Appendix A: Matlab Files

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%-------------------------------------%
%Droop Control and Network definition%
%-------------------------------------%
%Initial conditions
Eo= 1e+3*[149.5  145.75 149.75 145.5 145.5 149.75 148.5 146.2 149.75
 145.5 145.5 149.75 148.5 146.2];
%Capacities
C=1e-3*[200 100 100 140 150 150 140 200 100 200 150 140 100 150];
Cap=diag(C);
Cinv=inv(Cap);
%references
Es=1e+3*[150 150 145 150 145 150 150 145 150 150 145 150 150 145]';
%resistances and Rosen
dist=[100 40 120 300 50 100 120 100 40 70 250 40 70 150 120 40 50 150 380];

R=0.02;
Res=dist*R;
mat= zeros(19,19);
UK1=1;
UK2=2;
UK=3;
HUB1=4;
BE1=5;
BE=6;
HUB2=7;
NL1=8;
NL2=9;
NL=10;
HUB3=11;
DE1=12;
DE2=13;
DE=14;
HUB4=15;
DK1=16;
DK2=17;
DK=18;
HUB5=19;

mat(UK1,HUB1)=Res(1);
mat(UK2,HUB1)=Res(2);
mat(UK,HUB1)=Res(3);
mat(HUB1,HUB2)=Res(4);
mat(BE1,HUB2)=Res(5);
mat(BE,HUB2)=Res(6);
mat(HUB2,HUB3)=Res(7);
mat(NL1,HUB3)=Res(8);
mat(NL2,HUB3)=Res(9);
mat(NL,HUB3)=Res(10);
mat(HUB3,HUB4)=Res(11);
mat(DE1,HUB4)=Res(12);
mat(DE2,HUB4)=Res(13);
mat(DE,HUB4)=Res(14);
mat(HUB4,HUB5)=Res(15);
mat(DK1,HUB5)=Res(16);
mat(DK2,HUB5)=Res(17);
mat(DK,HUB5)=Res(18);
mat(HUB1,HUB5)=Res(19);
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for i=1:19
    for j=1:19
          if (mat(i,j)~=0)
           mat(j,i)=mat(i,j);
          end
    end
end

%Star 1 UK1-UK2-UK-Hub2-Hub5
Rs1=[mat(UK1,HUB1)
mat(UK2,HUB1)
mat(UK,HUB1)
mat(HUB1,HUB5)
mat(HUB1,HUB2)];

sum1=somma(Rs1);

[Rt1,Hub2,Rt1o]=meshing(Rs1,sum1);

Rs2=[Hub2';
mat(BE1,HUB2)
mat(BE,HUB2)
mat(HUB2,HUB3)];

sum2=somma(Rs2);
[Rt2,Hub3,Rt2o]=meshing(Rs2,sum2);

Rs3=[Hub3';
mat(NL1,HUB3)
mat(NL2,HUB3)
mat(NL,HUB3)
mat(HUB3,HUB4)];

sum3=somma(Rs3);
[Rt3,Hub4,Rt3o]=meshing(Rs3,sum3);

Rs4=[Hub4';
mat(DE1,HUB4)
mat(DE2,HUB4)
mat(DE,HUB4)];

sum4=somma(Rs4);
[Rt4,Hub5,Rt4o]=meshing(Rs4,sum4);

Rs5=[Hub5';
mat(DK1,HUB5)
mat(DK2,HUB5)
mat(DK,HUB5)];

sum5=somma(Rs5);
[Rt5,Hub5,Rt5o]=meshing(Rs5,sum5);
Rosen=zeros(14,14);

Rosen(1,:)= [0 Rt5(1:13)];
Rosen(2,:)= [0 0 Rt5(14:25)];
Rosen(3,:)= [0 0  0 Rt5(26:36)];
Rosen(4,:)= [0 0  0 0 Rt5(37:46)];
Rosen(5,:)= [0 0  0 0 0 Rt5(47:55)];
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Rosen(6,:)= [0 0  0 0 0 0 Rt5(56:63)];
Rosen(7,:)= [0 0  0 0 0 0 0 Rt5(64:70)];
Rosen(8,:)= [0 0  0 0 0 0 0 0 Rt5(71:76)];
Rosen(9,:)= [0 0  0 0 0 0 0 0 0 Rt5(77:81)];
Rosen(10,:)=[0 0  0 0 0 0 0 0 0 0 Rt5(82:85)];
Rosen(11,:)=[0 0  0 0 0 0 0 0 0 0 0 Rt5(86:88)];
Rosen(12,:)=[0 0  0 0 0 0 0 0 0 0 0 0 Rt5(89:90)];
Rosen(13,:)=[0 0  0 0 0 0 0 0 0 0 0 0 0 Rt5(90)];
Rosen(14,:)=[0 0  0 0 0 0 0 0 0 0 0 0 0 0 ];

for i=1:14
    for j=1:14
        if i>j
            Rosen(i,j)=Rosen(j,i);
        end
    end
end
Rosen=Rosen.*10000;

%Laplacian calculus
N=14;
Cond=zeros(N,N);

for i=1:N
    for j=1:N
        if(i~=j&&Rosen(i,j)~=0)
            Cond(i,j)=1/Rosen(i,j);
        else
            Cond(i,j)=0;
        end
    end
end

L=zeros(N,N);


for i=1:N
    for j=1:N
        if(i~=j)
            L(i,j)=-Cond(i,j);
        else
            sum=0;
            for k=1:N
                sum=sum+Cond(i,k);
            end

            L(i,j)=sum;
        end
    end
end

delta=-L*Es;

Imax=1e+3;

%Power
Pmax=1e+6*[140 150 100 120 100 130 140 100 130 120 100 140 140 100];
```

```
%Droop gains
md=[0.25 0.25 0.20 0.25 0.20 0.25 0.25 0.20 0.25 0.25 0.20 0.25 0.25 0.20]';

%Eh,El
Pc=[0 0  Pmax(3) 0 Pmax(5) 0 0 Pmax(8) 0 0 Pmax(11) 0 0 Pmax(14)]';
Pg=[Pmax(1) Pmax(2) -Pmax(3) Pmax(4) -Pmax(5) Pmax(6) Pmax(7) -Pmax(8) Pmax(9)
 Pmax(10) -Pmax(11) Pmax(12) Pmax(13) Pmax(14)]';

Eh=0.5*(Es+sqrt(Es.*Es-4*Pc./md));
El=0.5*(Es+sqrt(Es.*Es-4*Pg./md));
```

```
%----------------%
%Meshing function%
%----------------%
function [ Rt,Hub,Rto ] = meshing( Rs,sum )
j=1;
z=1;
x=1;
for i=1:length(Rs)-1
    for k=1:length(Rs)
        if(i~=k&&i<k)
            Rt(j)=Rs(i)*Rs(k)/sum;
            if(k==length(Rs))
                Hub(z)=Rt(j);
                z=z+1;
            else
                Rto(x)=Rt(j);
                x=x+1;
            end
            j=j+1;
        end
    end
end


end
```

```
%----------------------%
%Droop Control Funtion%
%----------------------%
function [I,Eh,El]  = droopf(E1,E2,E3,E4,E5,E6,E7,E8,E9,E10,E11,E12,
E13,E14,Pmax,Es)
E=[E1,E2,E3,E4,E5,E6,E7,E8,E9,E10,E11,E12,E13,E14];
N=14;
I=1000*ones(14,1);
md=[0.25 0.25 0.20 0.25 0.20 0.25 0.25 0.20 0.25 0.25 0.20 0.25 0.25 0.20]';

Imax=1e+3;

Pc=[0 0  -Pmax(3) 0 -Pmax(5) 0 0 -Pmax(8) 0 0 -Pmax(11) 0 0 -Pmax(14)]';
Pg=[Pmax(1) Pmax(2) Pmax(3) Pmax(4) Pmax(5) Pmax(6) Pmax(7) Pmax(8) Pmax(9)
 Pmax(10) Pmax(11) Pmax(12) Pmax(13) Pmax(14)]';

Eh=0.5*(Es+sqrt(Es.*Es-4*Pc./md));
El=0.5*(Es+sqrt(Es.*Es-4*Pg./md));


for i=1:N

    if  (E(i)<=Pg(i)/Imax);
        I(i)=Imax;


    else

            if (Pg(i)/Imax<E(i)&&E(i)<El(i))
                    I(i)=Pg(i)/E(i);

            else

                    if (E(i)>El(i) && E(i)<Eh(i))
                    I(i)=-md(i)*(E(i)-Es(i));

                    else

                        if (El(i)<E(i))
                        I(i)=Pc(i)/E(i);


                        end
                    end
            end

    end
end
end
```

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%-------------------------------------%
%Global PID Control Heterogeneous Case%
%-------------------------------------%
%Parameters
Eo=1e+3*[149.5  145.75 149.75 145.5 145.5 149.75 148.5 146.2 149.75
 145.5 145.5 149.75 148.5 146.2]';
C=1e-3*[200 100 100 140 150 150 140 200 100 200 150 140 100 150];
Cap=diag(C);
Cinv=inv(Cap);
Es=1e+3*[150 150 145 150 145 150 150 145 150 150 145 150 150 145]';
initial=Eo-Es;

%Calculation of alfa minimo
run H.m;
H1=eye(N-1)+Hc;
H2=Hc*(P1+p(1)*uno*uno')+(P1+p(1)*uno*uno')*Hc';
gamma=0.6;
alfamin=(gamma*eigL(2)+1/2*eigL(2))*(((norm(H1)^2)/(2*N*0.9))*(p1'*p1/abs(phi))
+norm(H2));
alfatmin=(alfamin-1);

%Parameters of the integral action
beta=5;
gamma=0.6;
alfa=25;

maxz=(sqrt(N*(N-1)))*(norm(Hc))*(1+(norm(pdiff,'fro')/(N*abs(phi))))*
*norm(delta','fro'); %limit of the integral action
maxnormH=N/(gamma*eigL(2)+1);  %upperbound of H
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%-------------%
%Hc Evaluation%
%-------------%

Lt=eye(N)+2*L;
Lti=inv(Lt);

l11=Lti(1,1);

L12=Lti(1,2:N);

L21=Lti(2:N,1);

L22=Lti(2:N,2:N);

Hc=L22-ones(N-1,1)*L12;
```