



Ministry of Education and Science of the Russian Federation
Peter the Great St. Petersburg State Polytechnic University
Institute of Computer Science and Control Systems

Control Systems and Technology Department

Report for Laboratory No. 5

Analysis of Nonlinear Stabilization System Using Simulink Model
Course: Mathematical Modeling and Simulation

Student Group: 13541/8

_____ Christopher W. Blake

_____ Susanne Garcia

_____ Valentyn Sichkar

_____ Christos Voulvoukelis

Professor

_____ Rostov N.V

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Contents

Introduction	3
Background	3
Stabilization Control System	3
Non-Linear PI-VR	3
Non-Linear PI-CR	4
Non-Linear DC Motor	4
Results	5
Control System Details	5
Motor Details	5
Influence of Parameters	5
Effect of g	6
Effect of M_L	7
Effect of dU	8
Effect of K_vf	9
Effect of M_{df}	10
Conclusion	11

Introduction

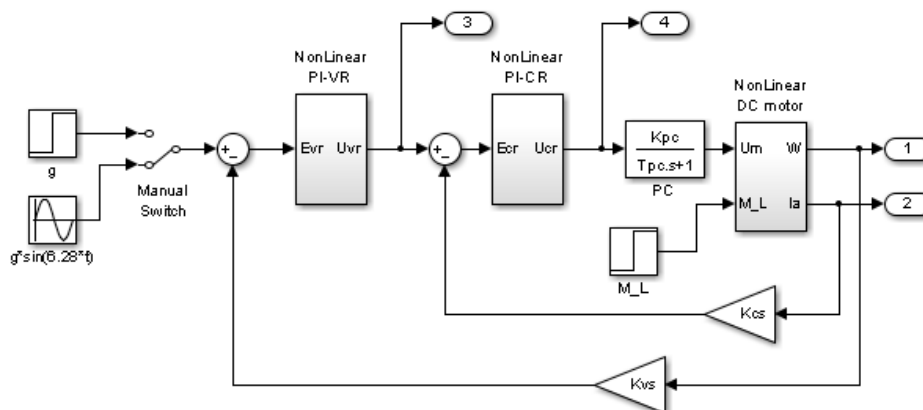
Lab 5 is about the analysis of a nonlinear stabilization system. A non-linear PI-VR and non-linear PI-CR are combined with a power controller to regulate the operation of a DC motor. A motor is selected randomly, providing required design constant values. Using these design constants, the system is analyzed for two different input types: step and sinusoidal. From these results, various plots for angular velocity, control response, and amperage are produced. Finally, using these plots and any critical values, a summary of the system's trends is produced.

The analysis software for this lab is Matlab and Simulink. All system models are produced in a graphical style, rather than producing transfer functions and writing code. These models are then used as a template and adjusted using Matlab code to test different scenarios. All code used for this analysis can be seen in Appendix 1.

Background

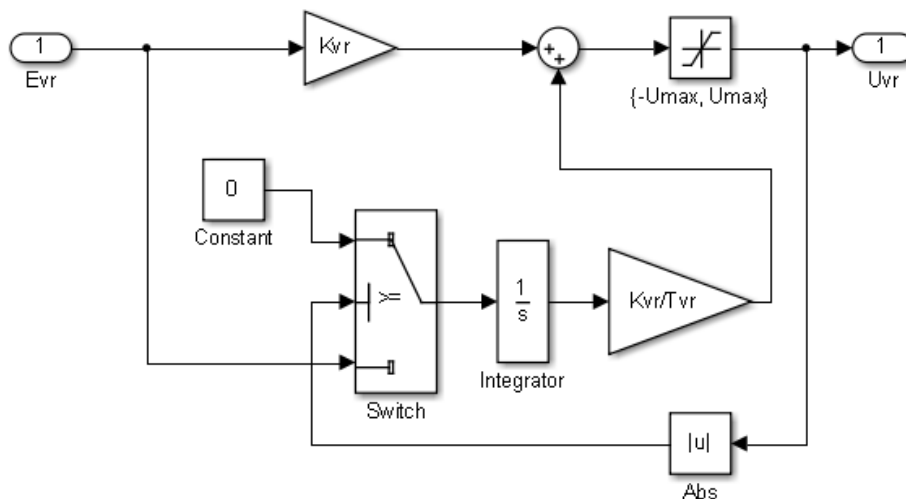
Stabilization Control System

The control system which stabilizes the motor consists of a PI-VR (Velocity Regulator), PI-CR (Current Regulator), PC (Power Controller), Non-Linear DC Motor, and two sensors. It is additionally configured with two different input options and a switch.



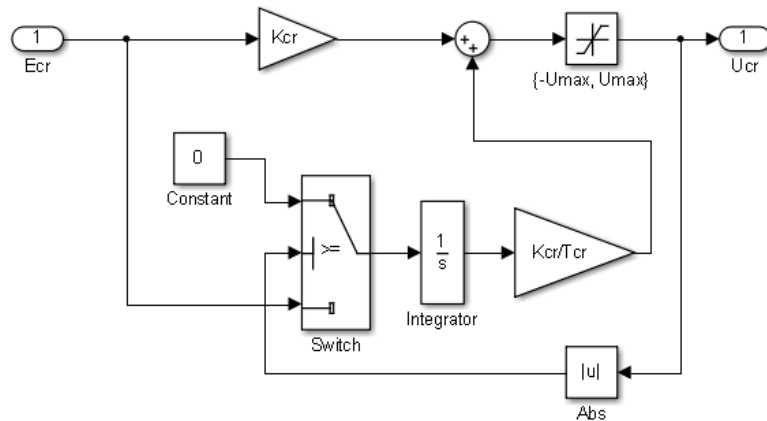
Non-Linear PI-VR

The velocity is regulated by means of the following schematic.



Non-Linear PI-CR

The current is regulated by means of the following schematic.

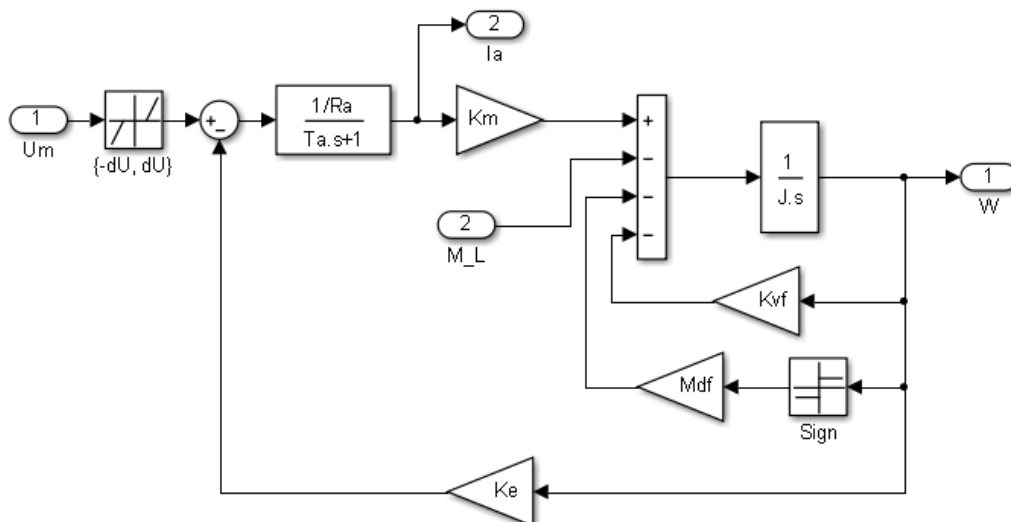
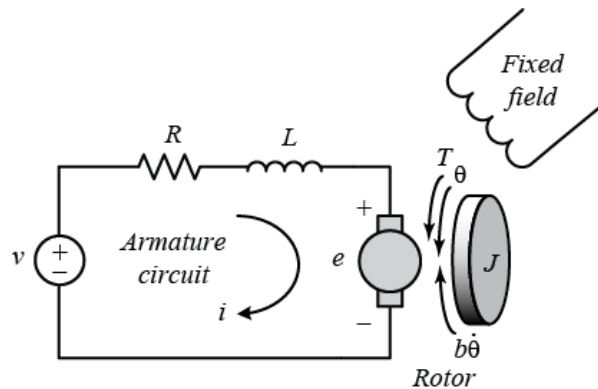


Non-Linear DC Motor

For testing a non-linear DC motor is utilized. This motor is controlled using the previously described non-linear plant.

Motor Constants

- R_a = Electrical Resistance
- L = Electrical Inductance
- K_e = Electromotive force constant
- K_m = Motor torque constant
- J = Moment of inertia of the rotor
- W_{DCM} = Angular motor speed



Results

Control System Details

The previously described control system uses the below values for testing.

Kcs	=10/3	= Current sensor constant
Kvs	=10/600	= Velocity sensor constant
Tcr	=Ta	= Current regulator, Inductance/Resistance constant
Kcr	=5	= Current regulator, Gain constant
Tvr	=8*Tpc	= Velocity regulator, Inductance/Resistance constant
Kvr	=5	= Velocity regulator, Gain constant
Kpc	= 3	= Power controller constant
Tpc	= 0.001	= Power controller Inductance/resistance ratio

Motor Details

A random motor was chosen with the following characteristics. This motor is combined into the previously mentioned plant and is the main component being tested.

Chosen Motor Design Constants

Ra	= 10	Ohms	= Electrical Resistance
L	= 0.1	Henrys	= Electrical Inductance
Ke	= 0.05	V/(rad/sec)	= Electromotive force constant
Km	= Ke	Nm / P ²	= Motor torque constant
J	= 0.5E-5	Kg/m ²	= Moment of inertia of the rotor
W _{DCM}	= (output)	rad/sec	= Angular motor speed

Influence of Parameters

Each parameter g, M_L, dU, Kv_f, and M_d_f was adjusted separately. By doing this, the effect of each parameter on the system can be shown. Each individual parameter is tested and the charts are analyzed to discuss trends. The interaction of these parameters is not investigated.

Effect of g

The charts below show that as the parameter “g” is increased, the following trends occur.

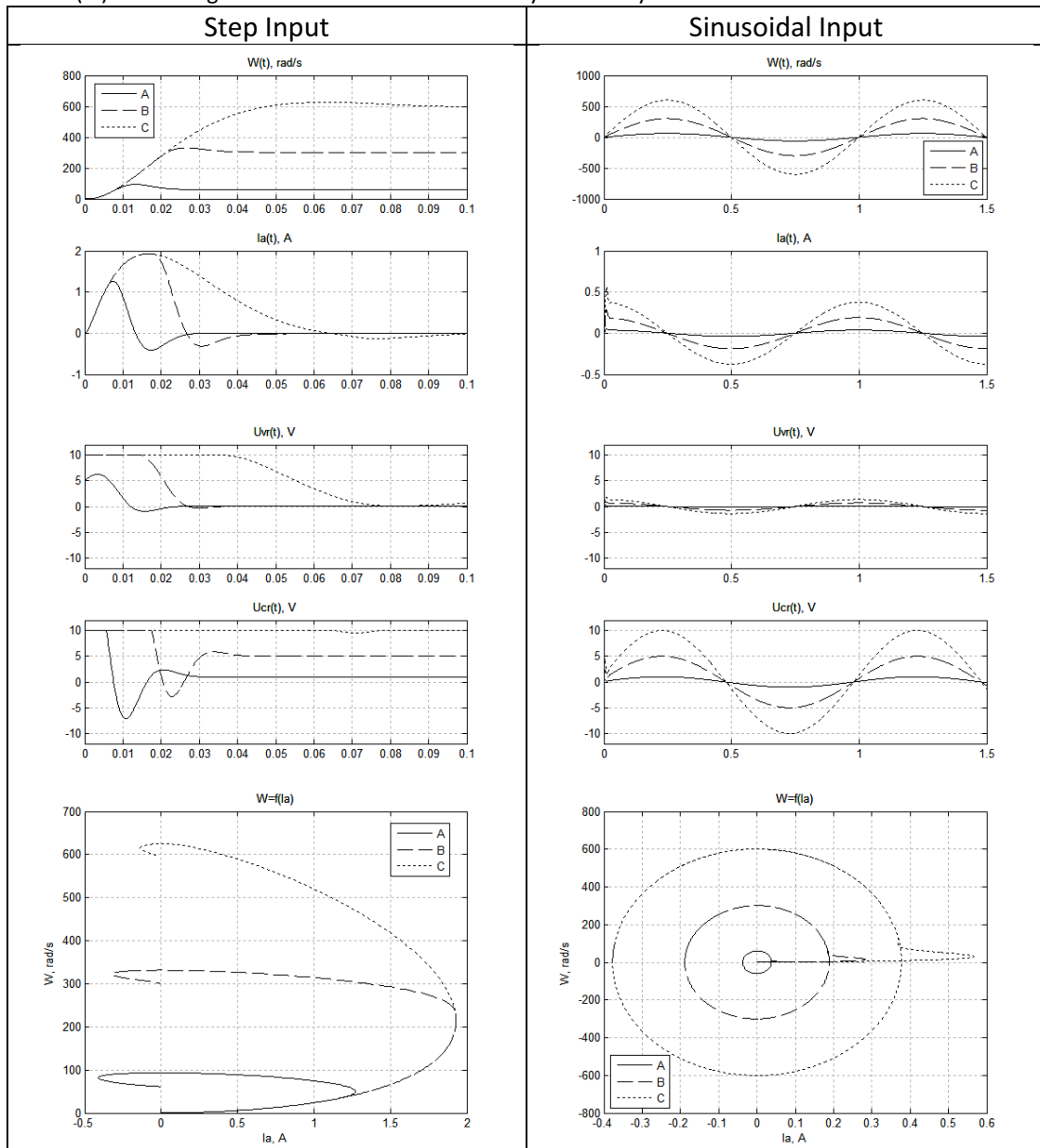
Legend	g	M_L	dU	Kvf	Mdf
A	1	0.00	0	0.0000	0.000
B	5	0.00	0	0.0000	0.000
C	10	0.00	0	0.0000	0.000

Step Input

1. $W(t)$ – The steady state value drastically increases. The overshoot goes away.
2. $I_a(t)$ – The steady state value is not affected. The overshoot drastically increases.
3. $U_{vr}(t)$ – The steady state value always drops to zero. The starting voltage drastically increases.
4. $U_{cr}(t)$ – The stabilization point drastically increases. The overshoot decreases.
5. $W(I_a)$ – The maximum velocity drastically increases. The required amperage increases.

Sinusoidal Input

1. $W(t)$ – The peak increases.
2. $I_a(t)$ – The peak increases.
3. $U_{vr}(t)$ – The peak slightly increases, but the overall magnitude is still very small.
4. $U_{cr}(t)$ – The peak drastically increases.
5. $W(I_a)$ – The magnitude of the maximum velocity drastically increases.



Effect of M_L

The charts below show that as the parameter “ dU ” is increased, the following trends occur.

Note: M_L is applied at the halfway point.

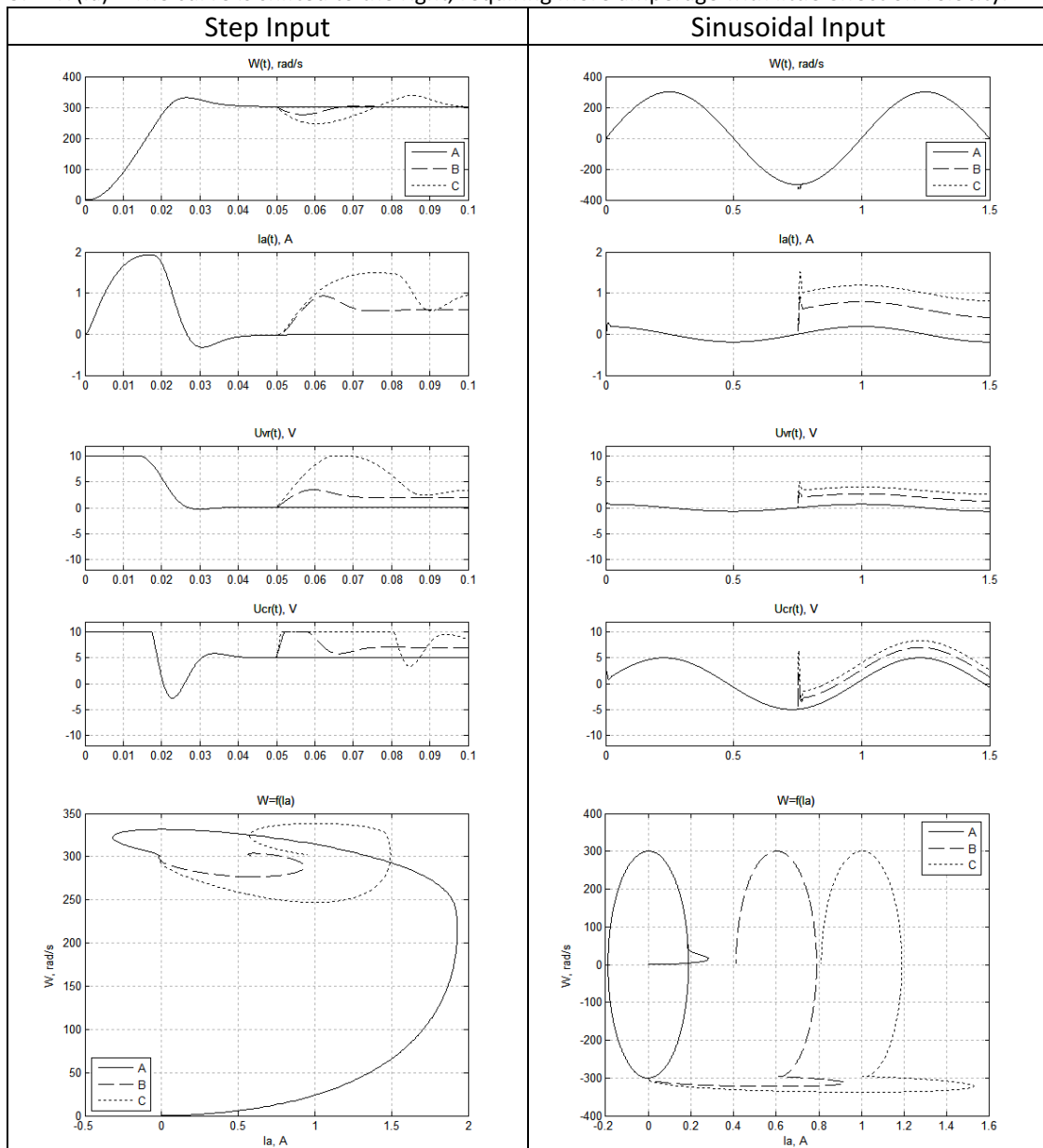
Legend	g	M_L	dU	K_{vf}	M_{df}
A	5	0.00	0	0.0000	0.000
B	5	0.03	0	0.0000	0.000
C	5	0.05	0	0.0000	0.000

Step Input

1. $W(t)$ – An oscillation occurs but it quickly stabilizes back to the steady state value.
2. $I_a(t)$ – A large overshoot occurs. This overshoot comes to a new steady state value.
3. $U_{vr}(t)$ – A large overshoot occurs. This overshoot comes to a new steady state value.
4. $U_{cr}(t)$ – A large overshoot occurs but is clipped at 10. This overshoot has a higher steady state value.
5. $W(I_a)$ – The velocity no longer originates from zero. Lower velocity options have been lost.

Sinusoidal Input

1. $W(t)$ – No change.
2. $I_a(t)$ – The curve is shifted significantly upward.
3. $U_{vr}(t)$ – The curve is shifted upward.
4. $U_{cr}(t)$ – The curve is shifted upward.
5. $W(I_a)$ – The curve is shifted to the right, requiring more amperage with little effect on velocity.



Effect of dU

The charts below show that as the parameter “dU” is increased, the following trends occur.

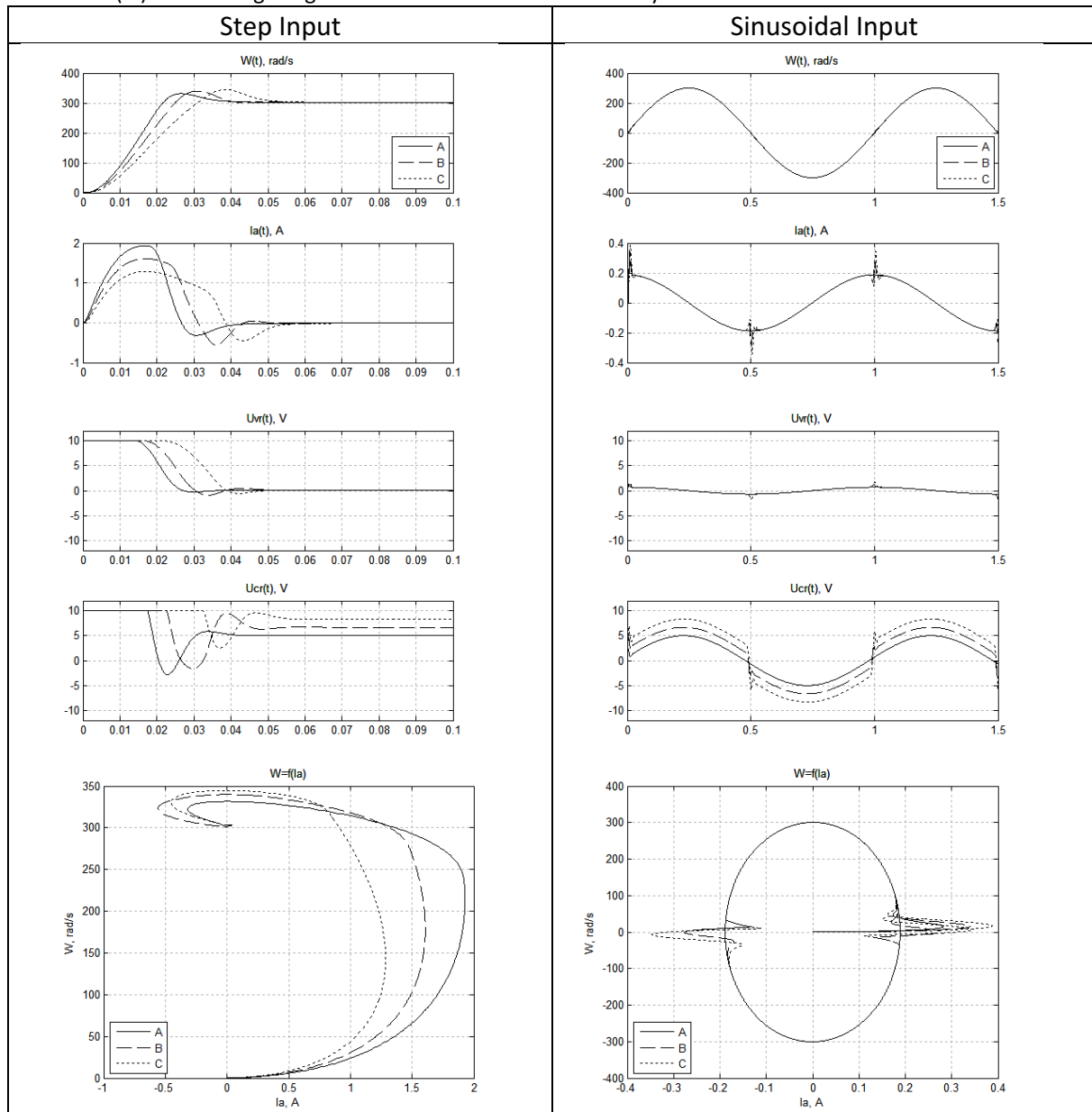
Legend	g	M_L	dU	Kvf	Mdf
A	5	0.00	0	0.0000	0.000
B	5	0.00	5	0.0000	0.000
C	5	0.00	10	0.0000	0.000

Step Input

6. $W(t)$ – The steady state value is not affected. The overshoot shifts to the right.
7. $I_a(t)$ – The steady state value is not affected. The overshoot decreases and shifts to the right.
8. $U_{vr}(t)$ – The steady state value is not affected. The overshoot shifts to the right.
9. $U_{cr}(t)$ – Steady state increases slightly. The overshoot shift significantly to the right.
10. $W(I_a)$ – The required amperage decreases. The maximum velocity slightly increases.

Sinusoidal Input

6. $W(t)$ – No Change.
7. $I_a(t)$ – No Change. Slight disturbance at peaks.
8. $U_{vr}(t)$ – No Change. Slight disturbance at peaks.
9. $U_{cr}(t)$ – Peaks are increased. There is a sudden jump across zero.
10. $W(I_a)$ – No Change. Significant disturbances when velocity is near zero.



Effect of K_{vf}

The charts below show that as the parameter “ K_{vf} ” is increased, the following trends occur.

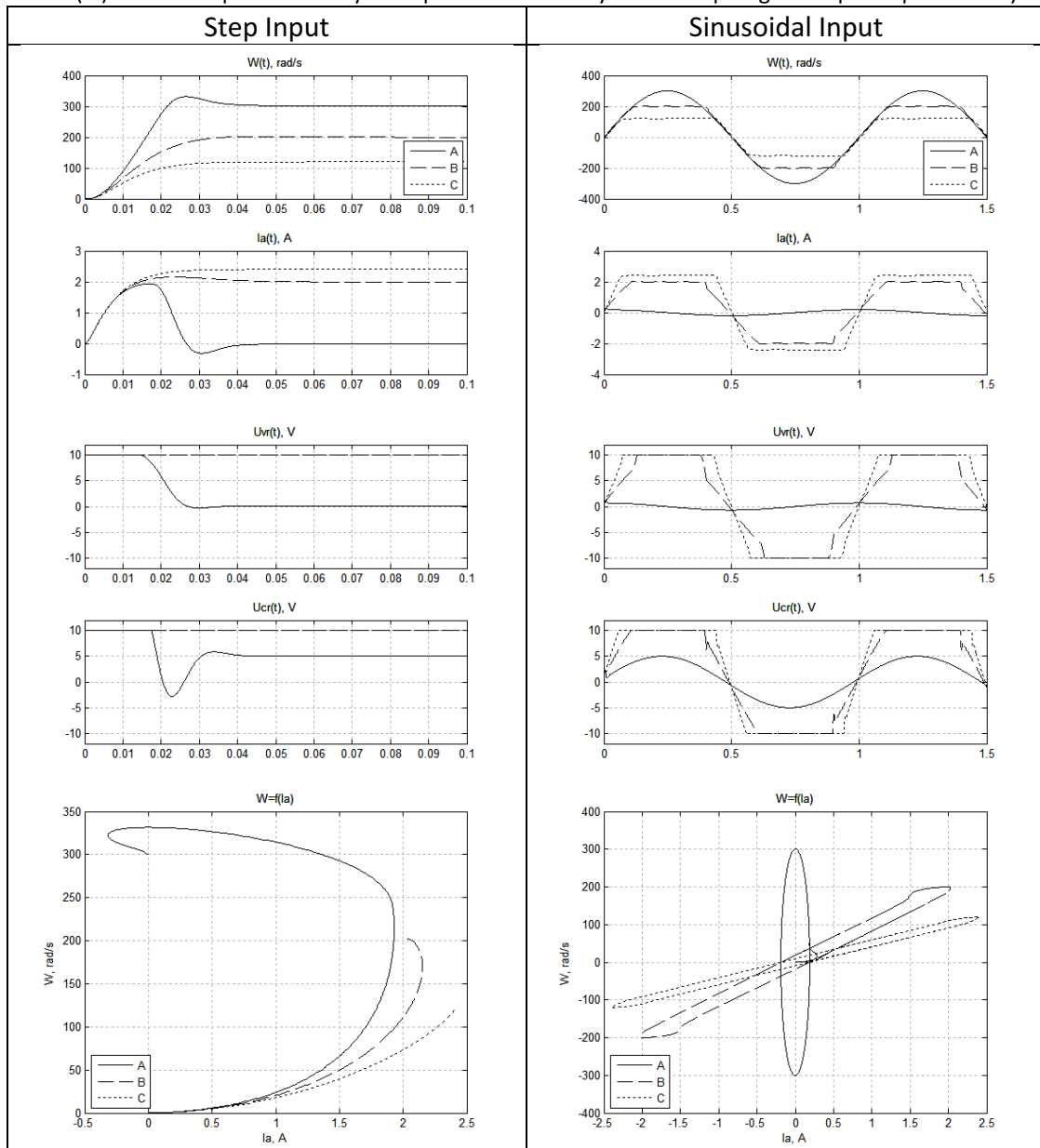
Legend	g	M_L	dU	K_{vf}	M_{df}
A	5	0.00	0	0.0000	0.000
B	5	0.00	0	0.0005	0.000
C	5	0.00	0	0.0010	0.000

Step Input

11. $W(t)$ – The overshoot disappears. The steady state value decreases significantly.
12. $I_a(t)$ – The overshoot disappears. The steady state value increases drastically.
13. $U_{vr}(t)$ – The curve quickly approaches 10, and gets clipped.
14. $U_{cr}(t)$ – The curve quickly approaches 10, and gets clipped.
15. $W(I_a)$ – The curve shifts collapses vertically and expands horizontally to the right.

Sinusoidal Input

11. $W(t)$ – Same curves, except the peaks are clipped.
12. $I_a(t)$ – Peaks are increased, but they are clipped.
13. $U_{vr}(t)$ – Peaks are increased, but they are clipped. Curve appears triangular.
14. $U_{cr}(t)$ – Peaks are increased, but they are clipped. Curve appears triangular.
15. $W(I_a)$ – The collapses vertically ad expands horizontally. More amperage is required per velocity.



Effect of Mdf

The charts below show that as the parameter “Mdf” is increased, the following trends occur.

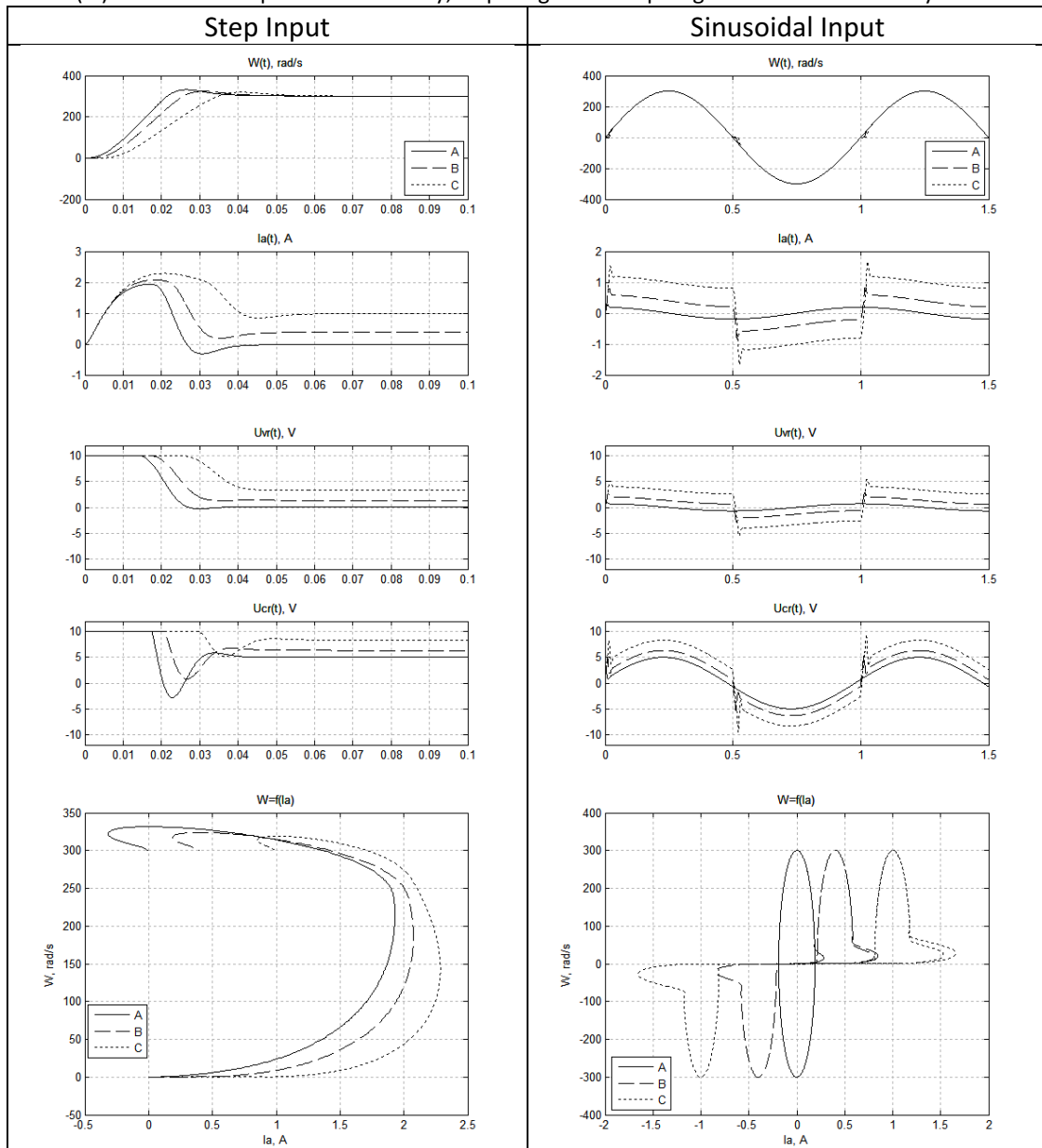
Legend	g	M_L	dU	Kvf	Mdf
A	5	0.00	0	0.0000	0.000
B	5	0.00	0	0.0000	0.02
C	5	0.00	0	0.0000	0.05

Step Input

16. $W(t)$ – The steady state value is not change. The overshoot decreases and shifts to the right.
17. $I_a(t)$ – The steady state value increases. The overshoot increases, is longer, and shifts to the right.
18. $U_{vr}(t)$ – The steady state value increases slightly. The curve shifts to the right.
19. $U_{cr}(t)$ – The steady state value increases slightly. The overshoot decreases and shifts right.
20. $W(I_a)$ – The curve expands horizontally to the right.

Sinusoidal Input

16. $W(t)$ – No change. Minor disturbances near zero velocity.
17. $I_a(t)$ – There is a drastic jump across zero velocity. The peaks are increased.
18. $U_{vr}(t)$ – There is a drastic jump across zero velocity. The peaks are increased.
19. $U_{cr}(t)$ – There is a drastic jump across zero velocity. The peaks are increased.
20. $W(I_a)$ – The curve expands horizontally, requiring more amperage for the same velocity.



Conclusion

Utilizing a step input and a sinusoidal input, a non-linear system with DC motor shows the following changes in response as the parameters g , M_L , dU , K_vf , and Mdf are adjusted independently. However, there may be additional interactions between these parameters, which is not investigated.

- As the parameter “ g ” is increased, the overall achievable range of velocities is drastically increased.
- As the parameter “ M_L ” is increased, the velocity per amperage is increased. However, lower velocities are no longer possible.
- As the parameter “ dU ” is increased, the overall achievable range of angular velocities significantly increase. The achieved velocity occurs at lower amperage.
- As the parameter “ K_vf ” is increased, the overall achievable range of angular velocities drastically decreased. Significant clipping occurred.
- As the parameter “ Mdf ” is increased, the overall achievable range of angular velocities slightly decreased. The required amperage for these velocities increased.

Appendix 1 – Matlab Code

```
% Lab 5
% Analysis of Nonlinear Stabilization System Using Simulink Model
clear all;close all;clc;

%% Model Properties
NonLinearStabSystem
% Simulink-model

%DC Motor
Ra=10;
Ta=0.01;
Ke=0.05;
Km = Ke;
J=0.5e-5;

%Power Controller
Kpc = 3; Tpc = 0.001;
Kcs=10/3;Kvs=10/600;
Tcr=Ta;Kcr=5;Tvr=8*Tpc;Kvr=5;
Umax = 10;

%Simulink Model
%Tend = 0.1; % For step
Tend = 1.5; % For sine
h = Tpc/10;
t_L=Tend/2;

%% Simulation A
%Model Properties
g = 5;
M_L=0.00;
dU=0;
Kvf=0.00000;
Mdf=0.000;
LINE = 'k-';
LegendA = 'A';

%Generate Data
[t,x,W,Ia,Uvr,Ucr]=sim('NonLinearStabSystem',Tend);

%Plot Charts
figure(1);
    subplot(2,1,1);
        plot(t,W,LINE);
        title('W(t), rad/s');
        grid on; hold on;
    subplot(2,1,2);
        plot(t,Ia,LINE);
        title('Ia(t), A');
        grid on; hold on;

figure(2);
    subplot(2,1,1);
        plot(t,Uvr,LINE);
        title('Uvr(t), V');
        grid on; hold on;
        axis([0 Tend -1.2*Umax 1.2*Umax]);
    subplot(2,1,2);
        plot(t,Ucr,LINE); title('Ucr(t), V');
```

```

        grid on; hold on;
        axis([0 Tend -1.2*Umax 1.2*Umax]);

figure(3);
    plot(Ia,W,LINE);
    title('W=f(Ia)'); xlabel('Ia, A');ylabel('W, rad/s');
    grid on; hold on;

%% Simulation B
%%Model Properties
g=5;
M_L=0.00;
dU=0;
Kvf=0.0000;
Mdf=0.02;
LINE = 'k--';
LegendB = 'B';

%%Generate Data
[t,x,W,Ia,Uvr,Ucr]=sim('NonLinearStabSystem',Tend);

%%Plot Charts
figure(1);
    subplot(2,1,1);
        plot(t,W,LINE);
        title('W(t), rad/s');
        grid on; hold on;
    subplot(2,1,2);
        plot(t,Ia,LINE);
        title('Ia(t), A');
        grid on; hold on;

figure(2);
    subplot(2,1,1);
        plot(t,Uvr,LINE);
        title('Uvr(t), V');
        grid on; hold on;
        axis([0 Tend -1.2*Umax 1.2*Umax]);
    subplot(2,1,2);
        plot(t,Ucr,LINE);
        title('Ucr(t), V');
        grid on; hold on;
        axis([0 Tend -1.2*Umax 1.2*Umax]);

figure(3);
    plot(Ia,W,LINE);
    title('W=f(Ia)'); xlabel('Ia, A');ylabel('W, rad/s');
    grid on; hold on;

%% Simulation C
%%Model Properties
g=5;
M_L=0.00;
dU=0;
Kvf=0.0000;
Mdf=0.05;
LINE = 'k: ';
LegendC = 'C';

%%Generate Data
[t,x,W,Ia,Uvr,Ucr]=sim('NonLinearStabSystem',Tend);

```

```

%Plot Charts
figure(1);
    subplot(2,1,1);
        plot(t,W,LINE);
        title('W(t), rad/s');
        grid on; hold on;
    subplot(2,1,2);
        plot(t,Ia,LINE);
        title('Ia(t), A');
        grid on; hold on;

figure(2);
    subplot(2,1,1);
        plot(t,Uvr,LINE);
        title('Uvr(t), V');
        grid on; hold on;
        axis([0 Tend -1.2*Umax 1.2*Umax]);
    subplot(2,1,2);
        plot(t,Ucr,LINE);
        title('Ucr(t), V');
        grid on; hold on;
        axis([0 Tend -1.2*Umax 1.2*Umax]);

figure(3);
    plot(Ia,W,LINE);
    title('W=f(Ia)'); xlabel('Ia, A');ylabel('W, rad/s');
    grid on; hold on;

```