

CAES: Combined Compressed Air Energy Storage

Operations Manual

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Team #7

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MATLAB code

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%System_Simulation
psi = 60; %unit conversion to psi
t = 1:0.1:24; %time span for plotting
tspan = 4:0.1:18; %time span for solving fill_ode
P_0 = 70/psi; %initial pressure in the pressure vessel 70 psi

%numerical diffeq solver for fill
[t1,P,] = ode45('fill_ode', tspan, P_0);
P = P*psi;

% for i = 1:length(t)
%     if P(i) > 150
%     P(i) = 150;
%     else if P(i) < 70
%         P(i) = 70;
%     else P(i) = P(i);
%     end
% end

figure(4)
plot(t1,P),axis([8 16 60 150]), title('Pressure Storage'), xlabel('time
(hr)'), ylabel('Pressure (psi)')

Wind = (-0.00001206)*t.^6 + 0.0008783*t.^5 - 0.023577*t.^4 + 0.2818397*t.^3 -
1.439047*t.^2 + 2.793162*t + 3.9378176; %wind data curve
Req_Power = 10*(0.1*sin((2*pi/13)*t-1.33) + 0.2); %residential load
Gen_Power = -0.0557*Wind.^3 + 1.6192*Wind.^2 - 12.443*Wind + 30.89;
%power curve for turbine

for i = 1:length(t)
    if Gen_Power(i) > Req_Power(i) + 10/3
        Comp_Power(i) = Gen_Power(i) - (Req_Power(i) + 10/3);
    else Comp_Power(i) = 0;
    end
end

RPM_Comp = 150*Comp_Power; %ratio for rpm to power
CFM = 0.0543*RPM_Comp - 12.697; %compute CFM for given rpm

figure(1), plot(t,Wind),xlabel('time (hr)'), ylabel('Wind Speed (m/s)'),
title('Daily Wind Speed')
figure(2), plot(t,Gen_Power,t,Req_Power,'-r'),xlabel('time (hr)'),
ylabel('Power (kW)'), legend('Wind Turbine Power','Residential Load'),
axis([1 24 1 16])
%figure(3), plot(t,CFM),
figure(5), plot(t,Comp_Power),xlabel('time (hr)'),ylabel('Power (kW)'),
title('Surplus Power for CAES')

tspan = 12:0.1:24; %tspan for discharge_ode evening hours
P_init = 150/psi; %initial value p = 150 psi (fully charged)
[t2,p2] = ode45('discharge_ode',tspan,P_init);
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p2 = p2*60;

% for j = 1:length(t2)
%     if Req_Power(j) < Gen_Power(j)
%         pr(j) = 150;
%     else pr(j) = pr(j);
%
%     end
%
% end

%figure(6), plot(t1,P), title('Pressure Variation for fill'),
%xlabel('time (hr)'), ylabel('Pressure (psi)'),legend('Power storage')
figure(7), plot(t2,p2, '-r'),xlabel('time (hr)'),ylabel('Pressure (psi)'),
title('Power Generation')

tspan = 1:0.1:10; %tspan for discharge morning hours
P_init = p2(length(t2))/psi; %initial value from last integration
[t3,p3] = ode45('discharge_ode',tspan,P_init);
p3 = p3*60;

figure(8), plot(t3,p3, '-r'),xlabel('time (hr)'),ylabel('Pressure (psi)'),
title('Power Generation')

%-----

function dpdt = fill_ode(t,p)

Wind = (-0.00001206)*t.^6 + 0.0008783*t.^5 - 0.023577*t.^4 + 0.2818397*t.^3 -
1.439047*t.^2 + 2.793162*t + 3.9378176;

Req_Power = 10*(0.1*sin((2*pi/13)*t-1.33) + 0.2);

%Power Curve = -0.0557*wspeed^3 + 1.6192*wspeed^2 - 12.443*wspeed + 30.89
%Provided by Sponsors

Gen_Power = -0.0557*Wind.^3 + 1.6192*Wind.^2 - 12.443*Wind + 30.89;

if Gen_Power > (Req_Power + 10/3)
    Comp_Power = Gen_Power - Req_Power - 10/3;
else Comp_Power = 0;
end

RPM_Comp = 150*Comp_Power;
CFM = 0.0543*RPM_Comp - 12.697;

if CFM > 10
    CFM = CFM;
else CFM = 0;
end

```

```

D = 12; L = 100; %dimensions in feet
Vol = 3.75*pi/4*D^2*L; %pressure vessel volume
P_out = 150; %outlet pressure from compressor

dpdt = 1/Vol*(P_out*CFM);

%-----

function dpdt = discharge_ode(t,pr)

Wind = (-0.00001206)*t.^6 + 0.0008783*t.^5 - 0.023577*t.^4 + 0.2818397*t.^3 -
1.439047*t.^2 + 2.793162*t + 3.9378176;

Req_Power = 10*(0.1*sin((2*pi/13)*t-1.33) + 0.2);

%Power Curve = -0.0557*wspeed^3 + 1.6192*wspeed^2 - 12.443*wspeed + 30.89
%Provided by Sponsors

Gen_Power = -0.0557*Wind.^3 + 1.6192*Wind.^2 - 12.443*Wind + 30.89;

if Req_Power > (Gen_Power)
    Load_Power = Req_Power - Gen_Power;
else Load_Power = 0;
end

if Load_Power == 0
    RPM_air = 0;
    CFM_air = 0;
else RPM_air = 21.711*Load_Power.^2 + 89.182*Load_Power + 28.268;
    CFM_air = (0.1684*RPM_air + 133.35)*1/1.77083;
end

L = 100; D = 12; Vol = 3.75*pi/4*D^2*L; %pressure vessel volume
P_in = 80; %operating pressure of air motor

dpdt = -1/Vol*(P_in*CFM_air);

%-----

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As the CAES project is a design and analysis rather than a functioning prototype, the operations manual is a breakdown of the MATLAB code used to simulate the system. The code, shown above, contains the essential parameters to the system, including: wind data, turbine power curve, turbine power generation, load requirement, compressor data, air motor data, pressure vessel volume, and the governing equations. These parameters can be easily manipulated to modify the system in any way. The power output of the turbine can be altered by changing the power curve, the load can be adjusted by inputting new data requirements, the storage volume can be manipulated and the compressor and/or air motor selection can be altered. This code will allow the operators to quickly explore the theoretical performance of a variety of systems to determine which will function properly.

The MATLAB code consists of three programs, System_Simulation, fill_ode and discharge_ode. The fill_ode and discharge_ode programs contain the definition for the governing equations of the integrated CAES system. The fill_ode program contains the data for the storage of surplus power from the turbine as compressed air. In this case, the turbine power exceeds the residential load requirements, and the surplus power is diverted to run the compressor. The compressor pumps air into the pressure vessel to a maximum of 150 psi in the current model. The fill_ode contains all the essential data for the system. If the system needs to be altered, or another setup is desired to be tested, the user must change whichever parameter is desired. If a different compressor is to be used, the compressor power, rpm and flow rate data should be changed in the code. Also, if a different pressure vessel or load curve needs to be tested, the data can easily be replaced. If a different turbine or multiple turbines are to be tested, the power curve can be replaced or multiplied respectively.

The discharge_ode program functions in the same manner as fill_ode. However, discharge_ode is for the second case, in which the residential load exceeds power generation from the turbine. Here, the pressure vessel is filled and the compressed air is released through an air motor to generate the surplus power. The discharge_ode contains the same data as the fill_ode, and whatever parameters are altered in fill_ode must also be updated in discharge_ode. The major difference between the two programs is the governing differential equations and discharge_ode contains the air motor data. It is possible to achieve variable power output from the air motor by throttle the incoming air. The corresponding flow rate was determined by the

air motor power curves provided in the appendix of the Final Report. As the residential load never received a maximum of 4-5 kW greater than the turbine power, a 7 kW air motor was chosen for the provided model. However, this can be easily altered by adjusting the power curve in discharge_ode.

System_Simulation is the program that actually runs the simulation of the CAES system for theoretical performance analysis. It also contains essential data that fill_ode and discharge_ode contain, and must be updated as well; however, the data in System_Simulation is for plotting purposes only, as the data for the system solution is housed in both fill_ode and discharge_ode. System_Simulation utilizes MATLAB's numerical solver, ode45, to solve the differential equations contained in the two supporting programs. System_Simulation solves fill_ode and discharge_ode separately and plots the results so each component can be individually analyzed. The program functions by calling each ode function and solving within the program. The results are generated for the time duration where surplus power is being used to compress air and both morning and evening when residential loads are peak and compressed is used for power generation.

As the current system is modeled, System_Simulation will output six plots representing the system. When the code is run, automatically generated will be plots of the wind speed data for 24 hours, the power distribution comparing wind turbine power and residential load, the surplus power generation from the turbine, the pressure vessel fill time corresponding to surplus power from the turbine and two plots for power generation from the air motor for both the morning and evening peaks. The current system and code provided above is for a single 20 kW wind turbine operating to supply a community of ten NREL zero energy homes, a compressor corresponding to the power input of the turbine, a 7 kW air motor, and a pressure vessel 3.75 times the volume of the current vessel located at Kueka Wind. With these parameters, the program will output the graphs shown below.





