Report of 1st Assignment

About

SCIG Turbine Generators

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Course: New Energy Resources

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Introduction

A fixed-speed turbine generator:

It is a type of wind turbine that uses a fixed-speed induction generator to convert the mechanical energy of the wind into electrical energy. The generator is connected to the grid directly, without the use of converter. This makes fixed-speed turbine-generators relatively simple and inexpensive to install, but it also limits their efficiency and output power.

The benefits of fixed-speed turbine generators include:

- **Simple and inexpensive to install:** Fixed-speed turbine generators do not require converter, which makes them relatively simple and inexpensive to install.
- **Reliable:** Fixed-speed turbine generators are generally very reliable and have a long lifespan.
- **Low maintenance:** Fixed-speed turbine generators require very little maintenance.

The weaknesses of fixed-speed turbine generators include:

- **Limited efficiency:** Fixed-speed turbine generators are less efficient than variable-speed turbine generators because they cannot operate at the optimal speed for all wind speeds.
- **Limited output power:** Fixed-speed turbine generators have a limited output power because they are directly connected to the grid.
- **Can cause grid instability:** Fixed-speed turbine generators can cause grid instability if they are not properly controlled.

The impact of adding an external resistance to the rotor circuit of a fixed-speed turbine generator is to increase the slip and efficiency of the generator. Slip is the difference between the speed of the rotor and the speed of the stator. When an external resistance is added to the rotor circuit, the rotor speed decreases and the slip increases. This increase in slip causes the generator to produce more power and operate at a higher efficiency.

However, adding an external resistance also increases the losses in the generator. Therefore, it is important to select the correct resistance value to maximize the benefits while minimizing the losses.

Overall, fixed-speed turbine generators are a simple and inexpensive option for small-scale wind power projects. However, they are not as efficient or powerful as variable-speed turbine generators. Adding an external resistance to the rotor circuit can improve the efficiency and output power of fixed-speed turbine generators, but it also increases the losses.

This Report:

In this report I used MATLAB programming to solve the problems and find requested items in a systematic way which allows us to easily change parameters and the system under study if needed and the codes can also be used in future studies.

Problem

The Vestas V47 is a three-bladed, variable-speed wind turbine with a rated power of 660 kW. It was first introduced in 1995 and was one of the most popular wind turbines of its time. The V47 has a rotor diameter of 47 meters and a hub height of 60 meters. It can operate in wind speeds of 4 to 25 meters per second.

Here are some additional details about the Vestas V47 turbine generator:

- Rated power: 660 kW
- Rotor diameter: 47 meters
- Hub height: 60 meters
- Operating wind speed range: 4 to 25 meters per second
- Generator type: Variable-speed asynchronous
- Transmission type: Gearbox
- Cooling system: Air-cooled
- Efficiency: > 35%
- Applications: Onshore and offshore wind farms, small-scale wind power projects

The Vestas V47 is no longer in production, but it remains a popular choice for wind power projects. It is a reliable and efficient wind turbine that has made a significant contribution to the growth of the wind power industry.

Parameters:

Generator type: Three phase asynchronous generator with wound rotor and Vestas rotor current control

Manufacturer and type : ABB M2CG 400 XL 4 B3 (code: -RXAVE007)

Fan type no. : CA40T/H431513

Building size : 400 Degree of protection : IP54

Insulation class (stator/rotor) : F/H

Winding connection (stator/rotor) : star/star Voltage : 690 V Frequency : 50 Hz

Number of poles : 4 Rated power output : 660 kW

Number of rotor systems : 1

Weight of Generator = 2,980 kg

Moment of Inertia (JG) = 28 kg/m2

- Equivalent diagram (stator side):

Rs= 0.0048 ohm Xls= 0.068 ohm R'r=0.0040 ohm X'lr=0.0897 **ohm** Xm =2.81 ohm

Locked rotor voltage (phase-phase) = 2464 V

Break down torque Tmax/TN : Generator=2.5 Motor= 2.4

- *Turbine and Gearbox Specifications:*

Moment of Inertia (Jt)=520000 kg/m2

Equivalent shaft stiffness (Ks-eq) = 0.6 pu/elec.rad

Damping (Dtg) = 1.5 pu

Gear ratio (n) = 52.7

Rotor diameter (2R) = 47 m

Air density (Rho) = 1.225 kg/m^3

Results

1

Output power, electrical and mechanical torque and power factor in different values of slip:

%S	Pgen (kW)	PF	Tm (N.m)	Te (N.m)
-0.2	225.7339	-0.7753	1.4425	1.4342
-0.3	336.5123	-0.8527	2.1523	2.1359
-0.4	444.4979	-0.8827	2.8460	2.8185
-0.5	548.7973	-0.8940	3.5179	3.4764
-0.6	648.6157	-0.8964	4.1628	4.1046
-0.7	743.2747	-0.8938	4.7762	4.6989
-0.8	832.2234	-0.8881	5.3545	5.2561

2

Wind speed and efficiency factor in different values of slip:

%S	Vw (m/s)	Cp
-0.2	7.9764	0.4210
-0.3	9.0540	0.4299
-0.4	10.1542	0.4034
-0.5	11.3828	0.3544
-0.6	12.9680	0.2839
-0.7	39.9001	0.0112
-0.8	42.6213	0.0103

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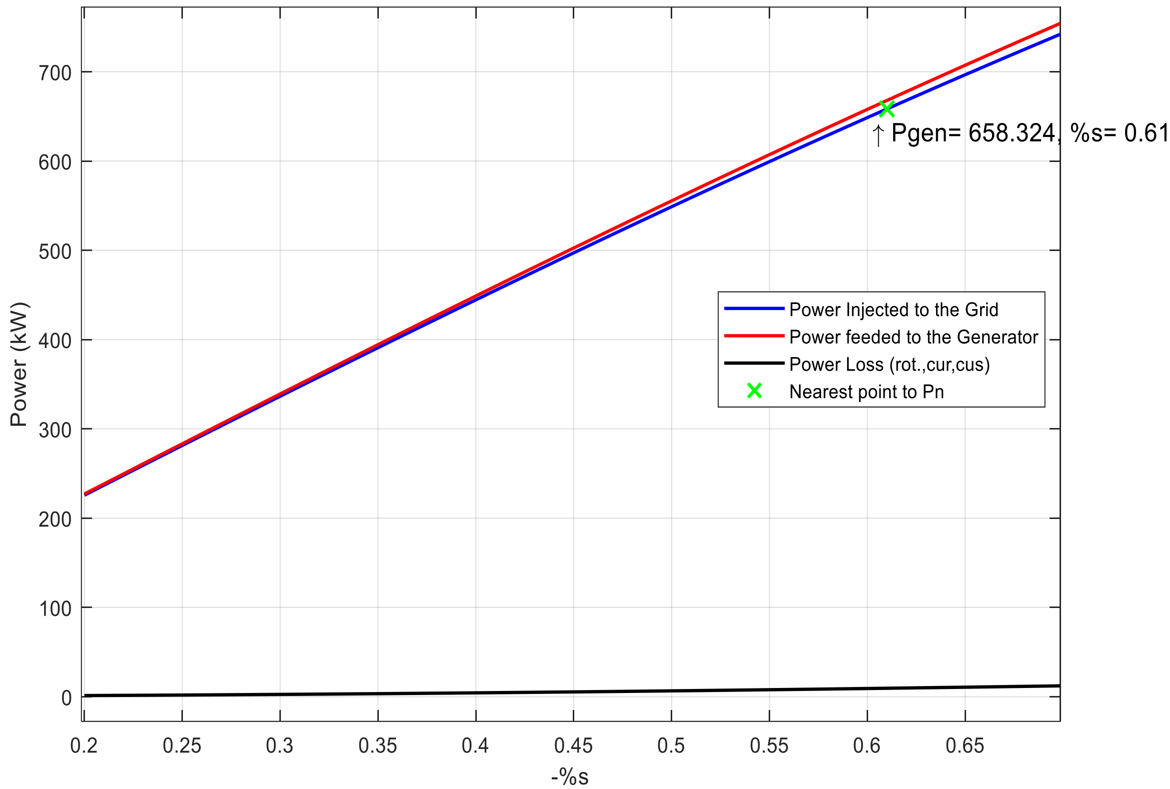
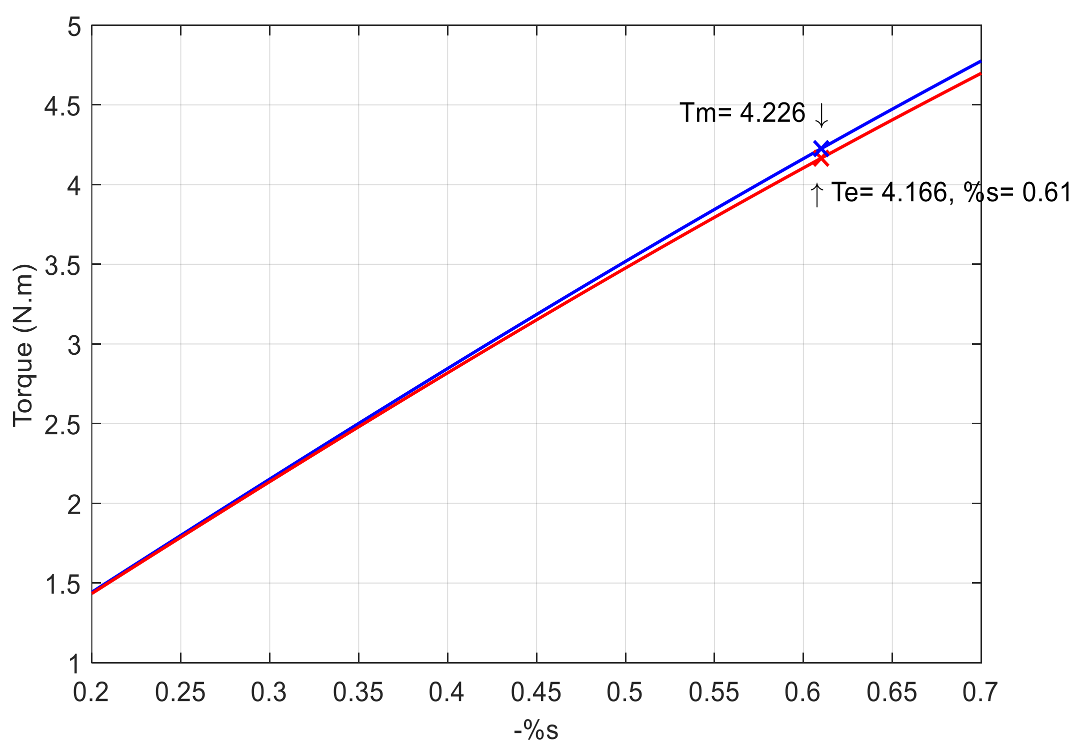
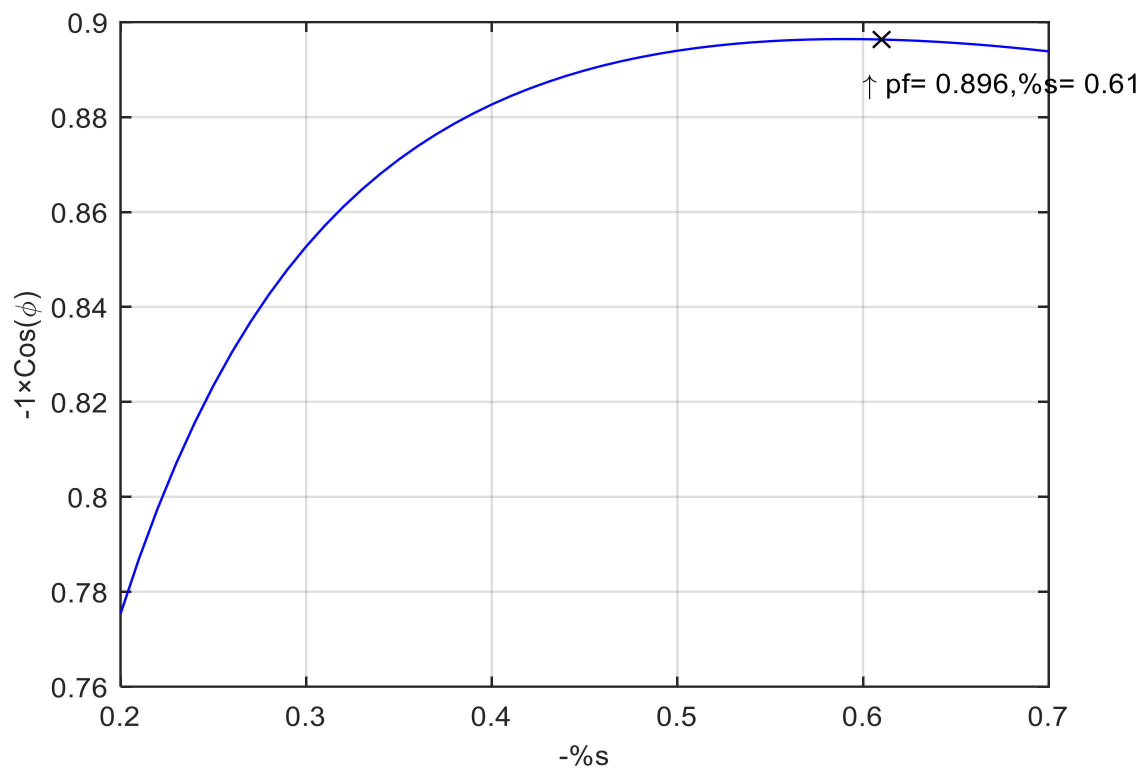
The nominal slip is the slip in which the nominal power is generated so we see:







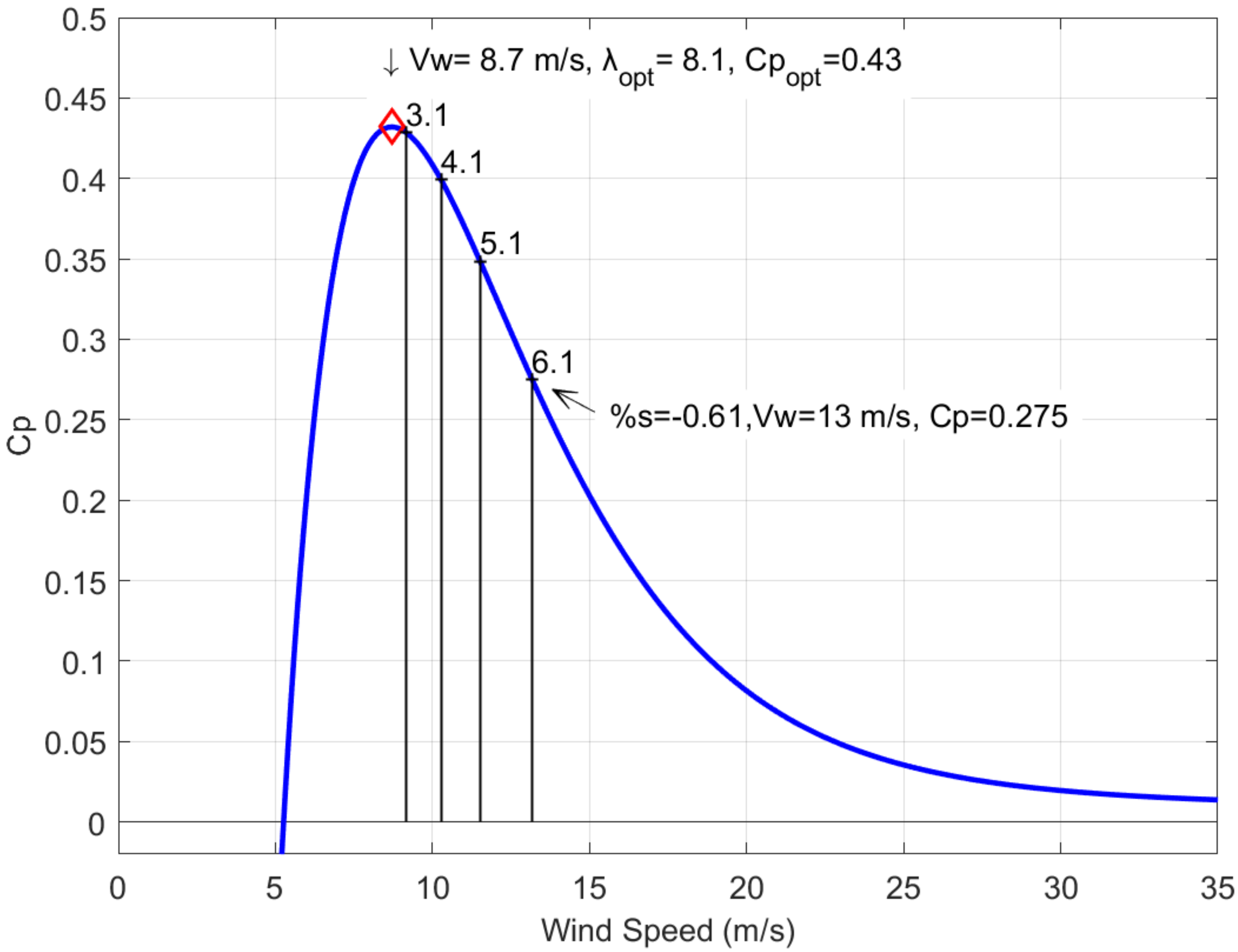
Finding the Capacity of Capacitor bank when we want to increase pf to 0.97 , Is , I'r and Ir:

```
Qc=Pgen.*(tan(acos(abs(pf)))-tan(acos(0.97)));  % in kVAr
Xc=(V47.Un)^2./(Qc*1e3);                        % Xc (Ohm) when bank is Y connected
Cc=(1e3)./((2*pi*V47.fn).*Xc);                          % in miliFarad
Pgen(nominal_i)
Xc(nominal_i)
Cc(nominal_i)
```

```
Qc =
  658.3239
Xc =
    2.9637
Cc =
    1.0740
```

```
>> abs(Isph(nominal_i))
ans =
  614.5504     (A rms)
>> abs(Irp(nominal_i))
ans =
  580.8722     (A rms)
>> abs(Ir(nominal_i))
ans =
  162.6631     (A rms)
```

Finding the minimum wind speed leading to the nominal power generated:



The figure above answers multiple questions like values of wind speed, slip, lambda and Cp in the condition that Cp is maximum and in the condition that electrical output power reaches its nominal value of 660 kW.

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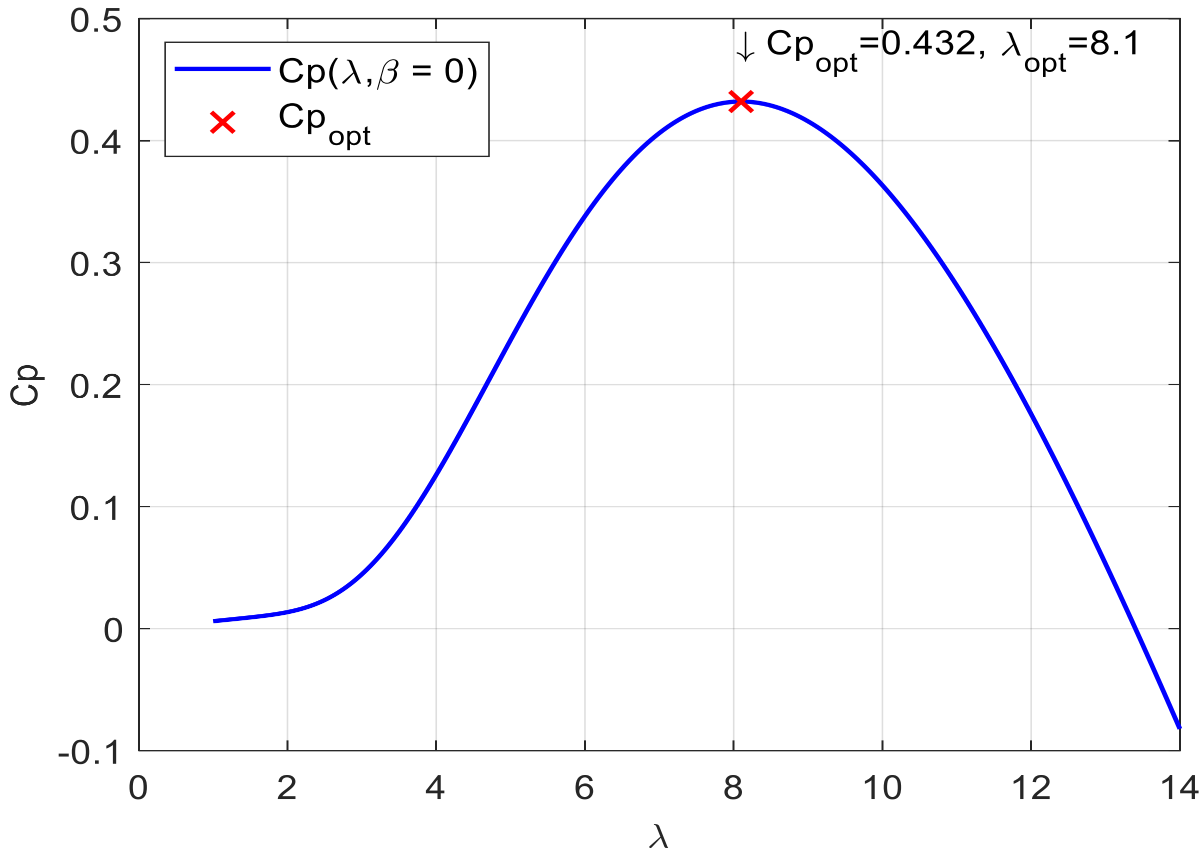
Cp vs. Lambda when beta is zero:



⇨ $Vw_{max\_efficiency}$ = (V47.R*V47.wsm/V47.ng)/8.1 = 8.6475 m/s

Just like in the previous page we saw Vm_{Cpopt}=8.7 m/s.

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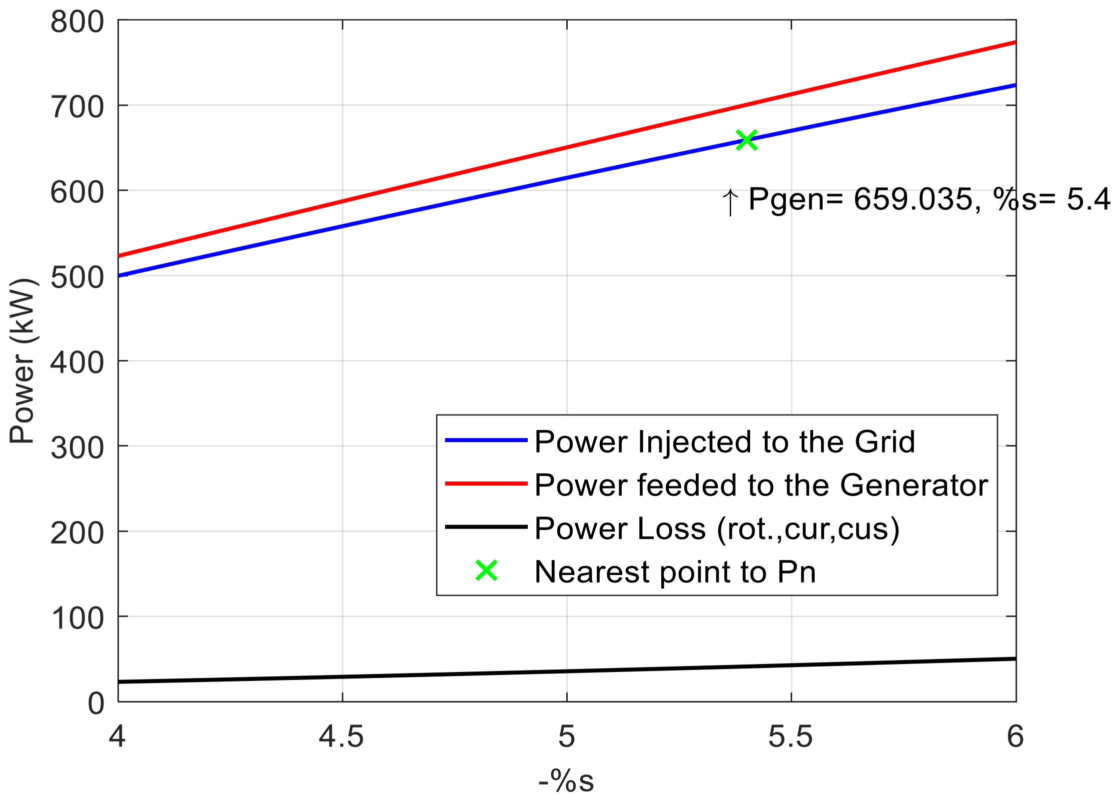
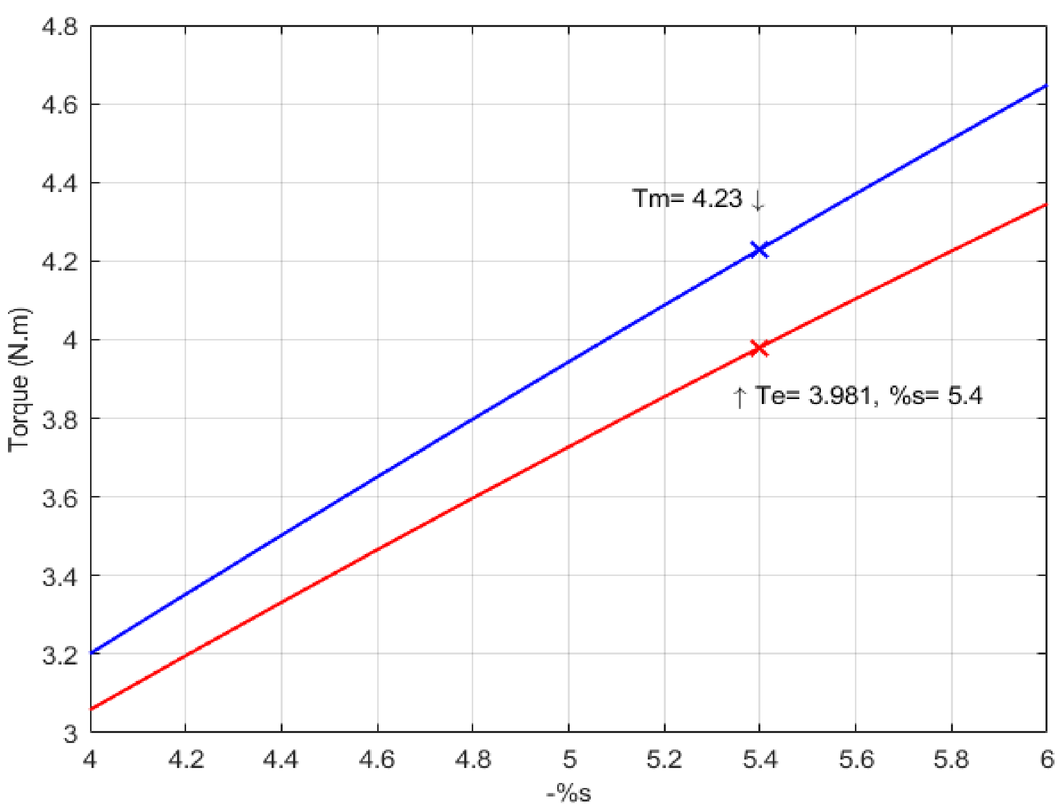
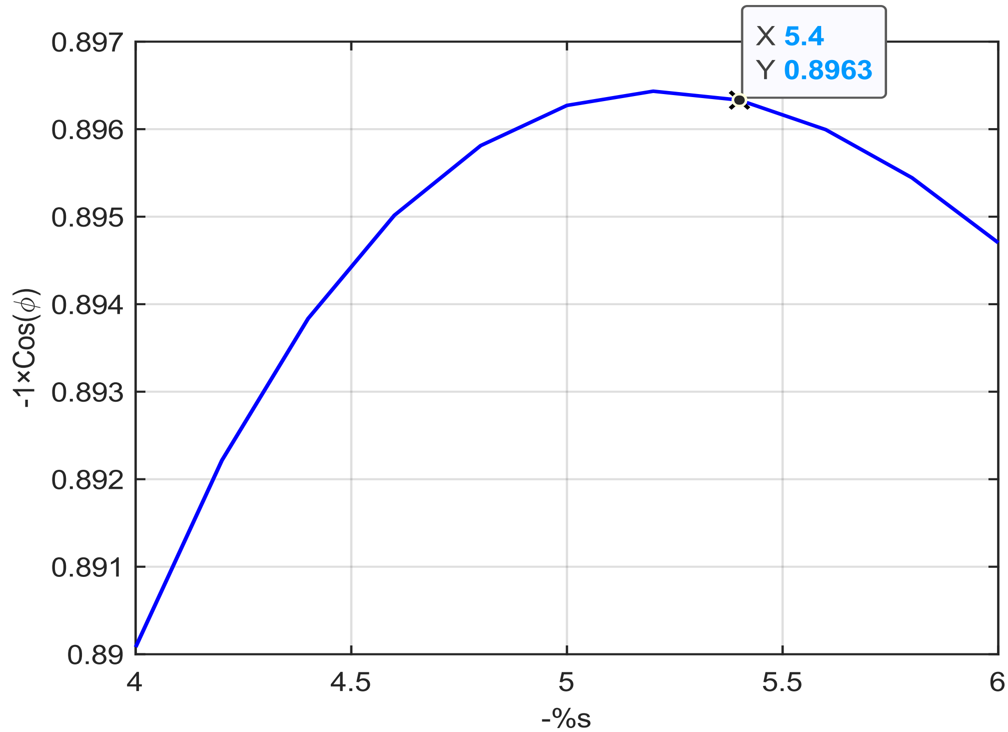
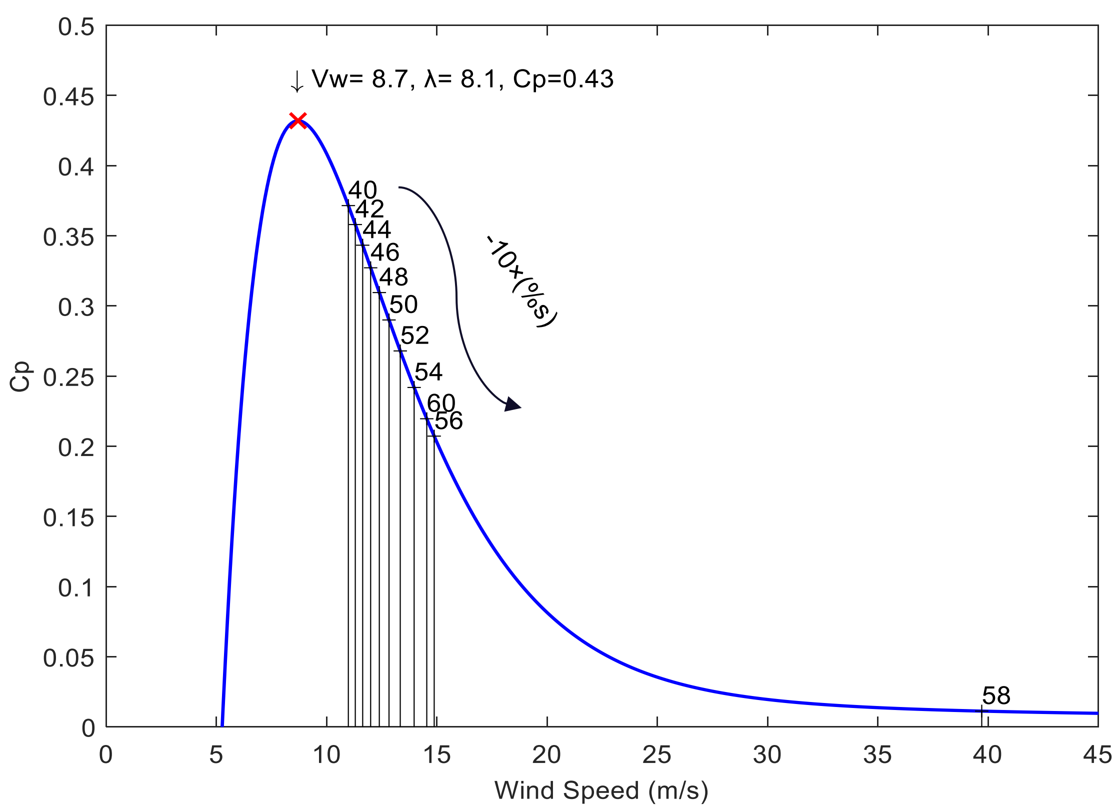
When we add an external resistance of 0.4 (Ohm) to the rotor we see:



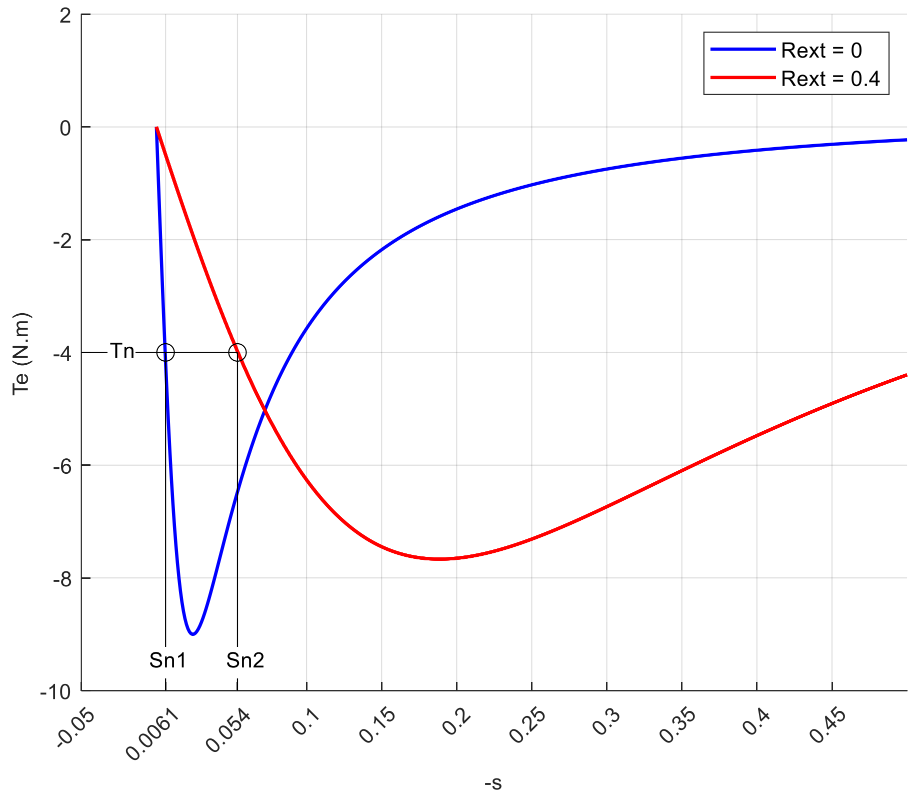



X 5.4
Y 0.8963
0.897
0.896
0.895
0.894
0.893
0.892
0.891
0.89
-1×Cos(ϕ)
4
4.5
5
5.5
6
-%s


↓ Vw= 8.7, λ= 8.1, Cp=0.43
40
42
44
46
48
50
52
54
60
56
58
-10×(%s)
Cp
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
Wind Speed (m/s)

Impact of adding an external resistance to the rotor circuit:

If we plot electric torque (Te) vs. Slip in the two conditions we see:



The range of speed change increased to almost 10 times! And it allows system to work in a wider range of slip and use wider range of wind speed and convert its energy and the fluctuations in wind speed can be appeared on generator speed instead of torque.

There are several benefits to adding an external resistance to the rotor circuit and controlling it in a fixed-speed turbine generator. These include:

- **Increased efficiency**: When an external resistance is added to the rotor circuit, it causes the rotor speed to decrease and the slip to increase. This increase in slip causes the generator to produce more power and operate at a higher efficiency.
- **Improved power factor**: The power factor is a measure of how efficiently electrical energy is used. Adding an external resistance to the rotor circuit can improve the power factor of the generator, which can save money on electricity bills.
- **Reduced harmonic currents**: Harmonic currents are currents that flow in the electrical system at frequencies that are multiples of the fundamental frequency. These currents can cause problems with transformers and other equipment. Adding an external resistance to the rotor circuit can help to reduce harmonic currents.
- **Improved transient response**: Transients are sudden changes in the electrical system. Adding an external resistance to the rotor circuit can help to improve the transient response of the generator, which can help to prevent damage to equipment.

However, there are also some drawbacks to adding an external resistance to the rotor circuit. These include:

- **Increased losses**: Adding an external resistance to the rotor circuit increases the losses in the generator. These losses can reduce the efficiency of the generator and increase the cost of operating it.
- **Increased complexity**: Adding an external resistance to the rotor circuit increases the complexity of the generator. This can make it more difficult to maintain and repair.

Overall, adding an external resistance to the rotor circuit can provide several benefits for fixed-speed turbine generators.

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Choosing Base Values:

Vb= 690 V, Sb= 660 kVA, Zb= (Vb^2)/Sb, fb=50, wbe=2*pi*fb, wbmg= (2/p)*wbe, wbmt= wbmg/ng, Tb=Sb/wbm, Lb=Zb/wbe

Per Unit Values (Results of Part 6 MATLAB code):

Rs_pu =
0.0067
Xls_pu =
0.0943
Lls_pu =
0.0943
Rrp_pu =
0.0055
Xlrp_pu =
0.1243
Llrp_pu =
0.1243
Xm_pu =
3.8954
Lm_pu =
3.8954
Hg =
0.5234 (s)
Ht =
3.4998 (s)

Conclusion

This report has presented an analysis of an example of a SCIG wind turbine-generator in different electrical conditions using a systematic solving by MATLAB programming and showing results graphically and tangible.

Appendix (MATLAB Codes)

V47 Class

I wrote this class to use the parameters wherever needed:

```
classdef Ex_1_V47
    properties
        % Generator Prperties
        Un=690;               % Generator nomial stator voltage Volt
        fn=50;                % Generator nomial frequency in Hz
        p=4;                  % Generator number of poles
        Pn=660;               % Generator rated power output in kW
        Wg=2980;              % Generator Weight in kg
        JG=28;                % Generator Rotational Momentum of Inertia in kg.m^2
        Rs=0.0048;            % Generator stator Resistance in ohm
        Xls=0.068;      % Generator stator Leakage Reactance in ohm
        Rrp=0.0040;     % Generator Rotor Resistance (referenced to stator) in ohm
        Xlrp=0.0897;    % Generator Rotor Reactance  (referenced to stator) in ohm
        Xm=2.81;        % Generator Magnetizing Reactance in ohm
        LRV=2464;       % Generator Locked Rotor Voltage in Volt
        % GearBox
        ng=52.7;

        % Wind Turbine Properties
        Jt=520000;      % WT Rotational Momentum of Inertia in kg.m^2
        Ks_eq_pu=0.6;   % WT spring coefficient
        Dtg_pu=1.5;     % WT damper coeffciient
        R=47/2;         % WT blades Radious
        c=[0.5176,116,0.4,5,21,0.0068,0.9]; % WT Coefficeints of aerodynamics
        Beta=0;                          % WT blades angle
    end

    methods
        function wse = wse(obj)
            wse = 2*pi*obj.fn;         % Generator synchronous electrical speed in rad/s
        end
        function wsm = wsm(obj)
            wsm = 2*pi*obj.fn*2/obj.p;  % Generator synchronous mechanical speed in rad/s
        end
        function ns = ns(obj)           % Generator synchronous mechanical speed in rpm
            ns = 120*obj.fn/obj.p;
        end
        function nr = nr(obj,s)         % Generator Rotor mechanical speed in rpm
            nr = (1-s).*(120*obj.fn/obj.p);
        end
        function k = Nr2Ns(obj)         % Generator Ns/Nr
            k = obj.LRV/obj.Un;
        end
        function lambda=Lambda(obj,wt,Vw)   % WT Lambda
            lambda = (obj.R.*wt)./Vw;
        end
        function cp = Cp(obj,Lambda)        % WT Cp
            invLi = (1./(Lambda+0.08.*obj.Beta))-(0.035./(obj.Beta.^3+1));
            cp = obj.c(7).*(obj.c(1).*(obj.c(2).*invLi-obj.c(3).*obj.Beta-obj.c(4)).* …
           … exp(-obj.c(5).*invLi)+obj.c(6).*Lambda);
        end
    end
end
```

Part 1, 2 and 3

```
close all
clear
clc

%%
j=1i;

%% Defining Turbine by class
V47 = Ex_1_V47;

%% Allocating Slip Values
s_percent = -(0.2:0.01:0.7)';
%s_percent = -(0.2:0.1:0.8)'
s = s_percent./100;
wr =V47.nr(s).*(2*pi/60);       % Generator rotor mechanical speed in rad/s

%% Initializing ciruit parameters
Vsph = V47.Un/sqrt(3);

%% Computing circuit thevenine Impedance
Zth = (V47.Rs+j*V47.Xls)+parallel((j*V47.Xm),(j*V47.Xlrp+(V47.Rrp./s)));

%% Solving and computing current
Isph = Vsph./Zth;
Irp = Isph.*((j*V47.Xm)./((j*V47.Xm)+(j*V47.Xlrp+(V47.Rrp./s))));
Ir = Irp./V47.Nr2Ns;

%% Computing Appearant Power (S=3.V_sph × I_sph*)
S = 3.*Vsph.*conj(Isph)./1e+03;        % in kVA
Pgen = -real(S);                       % in kW
Qcons = imag(S);                       % in kVAr
pf = cos(angle(S)) ;                   % power factor
Pcus = 3.*V47.Rs.*abs(Isph).^2./1e+03; % in kW
Pag = Pgen+Pcus;          % Air Gap Power in kW
Pm = (1-s).*Pag;          % Mechanical power on Generator's shaft in kW
Prot = 0.*Pm;             % Rotational Power Loss before Generator's shaft in kW
Pt = Prot + Pm ;          % Pwer after GearBox on High-speed shaft in kW
Tm = Pt./wr;              % Torque on High-speed shaft in N.m
Te = Pgen./wr ;           % Eletrical Torque

%% Plotting and Conclusion
figure
plot(-s_percent, Pgen,'-b','LineWidth',1.5);
hold on
plot(-s_percent, Pm,'-r','LineWidth',1.5);
grid on
plot(-s_percent, Pm-Pgen,'-k','LineWidth',1.5);
xlabel('-%s')        %-1×%s
ylabel('Power (kW)')
dif=abs(V47.Pn-Pgen);
nomial_i=find(dif==min(dif));
x = -1*s_percent(nomial_i);
y = Pgen(nomial_i);
plot(x,y,'xg','MarkerSize',10,'LineWidth',1.5);
txt=['\uparrow Pgen= ',num2str(round(Pgen(nomial_i),3)),',…
              … %s= ',num2str(-1*s_percent(nomial_i))];
text(x*0.99,y*0.90,txt,'FontSize',12,'HorizontalAlignment','left',…
              …'FontName','TimesNewRoman','Interpreter','tex');
legend({'Power Injected to the Grid','Power feeded to the Generator',…
…'Power Loss (rot.,cur,cus)','Nearest point to Pn'},'Location','best','FontName','TimesNewRoman');
```

```

figure
plot(-s_percent,Tm,'-b','LineWidth',1.5)
grid on
hold on
plot(-s_percent,Te,'-r','LineWidth',1.5)
plot(x,Te(nomial_i),'xr','MarkerSize',10,'LineWidth',1.5);
txt=['\uparrow Te= ',num2str(round(Te(nomial_i),3)),', %s= ',num2str(-1*s_percent(nomial_i))];
text(x*0.99,Te(nomial_i)*0.95,txt,'FontSize',12,'HorizontalAlignment','left',…
           …'FontName','TimesNewRoman','Interpreter','tex');
xlabel('-%s') %-1×%s
ylabel('Torque (N.m)')
plot(x,Tm(nomial_i),'xb','MarkerSize',10,'LineWidth',1.5);
txt=['Tm= ',num2str(round(Tm(nomial_i),3)) ,' \downarrow'];
text(x*1.01,Tm(nomial_i)*1.1,txt,'FontSize',12,'HorizontalAlignment','right',…
           …'FontName','TimesNewRoman','Interpreter','tex');

figure
plot(-s_percent,-(pf),'-b','LineWidth',1.5)
grid on
hold on
xlabel('-%s') %-1×%s
ylabel('-1×Cos(\phi)')
y=-pf(nomial_i);
plot(x,y,'xk','MarkerSize',10,'LineWidth',1.5);
txt=[' \uparrow pf= ',num2str(round(y,3)),',%s= ',num2str(-1*s_percent(nomial_i))];
text(x*0.975,y*0.99,txt,'FontSize',12,'HorizontalAlignment','left',…
           …'FontName','TimesNewRoman','Interpreter','tex');

%% Wind speed iteration for Part1_2
N=30;   %N = iteration count limit
e=0.1; % acceptable Tolerance in Power mismatch for different wind speeds in kW
rho = 1.225; %? in kg/m^3
wt = wr./V47.ng; % Turbine mechanical speed in radian/s
wtc = sum(wt)/length(wt);    % Turbine mechanical speed rad/s constant considered

wtc=round(wtc); %rounding wtc number

Vwi=(1000.*Pt./(0.5*rho*V47.R^2*0.7)).^(1/3); % initial guess for Wind speeds in m/s
Vw=Vwi;
flag=zeros(length(Vw),1);
for jj=1:length(Vwi)
    Pi = 0.5*rho*pi*V47.R^2*Vwi(jj)^3*V47.Cp(V47.R*wtc/Vwi(jj))/1000;
    if Pi>Pt(jj)
        Vw(jj) = Vwi(jj)*1.1;
    else
        Vw(jj) = Vwi(jj)*0.9;
    end
    Pf = 0.5*rho*pi*V47.R^2*Vw(jj)^3*V47.Cp(V47.R*wtc/Vw(jj))/1000;
    for ii=1:N
        if abs(Pf-Pt(jj))<e
            flag(jj)=1;
            break
        end

        if Pf>Pt(jj)*3
            Pf=Pt(jj)*2;
            Vw(jj)=(1000.*Pf./(0.5*rho*V47.R^2*0.5)).^(1/3);
        elseif Pf<Pt(jj)*0.1
            Pf=Pt(jj)*0.2;
            Vw(jj)=(1000.*Pf./(0.5*rho*V47.R^2*0.5)).^(1/3);
        end
```

```

        x1=Pi;
        x2=Pf;
        y1=Vwi(jj);
        y2=Vw(jj);
        [Vwi(jj),Vw(jj)]=swap(Vwi(jj),Vw(jj));
        Vw(jj)=(Pt(jj)-x1)*((y2-y1)/(x2-x1))+y1;
        Pi=Pf;
        Pf = 0.5*rho*pi*V47.R^2*Vw(jj)^3*V47.Cp(V47.R*wtc/Vw(jj))/1000;
    end
end
%Vw;
%Cps=V47.Cp(V47.R*wtc./Vw);

figure
Vw_temp=(5:0.1:round(V47.R.*wtc,0));
lambda_temp=(V47.R.*wtc)./Vw_temp;
Cp_temp=V47.Cp(lambda_temp);
plot(Vw_temp,Cp_temp,'-b','LineWidth',1.5);
grid on
hold on
index=find(Cp_temp==max(Cp_temp));
x=Vw_temp(index);
y=Cp_temp(index);
plot(x,y,'xr','MarkerSize',10,'LineWidth',1.5);
txt=[' \downarrow Vw= ',num2str(Vw_temp(index)),', ?= ',…
  …num2str(round(lambda_temp(index),1)),', Cp=',num2str(round(Cp_temp(index),2))];
text(x*0.88,Cp_temp(index)+0.05,txt,'FontSize',12,'HorizontalAlignment','left',…
  …'FontName','TimesNewRoman','Interpreter','tex');
xlabel("Wind Speed (m/s)")
ylabel("Cp")
lambda_cal=(V47.R.*wtc)./Vw;
Cp_cal=V47.Cp(lambda_cal);
stem(Vw,Cp_cal,'+k','MarkerSize',5)
text(Vw,Cp_cal,strcat([' '],[num2str(-s_percent.*10)]),'horiz','left','vert','bottom')

Pcal=(0.5*rho*pi*V47.R^2).*(Vw.^3).*(V47.Cp(V47.R.*wtc./Vw))./1000;

%% Part1_3 index of nomial condition: nomial_i
Qc=Pgen.*(tan(acos(abs(pf)))-tan(acos(0.97)));  % in kVAr
Xc=(V47.Un)^2./(Qc*1e3);                        % Xc (Ohm) when bank is Y connected
Cc=(1.e3)./((2*pi*V47.fn).*Xc);                 % in miliFarad
```

Part 4

```
clear
clc

%% Defining Turbine by class
V47=Ex_1_V47;

%% Allocating Lambda
Lambda=1:0.01:14;

%% Computing Cp
cp=V47.Cp(Lambda);

%% Plot
f=figure;
plot(Lambda,cp,'-b','LineWidth',1.5);

xlabel('\lambda')
ylabel('Cp')
grid on
hold on
max_i=find(cp==max(cp));
x = Lambda(max_i);
y = cp(max_i);
p=plot(x,y,'xr','MarkerSize',10,'LineWidth',1.5);

txt=['\downarrow Cp_{opt}=',num2str(round(cp(max_i),3)),', …
              …\lambda_{opt}=',num2str(Lambda(max_i))];
text(x*0.99,y*1.1,txt,'FontSize',12,'HorizontalAlignment','left','FontName',
…'TimesNewRoman','Interpreter','tex');
legend({'Cp(\lambda,\beta = 0)',…
              …'Cp_{opt}'},'Location','northwest','FontName','TimesNewRoman');



%% Print resualt
fprintf('Optimum point is \n ?= %4.2f and Cp= …
                 …%5.3f\n',Lambda(max_i),cp(max_i));
```

Part 5

```
close all
clear
clc

%%
j=1i;

%% Defining Turbine by class
V47 = Ex_1_V47;

%% Part_1_5 External Resistance Adding
V47.Rrp=V47.Rrp+0.4/((V47.Nr2Ns)^2);

%% Allocating Slip Values
s_percent = -(4:0.2:6)';
s = s_percent./100;
wr =V47.nr(s).*(2*pi/60);       % Generator rotor mechanical speed in rad/s

%% Initializing ciruit parameters
Vsph = V47.Un/sqrt(3);

%% Computing circuit thevenine Impedance
Zth = (V47.Rs+j*V47.Xls)+parallel((j*V47.Xm),(j*V47.Xlrp+(V47.Rrp./s)));

%% Solving and computing current
Isph = Vsph./Zth;
Irp = Isph.*((j*V47.Xm)./((j*V47.Xm)+(j*V47.Xlrp+(V47.Rrp./s))));
Ir = Irp./V47.Nr2Ns;

%% Computing Appearant Power (S=3.V_sph.I_sph*)
S = 3.*Vsph.*conj(Isph)./1e+03;        % in kVA
Pgen = -real(S);                       % in kW
Qcons = imag(S);                       % in kVAr
pf = cos(angle(S));                    % power factor
Pcus = 3.*V47.Rs.*abs(Isph).^2./1e+03; % in kW
Pag = Pgen+Pcus;         % Air Gap Power in kW
Pm = (1-s).*Pag;         % Mechanical power on Generator's shaft in kW
Prot = 0.*Pm;            % Rotational Power Loss before Generator's shaft in kW
Pt = Prot + Pm ;         % Pwer after GearBox on High-speed shaft in kW
Tm = Pt./wr;             % Torque on High-speed shaft in N.m
Te = Pgen./wr;           % Eletrical Torque
```

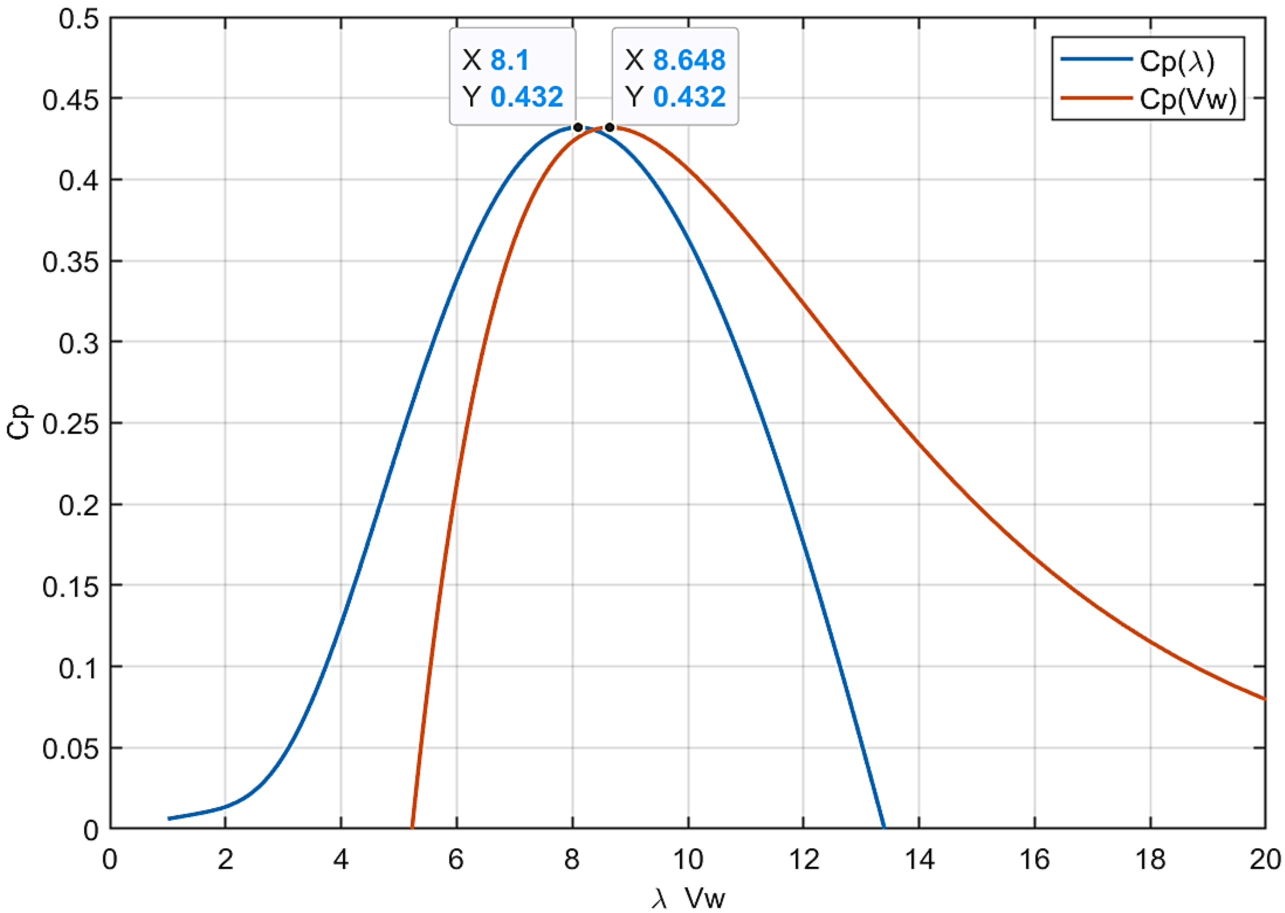
And it continues just like “Part 1, 2 and 3” in page 17

Part 6

```
close all
clear
clc
%%
j=1i;

%% Defining Turbine by class
V47 = Ex_1_V47;
%% Allocating Slip Values
s_percent = -0.65;
s = s_percent./100;
wr =V47.nr(s).*(2*pi/60);  % Generator rotor mechanical speed in rad/s

%% Determining Base Values
wb = V47.wse;
Sb = 660e3; % in VA
Vb = V47.Un;  Vbr = V47.Nr2Ns*Vb;
Ib = Sb/(sqrt(3)*Vb);
Zb = (Vb^2)/Sb;
Lb = Zb/wb;

wmgb = V47.wsm;
wegb = V47.wse;

wtb = wmgb/V47.ng;

Tgb = Sb/wmgb;
Ttb = Sb/wtb;

%% Equvalent Circuit Parameters Per Unit
Rs_pu = V47.Rs / Zb

Xls_pu = V47.Xls / Zb
Lls_pu = Xls_pu

Rrp_pu = V47.Rrp / Zb

Xlrp_pu = V47.Xlrp / Zb
Llrp_pu = Xlrp_pu

Xm_pu = V47.Xm / Zb
Lm_pu = Xm_pu
%% Inertia Constants
Hg = (0.5*V47.JG*(V47.wsm)^2) / Sb
Ht = (0.5*V47.Jt*(V47.wsm/V47.ng)^2) / Sb
```

Drawing Cp vs. Lambda and Vw

```
L=1:0.1:15;
wsynt = pi*50/52.7;
invLi = 1./L-0.035;
c = [ 0.5176   116     0.4     5       21      0.0068     0.9];
Cp = c(7).*(c(1).*(c(2).*invLi-c(4)).*exp(-c(5).*invLi)+c(6).*L);

figure
plot(L,Cp)
grid on
xlabel('\lambda  Vw')
ylabel('Cp')
Lopt=L(Cp==max(Cp));
Vwopt=23.5*wsynt/Lopt;
hold on
plot(23.5.*wsynt./L,Cp)
legend('Cp(\lambda)','Cp(Vw)')
xlim([0 20])
ylim([0 0.5])
```



Auxiliary Function ‘parallel’

```
function p=parallel(R1,R2)
    p=1./(1./R1+1./R2);
end
```

Auxiliary Function ‘swap’

```
function [a2,b2]=swap(a1,b1)
    a2=b1;
    b2=a1;
end
```

The End