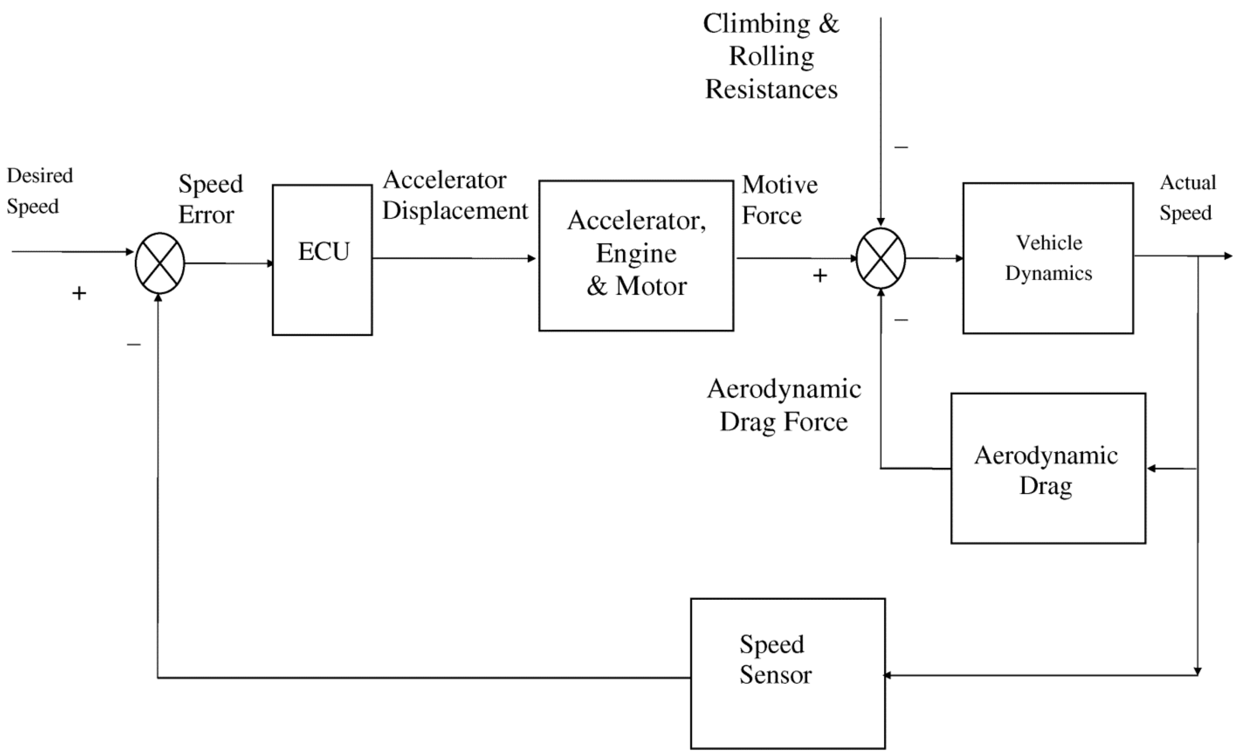


23.

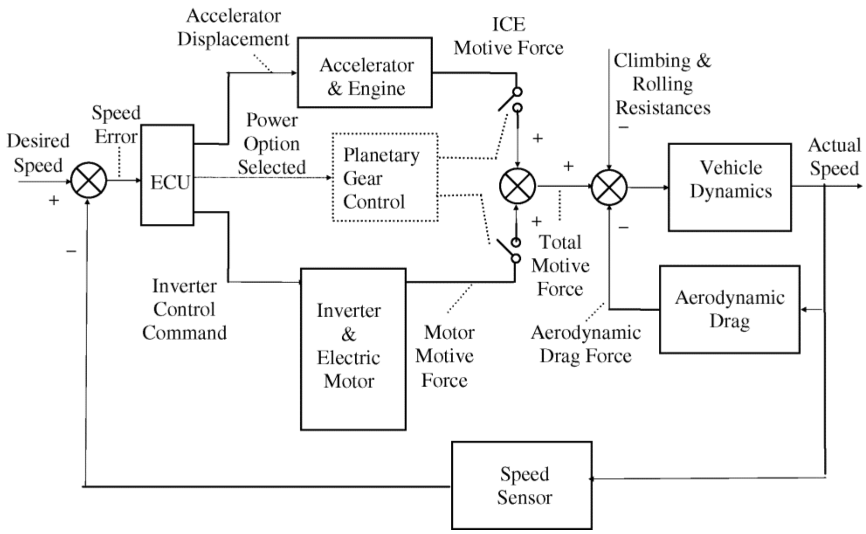
a.


Inverter
Control
Command
Controlled
Voltage
Climbing &
Rolling
Resistances
Speed
Error
Desired
Speed
ECU
Inverter
Electric
Motor
Motive
Force
Vehicle
Dynamics
Actual
Speed
+
–
Aerodynamic
Drag Force
Aerodynamic
Drag
Speed
Sensor

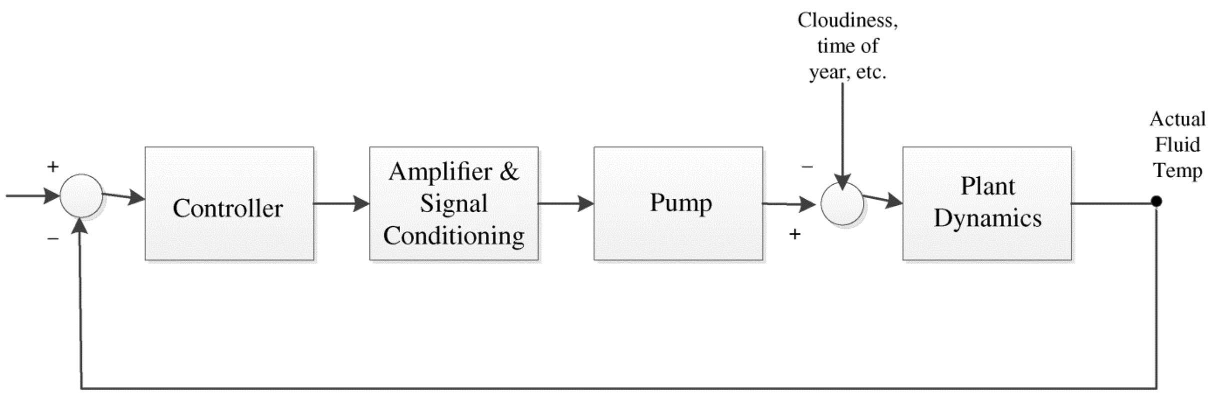
b.


Climbing &
Rolling
Resistances
Desired
Speed
Speed
Error
ECU
Accelerator
Displacement
Accelerator,
Engine
& Motor
Motive
Force
Vehicle
Dynamics
Actual
Speed
+
–
Aerodynamic
Drag Force
Aerodynamic
Drag
Speed
Sensor

c.


Accelerator
Displacement
Accelerator
& Engine
ICE
Motive Force
Climbing &
Rolling
Resistances
Desired
Speed
Speed
Error
ECU
Power
Option
Selected
Planetary
Gear
Control
Vehicle
Dynamics
Actual
Speed
Total
Motive
Force
Inverter
Control
Command
Inverter
&
Electric
Motor
Motor
Motive
Force
Aerodynamic
Drag Force
Aerodynamic
Drag
Speed
Sensor

24.


Cloudiness,
time of
year, etc.
Actual
Fluid
Temp
Controller
Amplifier &
Signal
Conditioning
Pump
Plant
Dynamics

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