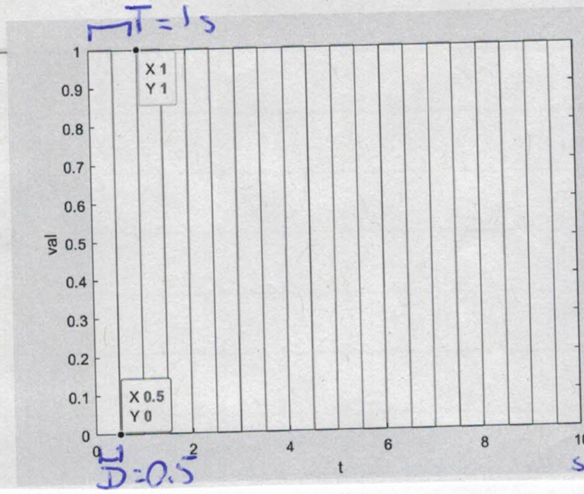
6 DI Preparation

3.1

Pwm function code and graph:

```
function v = pwm(t,T,d)
figure(1);
for i = 1:length(t)
pos = mod(t(i),T);
if(pos >= d)
     v(i) = 0;
else
     v(i) = 1;
end
end
plot(t,v)
end
```

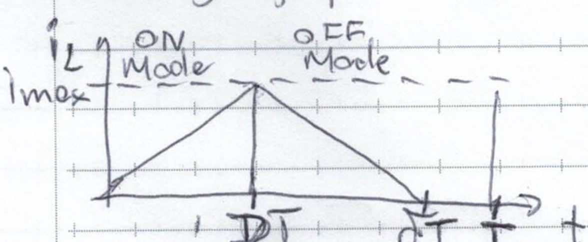


3.2

Discontinuous mode

We assume current falls to 0 in some point when it is in off-mode state.

Timing graph:



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~~Imax~~ = On mode:

$$\frac{i_{max}}{dt} = \frac{V_{in}}{L}, \text{ so } \quad i_{max} = \frac{dt\,V_{in}}{L} = \frac{DT\,V_{in}}{L}$$

Off mode:

$$L\frac{\cancel{i_{max}}}{dt} = V_{in} - V_{out}$$

$$i = \frac{V_{in} - V_{out} \cdot dt}{L}$$

$$i_{max} + \frac{(V_{in} - V_{out}) \cdot \delta T}{L} = 0$$

$$DT\,V_{in} + (V_{in} - V_{out})\,\delta T = 0$$

$$D V_{in} + \delta V_{in} - \delta V_{out} = 0$$

$$\delta = \frac{D V_{in}}{V_{out} - V_{in}}$$

We can calculate average i_{load} since it is i_{diode} during off state.

$$i_{load} = \frac{i_{max}}{2} \cdot \delta \cancel{T} \cdot \frac{1}{\cancel{T}} = \frac{DT\,V_{in}}{2L} \cdot \frac{D V_{in}}{V_{out} - V_{in}}$$

$$V_{load} = V_0 = \frac{i_{load}}{R}$$

$$\Delta = b^2 - 2ac$$

$$V_{out} = \frac{D^2 V_{in}^2 T R}{2L(V_{out} - V_{in})R}$$

$$(2LR V_{out} - 2LR V_{in}) V_{out} = D^2 V_{in}^2 T R$$

$$2LR V_{out}^2 - 2LR V_{in} V_{out} = D^2 V_{in}^2 T R$$

$$2LR V_{out}^2 - 2LR V_{in} V_{out} - D^2 T V_{in}^2 R = 0$$

$$\cancel{V_{out} = \frac{2LR V_{in} \pm \sqrt{4L^2R^2V_{in}^2 + 4LRD^2TV_{in}^2}}{4LR}} = \cancel{\frac{2LR V_{in} \pm \sqrt{4LRV_{in}^2(LR + D^2T)}}{4LR}} =$$

$$= (V_{out} - V_{in}) V_{out} = \frac{D^2 V_{in}^2 T R}{2L}$$

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$$V_{out}^2 - V_{in}V_{out} - \frac{D^2 V_{in}^2 TR}{2L} = 0$$

$$V_{out} = \frac{V_{in} \pm \sqrt{V_{in}^2 + 4\frac{2D^2TR}{L}V_{in}^2}}{2} = \frac{V_{in} \pm V_{in}\sqrt{1+\frac{2D^2TR}{L}}}{2}$$

$V_{out} > V_{in}$ so

$$V_{out} = \frac{V_{in} + V_{in}\sqrt{1+\frac{2D^2TR}{L}}}{2}$$

4.1

State space form, switch closed

$$\frac{d}{dt}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} + \begin{bmatrix} E \\ F \end{bmatrix} V_{in}$$

$$\Downarrow$$

$$\begin{cases} \frac{d}{dt} i_L = A \cdot i_L + B \cdot V_{out} + E \cdot V_{in} \\ \frac{d}{dt} V_{out} = C \cdot i_L + D \cdot V_{out} + F \cdot V_{in} \end{cases}$$

$$\begin{cases} \frac{di_L}{dt} = \frac{V_{in}}{L}, \text{ so } A=0, B=0, E=\frac{1}{L} \\ \frac{dV_{out}}{dt} = \frac{-V_{out}}{RC}, \text{ so } C=0, D=\frac{-1}{RC}, F=0 \end{cases}$$

$$\frac{d}{dt}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in}$$

switch opened diode forward region

$$\begin{cases} L\dfrac{di}{dt} = V_{in} - V_{out} \Leftrightarrow \dfrac{di_L}{dt} = \dfrac{1}{L}V_{in} - \dfrac{1}{L}V_{out} \\ \dfrac{dV_{out}}{dt} = \dfrac{1}{C}i_L - \dfrac{V_{out}}{CR} \end{cases}$$

$$\frac{d}{dt}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{CR} \end{bmatrix}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in}$$

switch opened, diode in reverse region

$$\frac{di_L}{dt} = 0 \qquad \frac{dV_{out}}{dt} = \frac{-V_{out}}{CR}$$

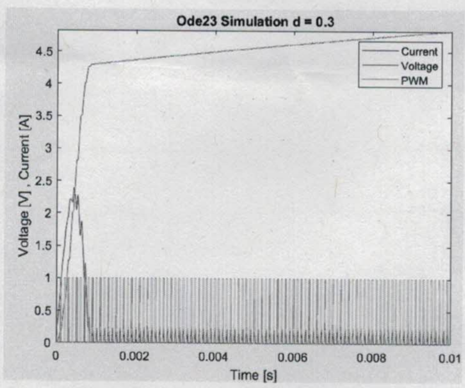
$$\frac{d}{dt}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{CR} \end{bmatrix}\begin{bmatrix} i_L \\ V_{out} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V_{in}$$

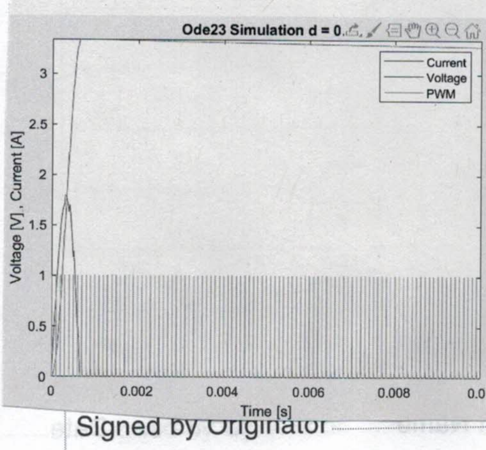
4.4

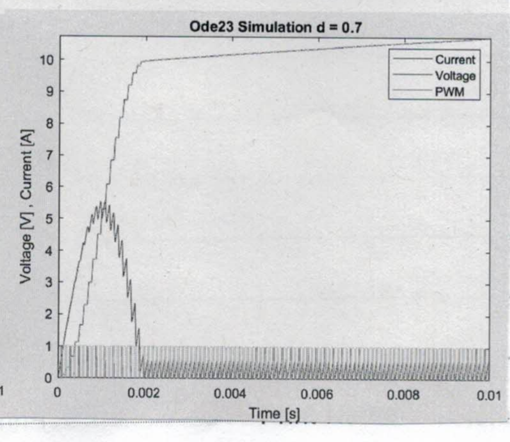
V_{in}	1.5
R	680 Ω
C	200 μF
L	180 μH

$d = 0.3$

```
function dx=boost(t,x)
global v_in R C L T d
dx=zeros(2,1);
if pwm(t,T,d)==1
dx(1) = v_in/L;
dx(2) = -x(2)/(R*C);
end
if pwm(t,T,d)==0 && x(1)>=0
dx(1) = -x(2)/L+v_in/L;
dx(2) = x(1)/C-x(2)/(C*R);
end
if pwm(t,T,d)==0 && x(1) <0
dx(1) = 0;
dx(2) = -x(2)/(C*R);
end
```

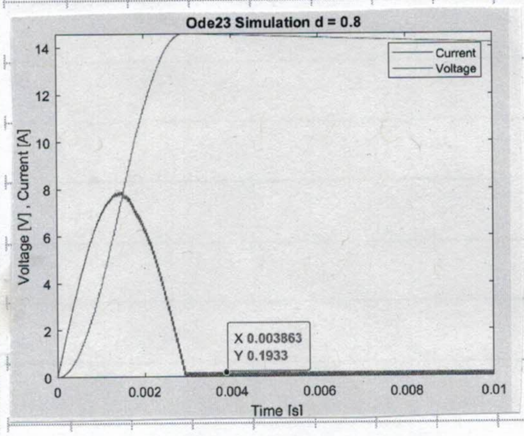






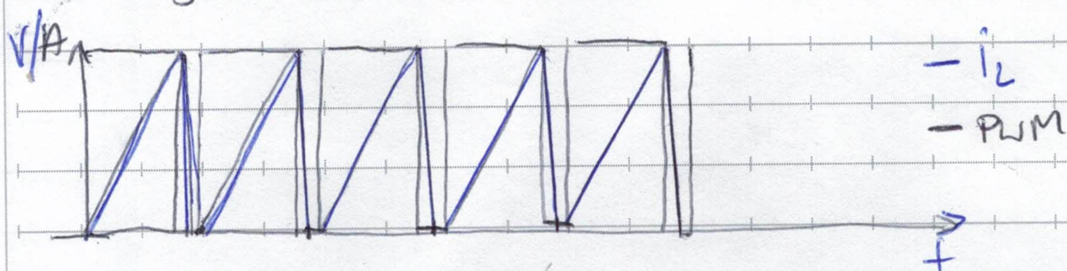
$D=0.1$	$T=24e^{-5}$	3.3 V
$D=0.3$	$T=8e^{-5}$	4.3 V
$D=0.5$	$T=4.8e^{-5}$	6 V
$D=0.6$	$T=4.5e^{-5}$	7.4 V
$D=0.8$	$T=3e^{-5}$	14 V

~~D=0.8 T=~~



Assumptions are valid, the current remains nearly 0.2 A and it matches my previous calculations.

The above example work in discountinous mode during stable state.



$$\gamma = \frac{(R_2+R_1)R_{dummy}}{R_1+R_2+R_{dummy}} = 663.11\ \Omega$$

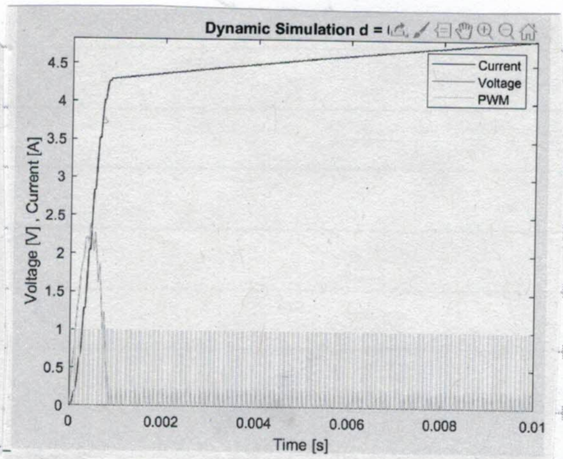
$$R_{dummy} = 680\,\Omega \qquad \frac{R_{dummy}-\gamma}{R_{dummy}} \cdot 100\% = 2{,}48\%$$

The value of total resistance has changed only by 2,48%. It is not significant value and that change won't influence on circuit's behaviour.

$\boxed{5}$

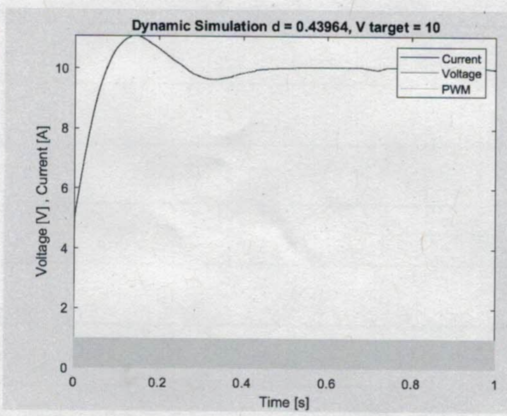
The complete case section of dynamic simulator code:

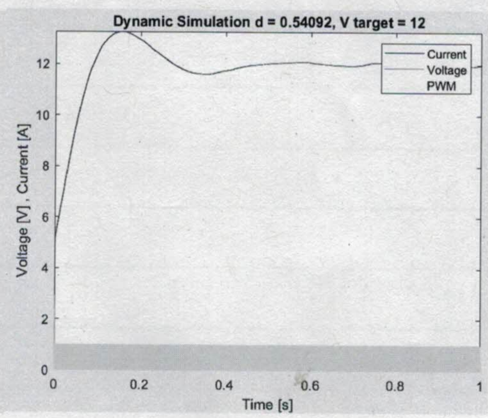
```
switch case1
    case 1
        %Case: Switch open and diode reverse biased
        dVout_dt= -Vout/(R*C);
        Vout=Vout+dVout_dt*timeStep; %Update Vout with new value
        diL_dt=0;

    case 2
       %Case: Switch open, diode forward biased

        diL_dt= -Vout/L+Vin/L;
        dVout_dt = iL/C-Vout/(C*R);
        iL=iL+diL_dt*timeStep;  %Update iL with new value
        Vout=Vout+dVout_dt*timeStep;  %Update Vout with new value

    case 3
        %Case: switch closed
        dVout_dt= -Vout/(R*C);
        Vout=Vout+dVout_dt*timeStep;
        diL_dt = Vin/L;
        iL=iL+diL_dt*timeStep;
end
```

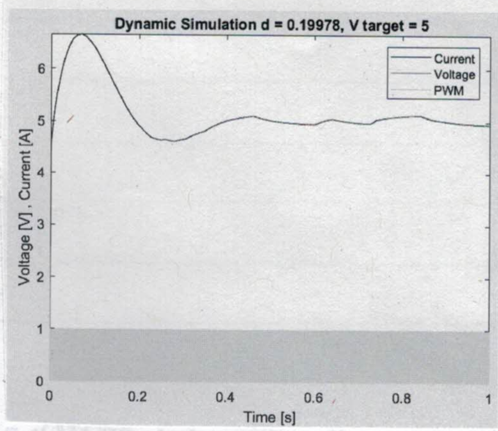


Dynamic simulations for different k_p and V_target values

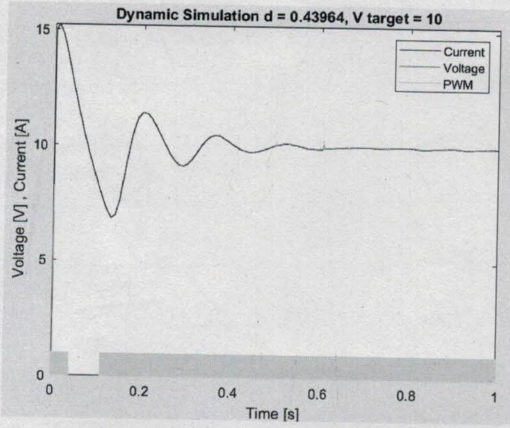
K = 0.01

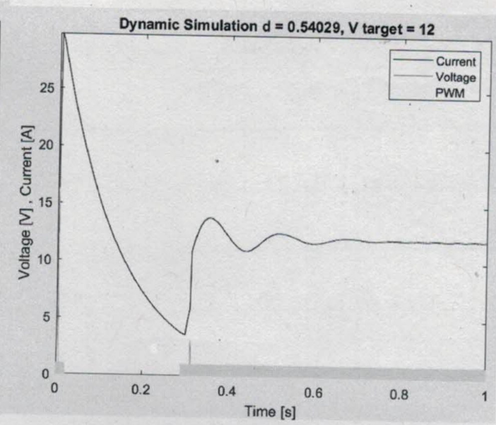


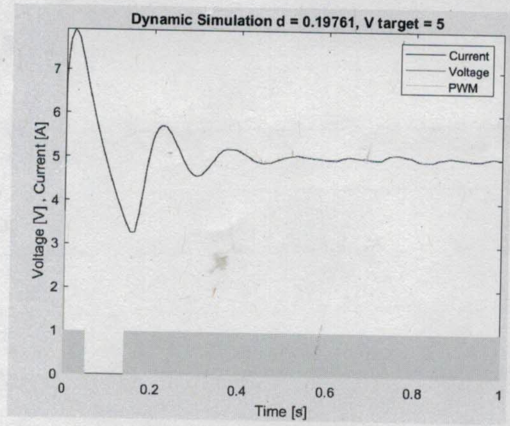




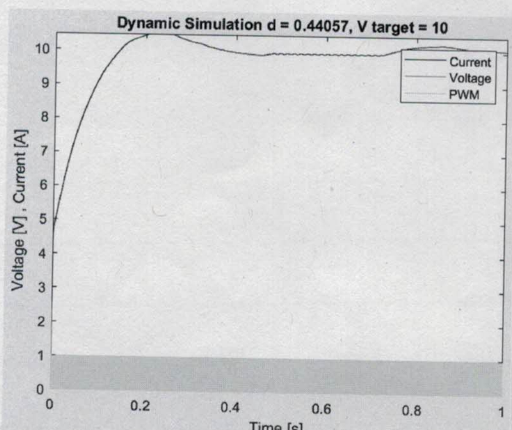
K=0.05

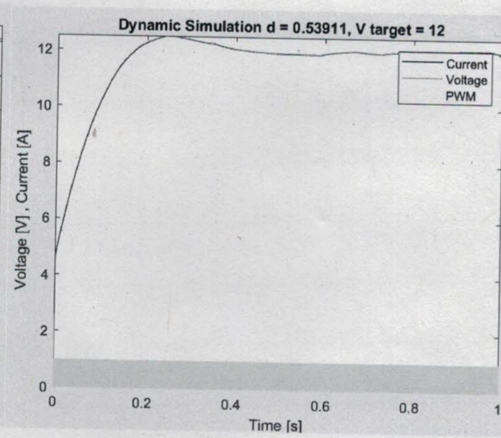

Dynamic Simulation d = 0.43964, V target = 10
Current
Voltage
PWM
Voltage [V] , Current [A]
Time [s]

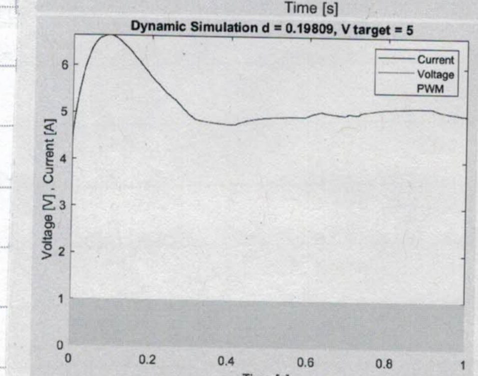

Dynamic Simulation d = 0.54029, V target = 12
Current
Voltage
PWM
Voltage [V] , Current [A]
Time [s]


Dynamic Simulation d = 0.19761, V target = 5
Current
Voltage
PWM
Voltage [V] , Current [A]
Time [s]

K = 0.005


Dynamic Simulation d = 0.44057, V target = 10
Current
Voltage
PWM
Voltage [V] , Current [A]
Time [s]


Dynamic Simulation d = 0.53911, V target = 12
Current
Voltage
PWM
Voltage [V] , Current [A]
Time [s]


Dynamic Simulation d = 0.19809, V target = 5
Current
Voltage
PWM
Voltage [V] , Current [A]
Time [s]

The 5.3

~~Optionel~~

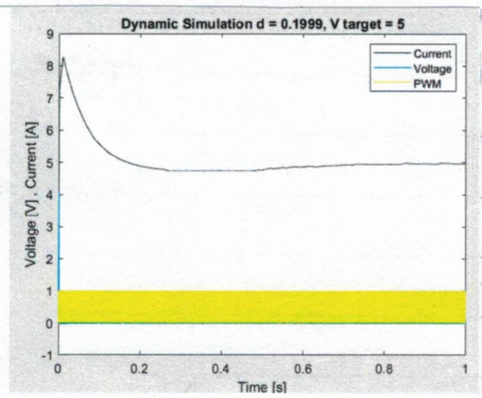
PID Controller

control function:

$$u(t) = \underbrace{K_p\, e(t)}_{\text{proportionel term}} + \underbrace{K_i \int_0^t e(t')\,dt'}_{\text{integrel term}} + \underbrace{K_d \frac{de(t)}{dt}}_{\text{derivetive term}}$$

PID implementation in dynamic simulator:

```
%Change duty cycle based on error (PID Controller)
 if(mod(time,0.01)<timeStep)    %Change every 0.01 seconds
     error=Vout-Vout_target;
     diferror = (error-errorprev)/0.01;%derivative (slope) of e(t)
     integerror = integerror + error*0.01; %integral of e(t')dt' in [0 t]

      kP=0.007;
      dutyCycle=dutyCycle-error*kP;    %proportional term
      kI = 0.016;
      dutyCycle=dutyCycle-integerror*kI;%integral term
      kD = 0.0005;
      dutyCycle=dutyCycle-diferror*kD;%derivative term

      errorprev = error;
 end
```



This is improved simulation for vtarget 5 V.
In previous propotiel controller the simulation reach stable state in 0.5 s while in PID controller it is much quicker and lests 0.2 s.

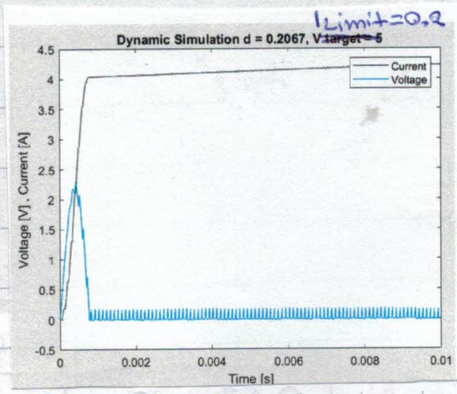
To achieve good controller stability it is necessary to get K_p, K_i, K_d ~~values~~ the best values.
There is stable which describe effects of increasing parameter independently:

Parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Small change	Decrease	Decrease	—	Improve, if Kd small

wikipedia.org
entry: PID_controller

Current limiter:

```
if (iL > ilimit)
        ierror = iL - ilimit;
        kPi = 0.0001;
        dutyCycle = dutyCycle - ierror * kPi;
end
```



S1

Lab Code:	None	Poor	OK	Good	Exceptional	Outstanding
Preparation	0	1	2	3	4	5
Progress	0	1	2	3	4	5
Understanding	0	1	2	3	4	5
Logbook Use	0	1	2	3	4	5
Demonstrators only						
Print Full Name	Tanchero R			Signed	TR	

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