HERITAGE INSTITUTE OF TECHNOLOGY
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Electrical System Design Report

Name- Kazi Masudur Rahaman
4th Year, (8th Semester)
Department - Electrical Engineering
Roll-1759002
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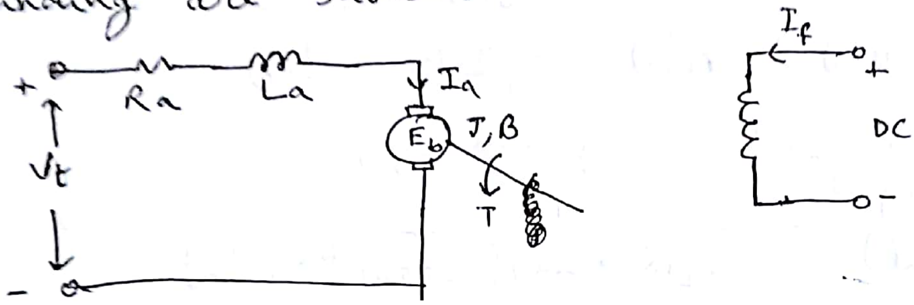
 Kazi Mahmudur Rahman /1759002

Speed Control of Separately Excited DC Motor using armature voltage control in Simulink

In case of separately excited DC Motor, field and armature coils are electrically isolated. Field coil is excited by independent ~~volt~~ DC voltage source, while armature has its own variable supply.

Mathematical Model and Control Theory

The electrical circuit of the armature and field winding are shown



Parameters of separately excited DC Motor

R_a = Armature Resistance
L_a = Armature Self Inductance
I_a = Armature Current
I_f = Field current
E_b = Back emf in armature
V = Applied voltage
T = Torque developed by Motor
θ = Angular displacement of motor shaft
J = Equivalent moment of inertia of motor shaft & load referred to motor
B = Equivalent coefficient of friction of motor shaft and load referred to motor

DC Motors are generally used in the linear range of the magnetization curve. Therefore, air gap flux ϕ is proportional to field current $\phi \propto i_f \Rightarrow \phi = K_f i_f$ ... (i) where K_f is constant

The torque T developed by the motor is proportional to armature current and air gap flux, i.e., $T \propto \phi i_a \Rightarrow T = K_a \phi i_a$

Therefore $T = K i_f i_a$ where K is motor constant ...(2)

In armature controlled DC motor, field current is kept constant, so from equation (i) ... $T_m = K_T i_a$ ...(iii)

where K_T = motor torque constant

The motor back emf being proportional to speed (θ) is given by $e_b = K_b \frac{d\theta}{dt}$ ...(iv) K_b = back emf constant

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The differential equation of armature circuit is

$$L_a \frac{di_a}{dt} + R_a i_a + e_b = e_a \quad \ldots (v)$$

The torque equation is

$$J \frac{d^2\theta}{dt^2} + f_o \frac{d\theta}{dt} = T_M = K_T i_a \quad \ldots (vi)$$

Taking laplace transformation of equation (iii) to (v) assuming zero initial condition, we get,

$$E_b(s) = K_b s \theta(s) \quad \ldots (vii)$$

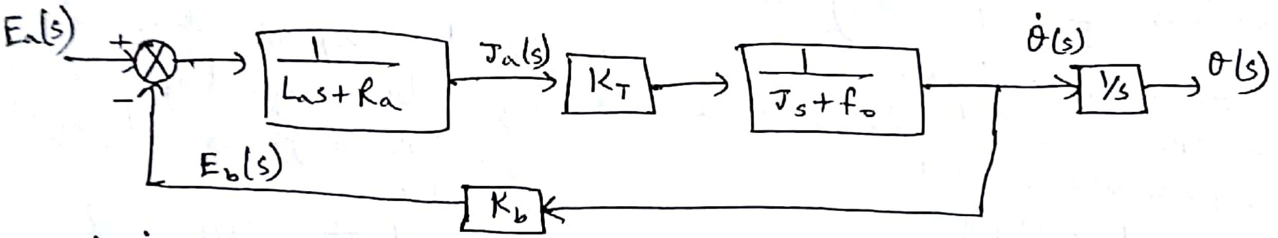
$$(L_a s + R_a) I_a(s) = E_a(s) - E_b(s) \quad \ldots (viii)$$

$$(Js^2 + f_o s)\theta(s) = T_M(s) = K_T I_a(s) \quad \ldots (ix)$$

Thus, transfer function is given by,

$$G(s) = \frac{\theta(s)}{E_a(s)} = \frac{K_T}{s[(R_a + sL_a)(Js + f_o) + K_T K_b]} \quad \ldots (x)$$

Block diagram :-



Speed $\dot{\theta}(s)$ is in rad/s unit (equivalent to ω)

$$\underset{(rad/s)}{\omega} = \frac{2\pi N(rpm)}{60} \quad \therefore N(rpm) = \left(\frac{30}{\pi}\right)\omega \text{ rad/s}$$

Field controlled DC Motor is open loop while armature controlled DC Motor is closed loop system and thus preferred. For small size motor, field control is advantageous because only a low power servo amplifier is required while armature current is not large. For large size motor, it is on the whole cheaper to use armature control scheme. Further in armature controlled motor, back emf contributes additional damping over and above load friction.

$$E_a(s) \rightarrow \boxed{\frac{K_T}{s[(R_a+sL_a)(Js+f_o)+K_T K_b]}} \rightarrow \theta(s)$$

From this simplified equation of transfer function, the armature inductance is very small in practice, hence the transfer function of DC motor speed to input voltage can be

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simplified as follows, $G_1(s) = \frac{\dot{\theta}(s)}{E_a(s)} = \frac{K_m}{\mu s+1} \ldots$

where, $K_m = \frac{K}{R_a B + K_b K_T}$ is the motor gain

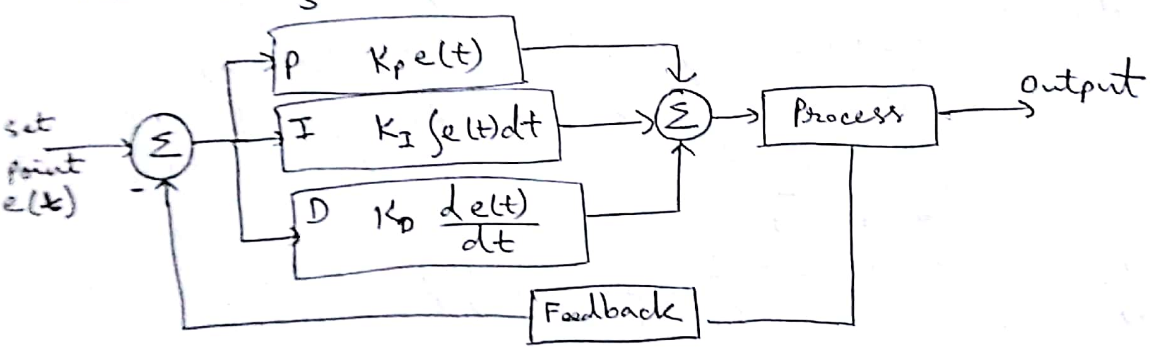
and $\mu = \frac{R_a J}{R_a B + K_b K}$ is motor time constant

Proportional - Integral - Derivative Controller Addition to circuit

A PID controller / Proportional - Integral - Derivative controller is a generic control loop feedback mechanism widely used in industrial control systems.

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In this section, the method to obtain the controller of a process is described using PID scheme. The transfer function of PID controller has form like

$$G(s) = K_P + \frac{K_I}{s} + K_D s$$

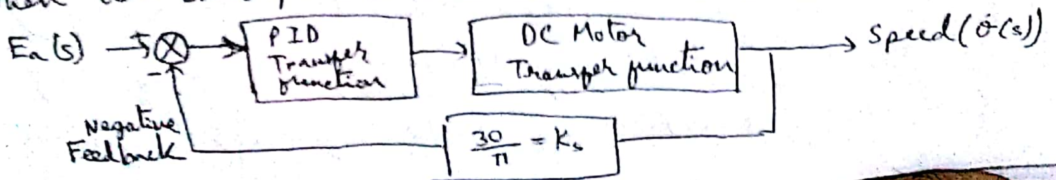


In our case, we know $W\ (\text{rad/s}) = \frac{2\pi N}{60}\ (\text{rpm})$

Transfer function of PID $= P + \frac{I}{s} + \frac{DN}{1+\frac{N}{s}} = \frac{Ps(s+N) + I(s+N) + DNs^2}{s(s+N)}$

$$= \frac{s^2 DN + sI + NI + Ps^2 + PsN}{s^2 + Ns}$$

When we incorporate PID controller in our circuit



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So, our DC Motor TF is $\dfrac{K_T}{s[(R_a+sL_a)(Js+f_o)+K_T K_b]}$

and PID Transfer equation derivation continues to,

$$PID(s) = \frac{s^2DN + sI + NI + s^2P + PsN}{s^2+Ns} = \frac{(DN+P)s^2 + (I+PN)s + NI}{s^2+Ns}$$

On adding DC Motor & PID controller

$$G(s) = \frac{K_T(DN+P)s^2 + K_T(I+PN)s + K_T NI}{s^3+Ns^2[(R_a+sL_a)(Js+f_o)+K_T K_b]}$$

$$= \frac{(DNK_T + PK_T)s^2 + (K_T I + PNK_T)s + K_T NI}{s^5 JL_a + s^4(f_oL_a + JR_a + NJL_a) + s^3(f_oR_a + K_TK_b + NJR_a + Nf_oL_a) + s^2(Nf_oR_a + NK_TK_b)} \quad \dots (7)$$

Now we are considering the feedback ~~ab~~ loop also,

Overall TF $= \dfrac{G(s)}{1+G(s)H(s)}$ (for negative feedback)

$G(s)$ = Forward TF derived in eqn (7)

$H(s)$ = feedback TF $= K_s$

We assume $JL_a = 8\times10^{-4} \approx 0$, So overall TF will look like

$$\frac{G(s)}{1+G(s)H(s)} = \frac{\overbrace{(DNK_T+PK_T)}^{A}s^2 + \overbrace{(K_TJ+PNK_T)}^{B}s + \overbrace{K_TNI}^{C}}{s^4\underbrace{(f_oL_a+JR_a+NJL_a)}_{D} + s^3\underbrace{(f_oR_a+K_TK_b+NJR_a+Nf_oL_a)}_{E} + s^2\underbrace{(Nf_oR_a+NK_TK_b+DNK_TK_s+PK_TK_s)}_{F}s + s\underbrace{(K_TIK_s+PNK_TK_s)}_{G} + \underbrace{K_TK_sNI}_{H}}$$

$$\frac{Y(s)}{U(s)} = \frac{As^2+Bs+C}{Ds^4+Es^3+Fs^2+Gs+H} = \frac{Y(s)}{X_1(s)}\,\frac{X_1(s)}{U(s)}$$

$$\frac{X_1(s)}{U(s)} = \frac{1}{s^4D+s^3E+s^2F+sG+H}$$

$$s^4DX_1(s) + s^3EX_1(s) + s^2FX_1(s) + sGX_1(s) + HX_1(s) = U(s) \quad \dots (a)$$

$$Y(s) = As^2X_1(s) + BsX_1(s) + CX_1(s)$$

$\mathcal{L}[x_1(t)] = X_1(s)$ $\qquad x_3(t) = \dot{x}_2(t) = \ddot{x}_1(t)$

$x_2(t) = \dot{x}_1(t)$ $\qquad x_4(t) = \dot{x}_3(t) = \dddot{x}_1(t)$

$y(t) = A\ddot{x}_1(t) + B\dot{x}_1(t) + Cx_1(t) = Ax_3(t) + Bx_2(t) + Cx_1(t)$

$$\ddddot{x}_1(t) + \left(\frac{E}{D}\right)\dddot{x}_1(t) + \left(\frac{F}{D}\right)\ddot{x}_1(t) + \left(\frac{G}{D}\right)\dot{x}_1(t) + \left(\frac{H}{D}\right)x_1(t) = \frac{1}{D}u(t)$$

$$\dot{x}_4(t) = -\frac{E}{D}x_4(t) - \frac{F}{D}x_3(t) - \frac{G}{D}x_2(t) - \frac{H}{D}x_1(t) + \frac{1}{D}u(t)$$

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State Equation $\dot{X} = [A_1]X + [B_1]V$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -H/D & -G/D & -F/D & -E/D \end{bmatrix}}_{A_1} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 0 \\ 0 \\ 1/D \end{bmatrix}}_{B_1} V$$

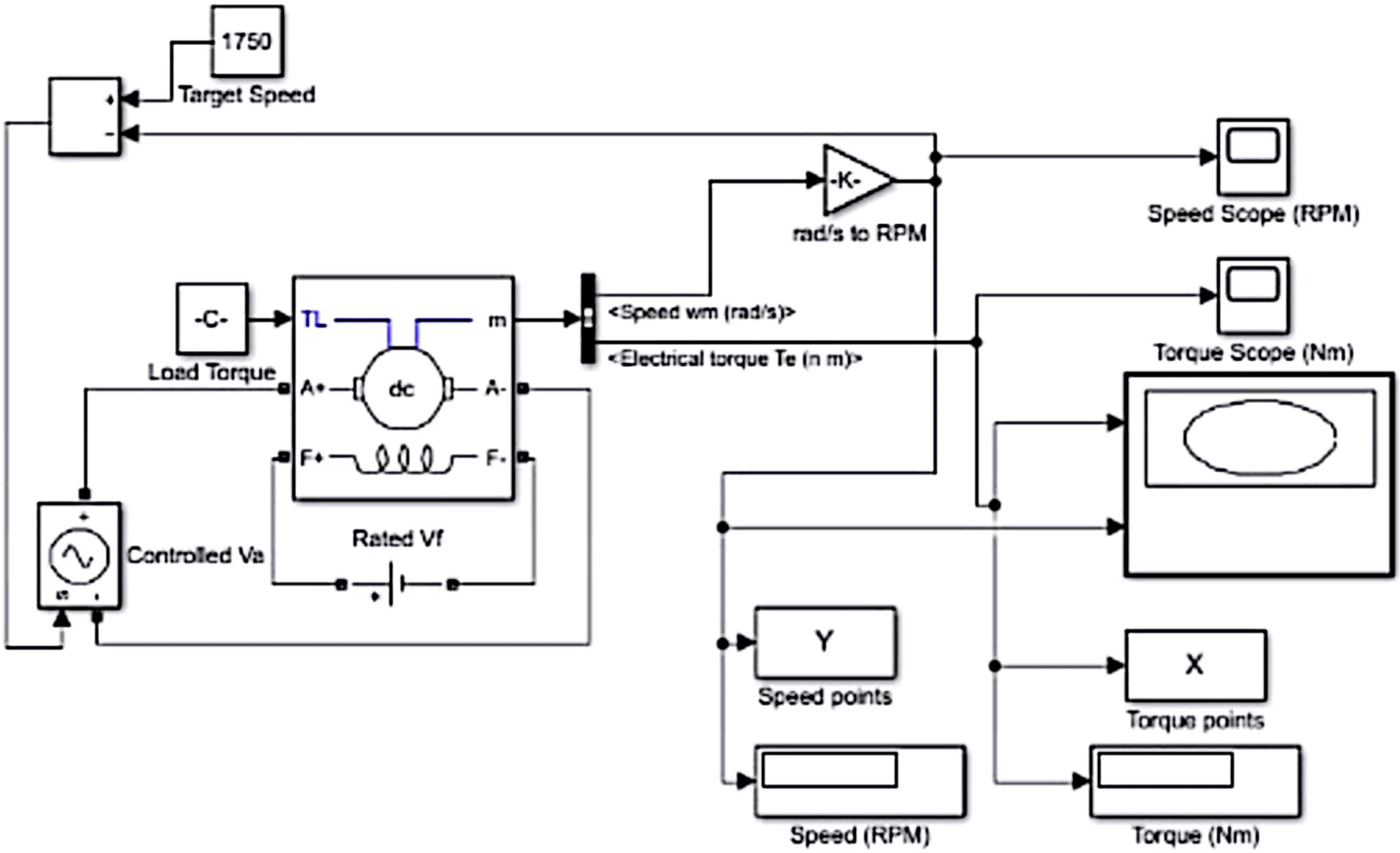
$$y = \underbrace{\begin{bmatrix} C & B & A & 0 \end{bmatrix}}_{C_1} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \underbrace{[0]}_{D_1} V$$

Parameters taken for building model

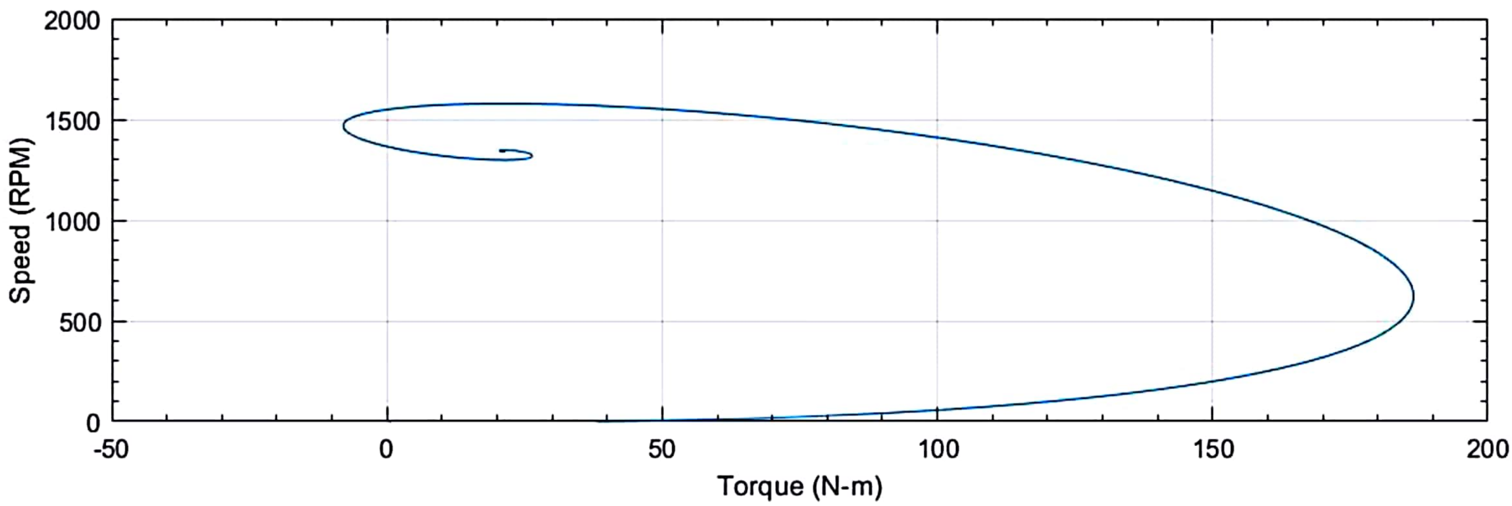
Rating :- 5 HP, 1750 RPM, Field voltage = 300 V

Calculated rated torque = $\frac{5\,HP}{1750\,RPM}$ = 20.3536 Nm = Load Torque

Armature Resistance (R_a) = 11.2 Ω
Armature Inductance (L_a) = 0.1215 H
Field Resistance (R_f) = 281.03 Ω
Field Inductance (L_f) = 156 H
Field Armature Mutual Inductance (L_{af}) = 1.976 H
Total inertia J = 0.02215 kgm^2
Viscous friction coefficient B_m = 0.002953 Nms
Coulomb friction Torque T_f = 0.576 Nm
rad/s to RPM gain = 9.5493
Target speed = 1750 rpm



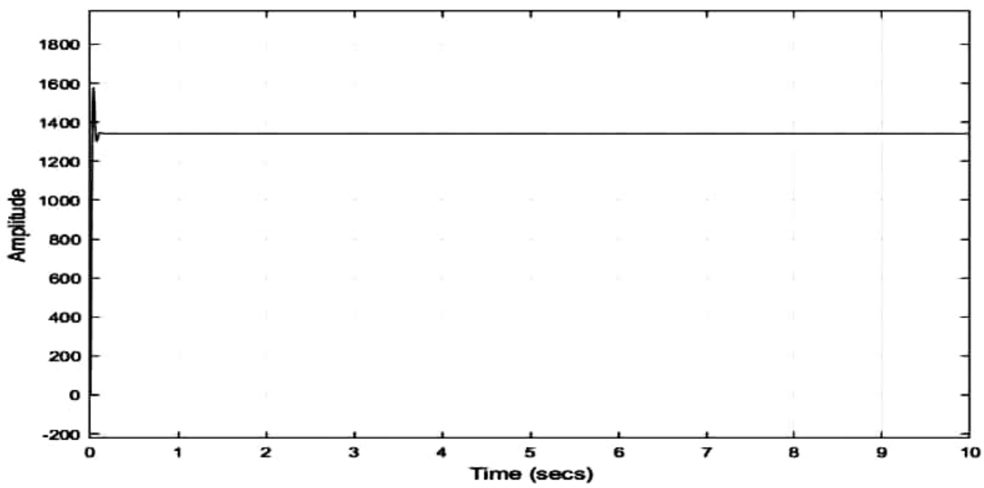
Circuit without PID Controller



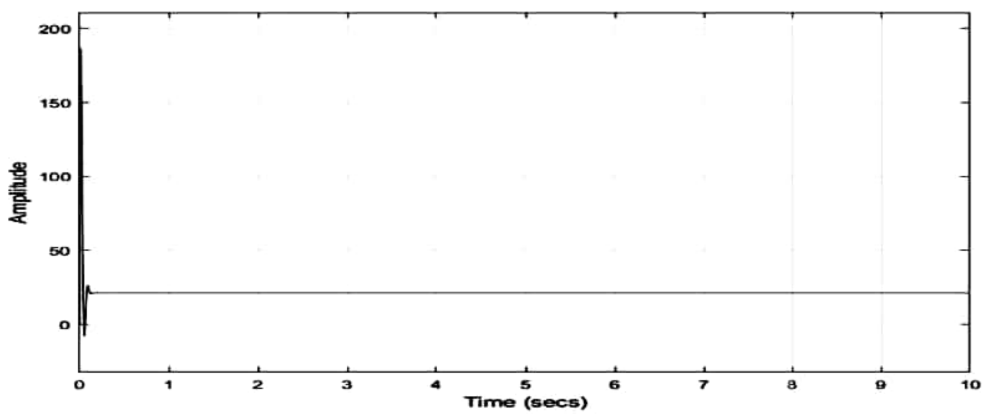
Output without PID Controller

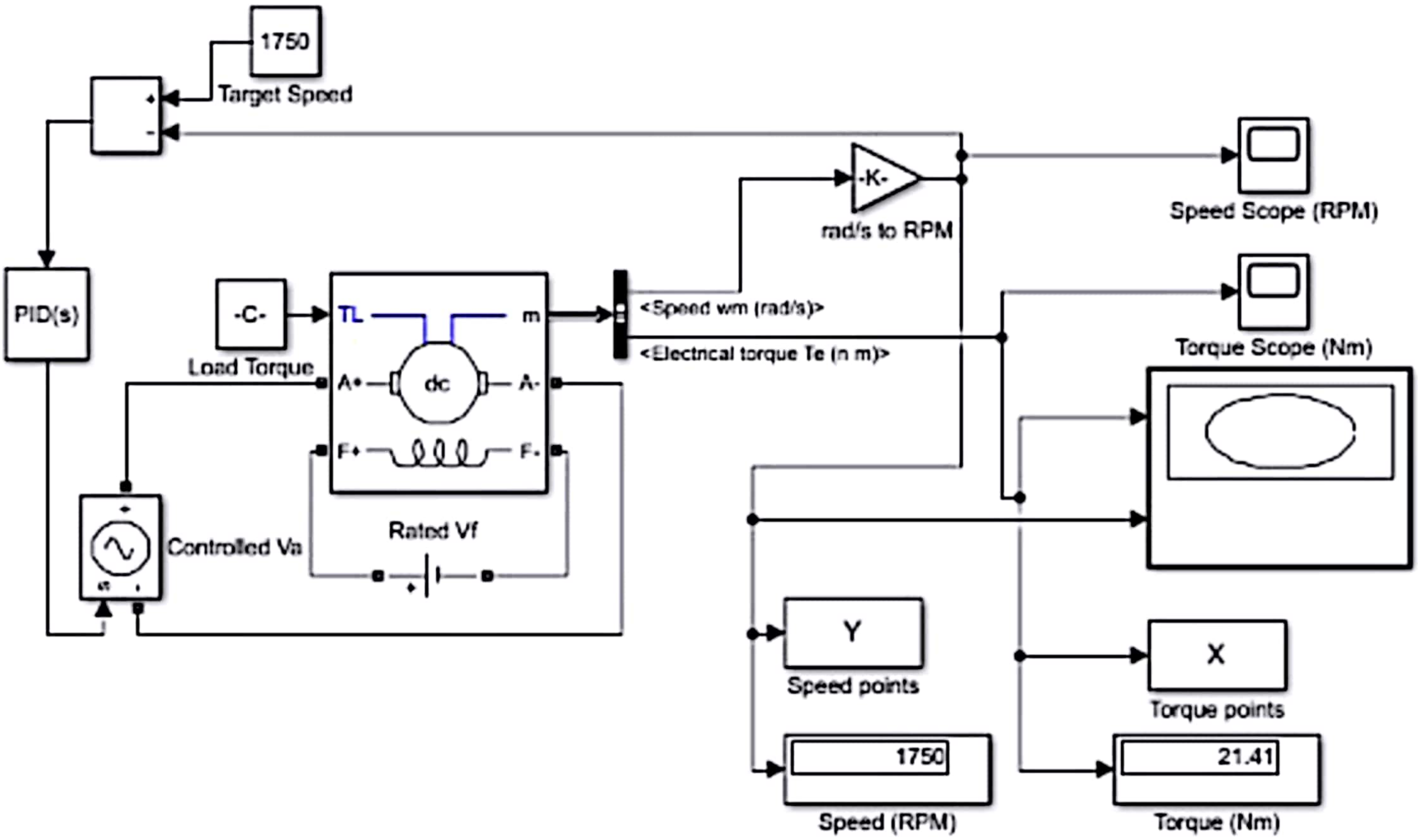
Without PID

Speed v/s Time
(without PID)

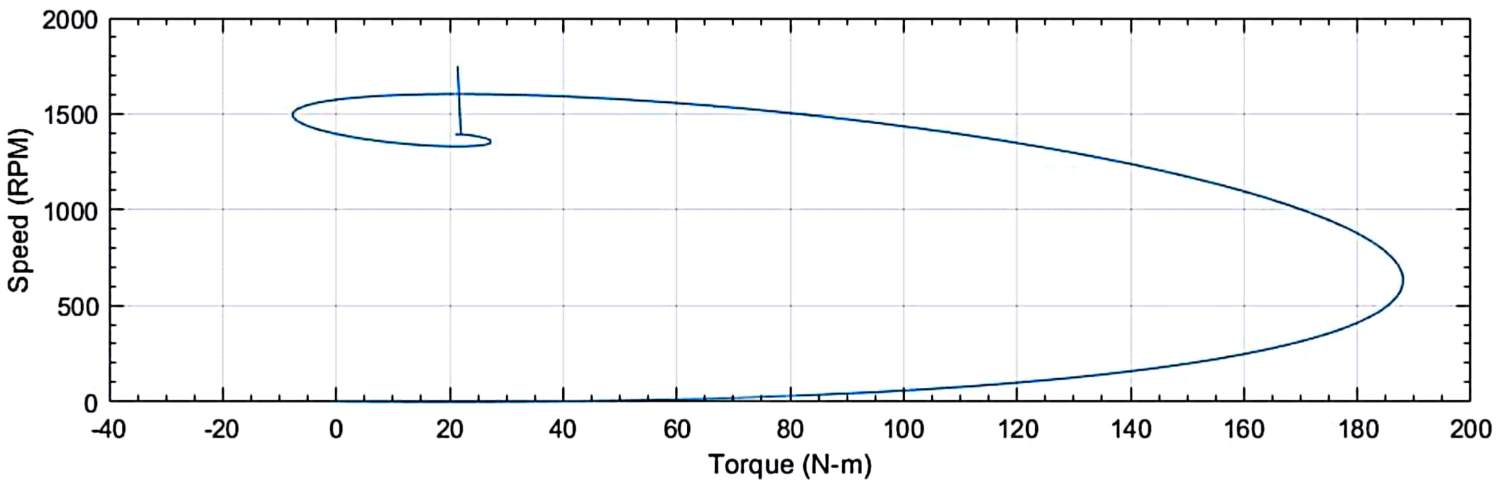


Torque v/s Time
(without PID)





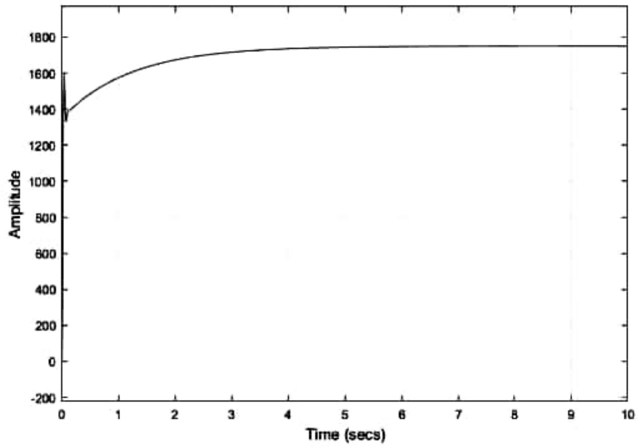
Circuit with PID Controller



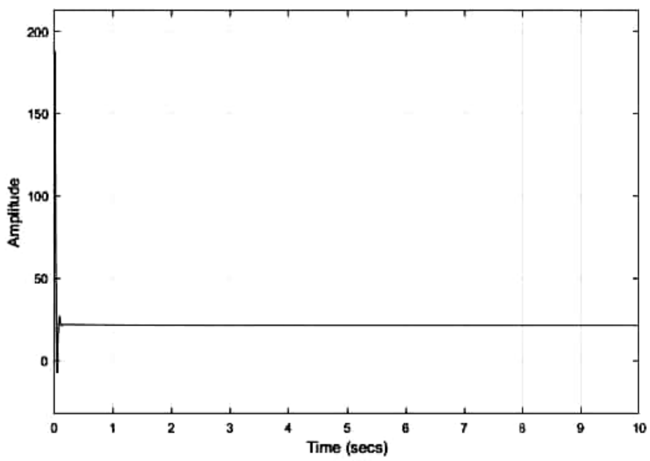
Output with PID Controller

With PID

Speed v/s Time



Torque v/s Time



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Power System Design

Distribution System Design of Ideal City (Block A)

Step I

Survey of model town
Dividing roads into small segments
Identify load position
We will calculate load street light load and we are putting street light hundred meter apart

We are going to collect and organize data in following format :-

Road segment No
Road length in map (cm)
Actual road length (m)
Road width in map (cm)
Actual road width (m)
Lighting wattage (W)
Lighting type (both side for each entry)
Number of light
Total wattage (kW)

And the total road length in actual is 35514 meters
Number of lights used - 708 pieces
Total wattage in kW = 141.6


IDEAL CITY FOR ELECTRIC
PROJECT.
BLOCK-A
BLOCK-B
BLOCK-C
BLOCK-D
STANDARD PHARMACEUTICAL WORKS
PARK
FACTORY QUARTER
HIGH SCHOOL
GIRLS SCHOOL
COLLEGE
V.C. BANGLO
HOSPITAL QUARTER
D.M. OFFICE
GUPTA PARA STATION
STATION MASTER BANGLOW
STADIUM
STADIUM FOR SWIMING
RLY QUARTER
WATER WORKS
MUNICIPAL MARKET
MUNICIPAL OFFICE
STATE BANK
BANK QUARTER
UCO BANK
POST OFFICE
WATER TANK
FACTORY QUARTER
RLY QUARTER
BHAGABANPUR STATION
STATION ROAD
BIRLA IRON AND STEEL WORKS LTD.
NEHERU STADIUM
UCO BANK
STATE BANK
TELEPHONE EXCHANGE
POLICE STATION & QUARTER
TOWN D.S.P. OFFICE
STAFF QUARTER
RABINDRA SADAN
AGRICULTURAL OFFICE
TELEPHONE EXCHANGE
RATION OFFICE QUARTER
F. C. I. GODOWN
UCO BANK HEAD OFFICE
STATE BANK HEAD OFFICE
NATIONAL STADIUM FOR SWIMING
ROY ROAD
BANK QUARTER
MEDICAL COLLEGE HOSPITAL
GIRL'S SCHOOL
PARK
GENERAL POST OFFICE
POST OFFICE QUARTER
BUS STAND
RATION OFFICE
K. G. SCHOOL
F.C.I. GODOWN
MUNICIPAL OFFICE
MUNICIPAL MARKET
HIGH SCHOOL
POLICE STATION
UNIVERSITY QUARTER
INDIRA GANDHI UNIVERSITY
MARKET
WATER TANK
MUNICIPAL MARKET
RAMKRISHNA MISSION SCHOOL
RABINDRA SADAN
MEDICAL SHOP
HIGH SCHOOL
POST OFFICE
POLICE STATION
BUS STAND
D.M. BANGLOW
S. D. O. BANGLOW
NEHERU HOSPITAL
MEDICAL OFFICERS AND STAFF QUARTER
RATION SHOP
STATE BUS STAND
M. L. A. HOSTEL

Distribution System Design Of Ideal City (Block - A)

STEP - I

Survey of Model Town. Divide the rods into small segments. Identify load position.

Calculate total street light load. Put street light 100 meter apart and

STREET LIGHT LOAD

Road segment no.	Road length in map (cm)	Actual road length (m)	Road width in map(cm)	Actual road width (m)	Lighting wattage (W)	Lighting Type	No. of light	Total Wattage (KW)
1	4.9	490	0.5	50	200	Both Side	10	2
2	30	3000	0.5	50	200	Both Side	60	12
3	3	300	0.5	50	200	Both Side	6	1.2
4	5	500	0.5	50	200	Both Side	10	2
5	7	700	0.5	50	200	Both Side	14	2.8
6	9.5	950	0.5	50	200	Both Side	19	3.8
7	12	1200	0.5	50	200	Both Side	24	4.8
8	1	100	0.5	50	200	Both Side	2	0.4
9	3	300	0.5	50	200	Both Side	6	1.2
10	4.2	420	0.5	50	200	Both Side	8	1.6
11	15.5	1550	0.5	50	200	Both Side	31	6.2
12	17	1700	0.5	50	200	Both Side	34	6.8
13	4.7	470	0.5	50	200	Both Side	9	1.8
14	4.5	450	0.5	50	200	Both Side	9	1.8
15	4.7	470	0.5	50	200	Both Side	9	1.8
16	4.7	470	0.5	50	200	Both Side	9	1.8
17	3.2	320	0.5	50	200	Both Side	6	1.2
18	4.9	490	0.5	50	200	Both Side	10	2
19	4.5	450	0.5	50	200	Both Side	9	1.8
20	4.2	420	0.5	50	200	Both Side	8	1.6
21	5	500	0.5	50	200	Both Side	10	2
22	5.3	530	0.5	50	200	Both Side	11	2.2
23	5.5	550	0.5	50	200	Both Side	11	2.2
24	8.5	850	0.5	50	200	Both Side	17	3.4
25	13.2	1320	0.5	50	200	Both Side	26	5.2
26	3.3	330	0.5	50	200	Both Side	7	1.4
27	9.5	950	0.5	50	200	Both Side	19	3.8
28	9	900	0.5	50	200	Both Side	18	3.6
29	2	200	0.5	50	200	Both Side	4	0.8
30	2.5	250	0.5	50	200	Both Side	5	1
31	7.7	770	0.5	50	200	Both Side	15	3
32	2	200	0.5	50	200	Both Side	4	0.8
33	8	800	0.5	50	200	Both Side	16	3.2
34	6.5	650	0.5	50	200	Both Side	13	2.6
35	3.5	350	0.5	50	200	Both Side	7	1.4
36	11.5	1150	0.5	50	200	Both Side	23	4.6
37	5	500	0.5	50	200	Both Side	10	2
38	5	500	0.5	50	200	Both Side	10	2
39	8.5	850	0.5	50	200	Both Side	17	3.4
40	5	500	0.5	50	200	Both Side	10	2
41	3.5	350	0.5	50	200	Both Side	7	1.4
42	4.5	450	0.5	50	200	Both Side	9	1.8
43	16.5	1650	0.5	50	200	Both Side	33	6.6
44	20	2000	0.5	50	200	Both Side	40	8
45	33.5	3350	0.5	50	200	Both Side	67	13.4
46	3.14	314	0.5	50	200	Both Side	6	1.2
Total		**35,514.00**					**708**	**141.6**

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Step II Estimation of different types of loads

Each flat load to be computed as:

Item	Watt/unit	Qty	Total wattage
Tube light	40	4	160
Bulb	60	5	300
Fan	80	3	240
TV	120	2	240
Refrigerator	350	1	350

Each flat total load = 1290 W
= 1.29 kW

Domestic Load Description:

Type of Building	Flat/Building	Total No of Building	Total no of flat	Load/building (kW)	Total Building Load (kW)
2-Storied	4	300	1200	5.16	1548
3-Storied	6	120	720	7.74	928.8
Multi Storied	10	50	500	12.9	645
Station master bungalow					15
MLA Hostel					26
			2420 (Total flats)		3162.8 (Total load)

∴ Total 3162.8 kW domestic load in 2420 flats

Commercial Load calculation:

Item	Load (kW)
United Bank	15
State Bank	15
Police Station 1	100
Police station 2	100
Market	40
New Market	40
Post office	5

Item	Load (kW)
Bus Stand 1	3
Bus Stand 2	3
High Court	40
Office	10
FCI Ord.	30
Kali Temple	10
Medical college	50
Telecom executive	30

Total Commercial Load is 491 kW

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Industrial Load Calculation:

Item	Load(kW)
Steel & iron factory	150
Ashok rubber factory	100
Ink Factory	50
K Dutta Glass Factory	100
Ghosh & Dutta works Ltd	75
Total	475

Public Load Calculation:

Item	Load(kW)
High School	30
Girls School	30
KG School	8
Railway Station	40
Bidhan College & Hospital	50
Girls College & Hostel	50
Water Works	1670
Water Tank	850
Total	2728

Capacity Calculation of Water Works:

Water consumption/head/day = 20 ltr (assume)

Total population = (Total no of flats × person per flat) + outsiders per day

= 2420 × 6 + 30% (2420×6) = 18876

Total water consumption = 18876 × 20 = 377520 ltr/day

Total water generation = 377520 + 10% (wastage) = 415272 ltr/day

Supply time = 5hr/day   Pump size = 3000 ltr/day   Motor size = 420kW

$$\text{No of pump} = \frac{\text{Total water consumption}}{\text{Pump Capacity} \times \text{Supply time}} = 6$$

Total power consumption = 2520kW

Power consumption for filling water = (420×2+10) = 850kW

Therefore actual power consumption = 2520 − 850 = 1670kW

Each Area Load (LT)

Domestic Load	3163kW
Street light load	142kW
Public load	208kW
Commercial load	491kW
Industrial load	0
Total	4003 kW

Each Area Load (HT)

Public Load	2520kW
Commercial load	0kW
Industrial load	475kW
Total	2995 kW

Total connected load (HT+LT) = 6998 kW

SL. NO.	**Load Type**		**Qty**	**Power consumtion(kW Each)**
1	DOMESTIC	Multistorried building	50	
2	DOMESTIC	3- Storried building	120	
3	DOMESTIC	2- Storried building	300	
4	DOMESTIC	Station master banglo	1	
5	DOMESTIC	M.L.A. HOSTEL	1	
6	PUBLIC	Water works	1	
7	PUBLIC	Water tank	1	
8	PUBLIC	Railway station	1	40
9	PUBLIC	High school	1	30
10	PUBLIC	Girl's school	1	30
11	PUBLIC	K.G. SCHOOL	2	4
12	COMMERCIAL	United bank	1	15
13	COMMERCIAL	State bank	1	15
14	COMMERCIAL	Police station	1	10
15	COMMERCIAL	Market	2	40
16	COMMERCIAL	Post office	2	5
17	COMMERCIAL	bus stand	1	3
18	COMMERCIAL	High court	1	40
19	COMMERCIAL	High school	1	20
20	COMMERCIAL	FCI Godown	1	30
21	COMMERCIAL	Kali Temple	1	10
22	COMMERCIAL	Telephone exchange	1	30
23	INDUSTRIAL	Steel and iron factory	1	150
24	INDUSTRIAL	Ashoke rubber factory	1	100
25	INDUSTRIAL	Ink factory	1	50
26	INDUSTRIAL	K.Dutta glass factory Ltd.	1	100
27	INDUSTRIAL	Ghosh &duttasons Works Ltd.	1	75

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Step III

Area II

Loop A

Total connected load in kW

Domestic load	1981
street light Load	78
Public load	954
Commercial load	148
Industrial load	300
Total	3461

Loop B

Total connected Load in kW

Domestic load	= 1285
street light load	= 63
Public load	= 1770
Commercial load	= 168
Industrial load	= 175
Total	3462

Now we can see from attached chart, the estimated demand factor of different loads of summer & winter (hourly basis for 24 hrs of the day in step of 4 hrs)

Calculating effective load on hourly basis for different loops (for summer & winter):

For loop A summer

Duration (hrs)

	6-10	10-14	14-18	18-20	20-22	22-02	02-06
Total connected load	1328.59	1617.05	1318.51	2164.01	2023.95	940.95	940.95

For loop A winter

Duration (hrs)

	5.30-9.30	9.30-13.30	13.30-17.30	17.30-19.30	19.30-21.30	21.30-1.30	1.30-5.30
Total connected load	870.35	1389.15	1044.95	1836.9	1381.1	536.5	536.5

For loop B winter

	5.30-9.30	9.30-13.30	13.30-17.30	17.30-19.30	19.30-21.30	21.30-1.30	1.30-5.30
Total connected load	742.58	1849.6	1150.00	1338.21	1030.05	473.23	473.23

Divition of Loops :

Loop No.	Domestic Laod (KW)	Street Light Load (KW)	Public Load (KW)	Commercial Load (KW)	Industrial Load (KW)
Loop - A [o]	50	78.2	850	3	50
Loop - A [o]	50		4	30	100
Loop - A [o]	77.4		30	15	150
Loop - A [o]	108.2		30	5	
Loop - A [o]	195.8		40	30	
Loop - A [o]	115.9			15	
Loop - A [o]	149.2			40	
Loop - A [o]	154			10	
Loop - A [o]	193				
Loop - A [o]	87.6				
Loop - A [o]	90.1				
Loop - A [o]	51.6				
Loop - A [o]	51.6				
Loop - A [o]	51.6				
Loop - A [o]	82.6				
Loop - A [o]	51.6				
Loop - A [o]	30.8				
Loop - A [o]	90.1				
Loop - A [o]	51.6				
Loop - A [o]	77.4				
Loop - A [o]	40				
Loop - A [o]	115.9				
Loop - A [o]	15				
TOTAL	**1981**	**78.2**	**954**	**148**	**300**

Loop No.	Domestic Laod (KW)	Street Light Load (KW)	Public Load (KW)	Commercial Load (KW)	Industrial Load (KW)
Loop - B [*]	159.8	63.4	1670	50	75
Loop - B [*]	61.8		50	5	100
Loop - B [*]	157.3		50	40	
Loop - B [*]	229.2			10	
Loop - B [*]	201.2			10	
Loop - B [*]	50			10	
Loop - B [*]	118.3			3	
Loop - B [*]	26			40	
Loop - B [*]	50				
Loop - B [*]	164.7				
Loop - B [*]	67				
TOTAL	**1285.3**	**63.4**	**1770**	**168**	**175**

Note: Highlited Cells are HT Load

ii) Calculate effective load on hourly basis for different loops (for summer & winter)

For Loop - A Summer

Type of load	Total connected Load (KW)	Duration (hrs)						
		06 -- 10	10 -- 14	14 -- 18	18 -- 20	20 -- 22	22 -- 02	02 -- 06
Domestic	1981	693.35	495.25	495.25	1485.75	1485.75	495.25	495.25
Street Light	78.2	0	0	0	78.2	78.2	78.2	78.2
Public	954	343.44	763.2	524.7	238.5	190.8	143.1	143.1
Commercial	148	51.8	103.6	106.56	106.56	59.2	44.4	44.4
Industrial	300	240	255	255	255	210	180	180
Total		**1,328.59**	**1,617.05**	**1,381.51**	**2,164.01**	**2,023.95**	**940.95**	**940.95**

For Loop - A Winter

Type of load	Total connected Load (KW)	Duration (hrs)						
		5.30 - 9.30	9.30 - 13.30	13.30 - 17.30	17.30 - 19.30	19.30 - 21.30	21.30 - 1.30	1.30 - 5.30
Domestic	1981	495.25	297.15	297.15	1386.7	990.5	198.1	198.1
Street Light	78.2	0	0	0	78.2	78.2	78.2	78.2
Public	954	143.1	763.2	381.6	95.4	95.4	95.4	95.4
Commercial	148	37	88.8	96.2	66.6	37	14.8	14.8
Industrial	300	195	240	240	210	180	150	150
Total		**870.35**	**1,389.15**	**1,014.95**	**1,836.90**	**1,381.10**	**536.50**	**536.50**

For Loop -B Summer

Type of load	Total connected Load (KW)	Duration (hrs)						
		06 -- 10	10 -- 14	14 -- 18	18 -- 20	20 -- 22	22 -- 02	02 -- 06
Domestic	1285.3	449.855	321.325	321.325	963.975	963.975	321.325	321.325
Street Light	63.4	0	0	0	63.4	63.4	63.4	63.4
Public	1770	637.2	1416	973.5	442.5	354	265.5	265.5
Commercial	168	58.8	117.6	120.96	120.96	67.2	50.4	50.4
Industrial	175	140	148.75	148.75	148.75	122.5	105	105
Total		**1,285.86**	**2,003.68**	**1,564.54**	**1,739.59**	**1,571.08**	**805.63**	**805.63**

For Loop - B Winter

Type of load	Total connected Load (KW)	Duration (hrs)						
		5.30 - 9.30	9.30 - 13.30	13.30 - 17.30	17.30 - 19.30	19.30 - 21.30	21.30 - 1.30	1.30 - 5.30
Domestic	1285.3	321.325	192.795	192.795	899.71	642.65	128.53	128.53
Street Light	63.4	0	0	0	63.4	63.4	63.4	63.4
Public	1770	265.5	1416	708	177	177	177	177
Commercial	168	42	100.8	109.2	75.6	42	16.8	16.8
Industrial	175	113.75	140	140	122.5	105	87.5	87.5
Total		**742.58**	**1,849.60**	**1,150.00**	**1,338.21**	**1,030.05**	**473.23**	**473.23**

Kazi Masudur Rahaman
1734002

Transformer selection:

	Loop A	Loop B
Maximum Demand (kW)	2164	2004
Maximum Demand (kVA, pf 0.8)	2546	2357
Maximum Demand (taking 50% extra for power loss and future extension)	3819	3536
HT load (kW)	1150	1845
HT Load (kVA, pf = 0.85)	1353	2171
LT load (kVA)	2466	1365
Transformer rating (kVA)	500	500
No of Transformer (500 kVA)	5	4

Load distribution in Transformers:

Transformer Number	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Total connected Load	431.4	436.3	459.1	435.5	406.7	381.7	413.5	367.1	391
Connected load details	50 50 77.4 103.2 145.8	149.2 3 129 15 90.1 50	115.9 154 30 5 87.6 51.6 15	51.6 4 30 51.6 40 15 10 115.9 40 77.4	30 90.1 40 82.6 30 51.6 51.6 30.8	40 67 164.7 50 10 50	3 10 118.3 26 201.2 5 40 10	50 159.8 157.3	229.2 50 50 61.8

Kazi Mahmudur Rahaman / 1759002

Step 4 : Determination of load centre is required for power system distribution optimization. It has been done statistically.

Determine that a distribution system operater most optimally when electrical loads are considered as masses and supply transformer is placed at the C.G. of the designated loop determined as;

$$X = \frac{\Sigma P_i X_i}{\Sigma P_i} \quad \& \quad Y = \frac{\Sigma P_i Y_i}{\Sigma P_i}$$

where, P_i = ith load

X_i, Y_i = corresponding distance from reference axes X & Y

	LOAD CENTER CALCULATION FOR LT LOAD:									
Transformer	P(kW)	Xi(cm)	Yi(cm)	PXi	Pyi	current (A)	X(cm)	Y(cm)	TOTAL AMP(A)	PRIMARY CURRENT (A)
T1	50.00	4.00	2.00	200.00	100.00	81.84	7.33	2.70	706.08	26.64
	50.00	4.60	4.00	230.00	200.00	81.84				
	77.40	6.50	0.60	503.10	46.44	126.68				
	108.20	7.80	1.50	843.96	162.30	177.09				
	145.80	9.50	4.50	1385.10	656.10	238.63				
T2	149.20	15.60	2.50	2327.52	373.00	244.20	15.08	3.96	714.10	26.94
	3.00	15.00	3.70	45.00	11.10	4.91				
	129.00	13.40	5.70	1728.60	735.30	211.14				
	15.00	15.70	5.90	235.50	88.50	24.55				
	90.10	17.90	4.50	1612.79	405.45	147.47				
	50.00	12.60	2.30	630.00	115.00	81.84				
T3	115.90	9.20	9.00	1066.28	1043.10	189.69	11.43	10.38	751.41	28.35
	154.00	9.90	9.60	1524.60	1478.40	252.05				
	30.00	11.00	11.10	330.00	333.00	49.10				
	5.00	12.70	13.30	63.50	66.50	8.18				
	87.60	14.80	9.80	1296.48	858.48	143.38				
	51.60	14.20	15.30	732.72	789.48	84.45				
	15.00	15.50	13.20	232.50	198.00	24.55				
T4	51.60	16.10	17.80	830.76	918.48	84.45	22.96	17.06	712.79	26.89
	4.00	17.00	15.50	68.00	62.00	6.55				
	30.00	18.90	18.00	567.00	540.00	49.10				
	51.60	21.90	17.60	1130.04	908.16	84.45				
	40.00	23.50	19.40	940.00	776.00	65.47				
	15.00	28.00	19.00	420.00	285.00	24.55				
	10.00	26.40	19.50	264.00	195.00	16.37				
	115.90	25.90	16.70	3001.81	1935.53	189.69				
	40.00	22.20	17.20	888.00	688.00	65.47				
	77.40	24.40	14.50	1888.56	1122.30	126.68				
T5	30.00	20.20	15.00	606.00	450.00	49.10	19.28	11.84	665.65	25.11
	90.10	21.70	12.50	1955.17	1126.25	147.47				
	40.00	18.20	12.70	728.00	508.00	65.47				
	82.60	20.10	9.90	1660.26	817.74	135.19				
	30.00	17.80	8.00	534.00	240.00	49.10				
	51.60	16.30	10.50	841.08	541.80	84.45				
	51.60	18.00	12.80	928.80	660.48	84.45				
	30.80	19.10	15.30	588.28	471.24	50.41				
T6	40.00	21.00	7.70	840.00	308.00	65.47	23.46	4.97	624.73	23.57
	67.00	21.70	8.80	1453.90	589.60	109.66				
	164.70	23.50	3.00	3870.45	494.10	269.57				
	50.00	26.50	6.20	1325.00	310.00	81.84				
	10.00	23.60	7.60	236.00	76.00	16.37				
	50.00	24.60	2.40	1230.00	120.00	81.84				
T7	3.00	22.60	1.30	67.80	3.90	4.91	27.05	6.61	676.78	25.53
	10.00	23.90	4.00	239.00	40.00	16.37				
	118.30	25.30	6.30	2992.99	745.29	193.62				
	26.00	26.80	3.20	696.80	83.20	42.55				
	201.20	27.80	6.60	5593.36	1327.92	329.31				
	5.00	25.00	7.90	125.00	39.50	8.18				
	40.00	29.40	9.40	1176.00	376.00	65.47				
	10.00	29.30	11.80	293.00	118.00	16.37				
T8	50.00	25.40	14.60	1270.00	730.00	81.84	27.57	13.57	600.84	22.67
	159.80	29.30	14.80	4682.14	2365.04	261.55				
	157.30	26.50	12.00	4168.45	1887.60	257.45				
T9	229.20	20.30	12.80	4652.76	2933.76	375.13	21.79	12.94	639.95	24.14
	50.00	23.00	12.60	1150.00	630.00	81.84				
	50.00	25.20	14.20	1260.00	710.00	81.84				
	61.80	23.60	12.70	1458.48	784.86	101.15				

LOAD CENTER CALCULATION FOR HT LOAD:

Transformer & HT Load	P(kW)	Xi(cm)	Yi(cm)	PXi	Pyi	current(A)	X(cm)	Y(cm)	11kv, TOTAL AMP(A)	132kv, PRIMARY CURRENT (A)
T1	425.00	**7.33**	**2.70**	**3115.25**	1147.56	26.24	22.21	10.28	421.13	35.09
T2	425.00	15.08	3.96	**6409.01**	1683.59	26.24				
T3	425.00	11.43	10.38	**4856.42**	4412.89	26.24				
T4	425.00	22.96	17.06	**9757.11**	7251.32	26.24				
T5	425.00	19.28	11.84	**8194.43**	5032.19	26.24				
HT Load	50.00	6.20	5.50	**310.00**	275.00	3.09				
HT Load	100.00	7.80	7.30	**780.00**	730.00	6.17				
HT Load	150.00	11.90	4.50	**1785.00**	675.00	9.26				
HT Load	850.00	19.50	0.70	**16575.00**	595.00	52.49				
T6	425.00	23.46	4.97	**9971.24**	2112.97	26.24				
T7	425.00	32.05	6.61	**13619.99**	2809.84	26.24				
T8	425.00	32.57	13.57	**13841.84**	5768.52	26.24				
T9	425.00	26.79	12.94	**11387.22**	5498.50	26.24				
HT Load	100.00	20.60	2.40	**2060.00**	240.00	6.17				
HT Load	75.00	27.00	6.30	**2025.00**	472.50	4.63				
HT Load	1670.00	28.00	18.80	**46760.00**	31396.00	103.12				

Therefore rating of the transmission transformer = 4.63 MVA

Conductor Selection :

Feeder Specification:	Code Name	Size	Standerd (Al/St)	Dia (inch)				Weight per 1000 ft (lbs)			Content %		Rated Strenght (Lbs)	Resistance ohm / 1000 ft		Current rating (Amps)
				Individual (AL)	Wire (STL)	Steel Core	Complete Cable	AL	Stl	Total	Al	Stl		DC @ 20° C	AC @ 75° C	
LT feeder	Stilt	715.5	24/7	0.1727	0.1151	0.3453	1.036	675.2	246.5	921.8	73.23	26.77	25500	0.0239	0.0294	844
for all HT load service line	Turkey	6	6/1	.0661	.0661	.0661	.198	24.5	11.6	36.1	67.90	32.10	1190	.641	.806	105
HT feeder	Waxwing	266.8	18/1	0.1217	0.1217	0.1217	0.609	250.3	39.2	289.5	86.45	13.55	6,880	0.0643	0.0787	449

LT distribution size justification :

	Current (A)	Length (cm)	Resistance (ohm / 1000 ft)	Resistance (ohm)	Voltage Drop (%)
Loop of T1	238.63	2.3	0.0294	0.02219	0.0128
		1.5	0.0294	0.01447	0

Paper Code :- BIOT 4282

Step V : Calculation of All Day Efficiency (Summer)

Duration (hrs)	06-10	10-14	14-18	18-20	20-22	22-02	02-06
Total load demand (kW)	150.99	107.85	107.85	323.55	323.55	107.85	107.85
Load demand × hrs (kWh)	603.96	431.40	431.4	1294.20	647.10	431.40	431.4
KVA load demand	710.54	507.53	507.53	1522.59	761.29	507.53	507.53
Fractional loading (X)	1.42	1.02	1.02	3.05	1.52	1.02	1.02
Cu loss (kW)	50.49	25.76	25.76	231.83	57.96	25.76	25.76
Cu loss (kWh)	201.95	103.03	103.03	927.31	115.91	103.03	103.03

Total output (kWh) ⟶ 4270.86

Total Cu loss (kWh) ⟶ 1657.31

All day efficiency of Transfor (T_1) = 72.04%

Calculation of All Day Efficiency (Winter)

Duration (hrs)	06-10	10-14	14-18	18-20	20-22	22-02	02-06
Total load demand (kW)	107.85	64.71	64.71	301.98	215.7	43.14	43.14
Load demand × hr (kWh)	431.40	258.84	258.84	1207.92	431.4	172.56	172.56
KVA load demand	507.53	304.52	304.52	1421.08	507.53	203.01	203.01
Fractional loading (x)	1.02	0.61	0.61	2.84	1.02	0.41	0.41
Cu loss (kW)	25.76	9.27	9.27	201.95	25.76	4.12	4.12
Cu loss (kWh)	103.03	37.09	37.09	807.79	51.52	16.49	16.49

Total output (kWh) ⟶ 2933.52

All Day Efficiency of Transformer (T_1) ⟶ 73.28%

Total Cu loss (kWh) ⟶ 1069.50

M Str	3 Str	2 Str								Domestic Laod (KW)	Street Light Load (KW)	Public Load (KW)	Commercial Load (KW)	Industrial Load (KW)
3	1		46.4	LOOP =	3,336.50	3,355.00	6,691.50	6,833.50	L-A=O	50				
3	1		46.4		1670	850		(164.90)	L-A=O	50				
		15	77.4		50	3			L-A=O	77.4				
	4	15	108.2		159.8	129			L-A=O	108.2				50
4	8	16	195.8		50	154			L-A=O	195.8				100
	5	15	115.9		157.3	115.9			L-A=O	115.9				150
	10	14	149.2		50	150			L-A=O	149.2				
	20		154.0		229.2	149.2			L-A=O	154				
10			129.0		10	196.8			L-A=O	193				
	2	14	87.6		40	100			L-A=O				3	
	5	10	90.1		5	108.2			L-A=O	87.6		850	30	
		10	51.6		201.2	50			L-A=O	90.1			15	
		10	51.6		26	77.4			L-A=O	51.6			5	
		10	51.6		118.3	50			L-A=O				30	
		16	82.6		10	50			L-A=O	51.6				
		10	51.6		3	15			L-A=O				15	
	4		30.8		75	90.1			L-A=O	51.6			40	
	5	10	90.1		50	30			L-A=O	82.6				
		10	51.6		50	40			L-A=O	51.6				
		15	77.4		10	82.6			L-A=O			4		
	5	15	115.9		164.7	30			L-A=O	30.8				
	2	10	67.0		67	90.1			L-A=O			30		
	10	17	164.7		40	40			L-A=O	90.1				
3	1		46.4		100	77.4			L-A=O			30		
	2	8	56.7			10			L-A=O	51.6				
5	10	17	229.2			115.9			L-A=O	77.4		40		
	8		61.6			50			L-A=O	40			10	
5	2	15	157.3			40			L-A=O	115.9				
3	5	16	159.8			51.6			L-A=O	15				
14		4	201.2			30			L-A=O					
	10	8	118.3			51.6			L-A=O		78.2			
50	**120**	**300**	**3117.0**			4			**3461.2**	**1981**	**78.2**	**954**	**148**	**300**
						30.8			L-B=*		63.4			
						51.6			L-B=*			1670		
						15			L-B=*				50	
						51.6			L-B=*	159.8				
						5			L-B=*	61.8		50		
						51.6			L-B=*	157.3				
						30			L-B=*			50		
						87.6			L-B=*	229.2				
									L-B=*				5	
									L-B=*				40	
									L-B=*				10	
									L-B=*	201.2				
									L-B=*					75
									L-B=*				10	
									L-B=*	50				
									L-B=*				10	
									L-B=*	118.3				
									L-B=*	26				
									L-B=*	50			3	
									L-B=*	164.7				
									L-B=*				40	100
									L-B=*	67				
									3461.7	**1285.3**	**63.4**	**1770**	**168**	**175**