Contents


```
clear
clc
```

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```
[Ybus, Yf, Yt] = makeYbus(case57);
Y=full(imag(Ybus));
L=-Y;
for i=1:57
    L(i,i)=0;
    L(i,i)=-sum(L(i,:));
end
```

Q1

```
rng('default')
i = 1; j = 1;
n = 57; norm = 10000;
demand_norm = 26869/norm;

generator_index =  [1 2 3 6 8 9 12];
random_num = rand(50,1);
total = sum(random_num );
PD = zeros(n,1);
PD(setdiff(1:n, generator_index)) = (random_num/total)* demand_norm;

indexer =[1 2 3 4 5 6 7];
indexer_PG  =zeros(n,1);
indexer_PG(generator_index) =1;

cvx_begin quiet
    variables PG(n) theta(n)
    minimize  indexer * PG(generator_index)
    subject to

        PG .* (1 - indexer_PG) == 0;
        PG - PD == L * theta;

        for  i = 1:n
            for j = 1:n
                if sign(L) ~= 0
                    abs(theta(i) - theta(j)) <= pi/10;
                end
            end
        end
        abs(theta(4) -  theta(6)) <= 0;
        abs(theta(8) -  theta(9)) <= 0;
```

```
        PG >= 0;
 cvx_end
Q1_thetas = theta;
Q1_costs = indexer * PG(generator_index) * norm
Q1_PG = PG * norm
```

```
Q1_costs =

     5.752079028527671e+04


Q1_PG =

   1.0e+04 *

   1.894289028553581
   0.000000004448515
   0.000000001772996
                   0
                   0
   0.448937902159766
                   0
   0.000000003240359
   0.343673057856264
                   0
                   0
   0.000000001968519
                   0
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Q2

```
PG_all = zeros(n,24);
cost_all = zeros(1,24);
lambda_all = [];
demand_list = ([20477 19854 19223 18902 18973 19687 21188 22541 22070 20910 ...
    19115 17753 17151 17166 17604 18392 19667 21663 23959 26034 26869 26126 24958 23422]);
demand_norm_list = demand_list/norm;

random_num_list = rand(50,24);
total_list = sum(random_num_list );
a = zeros(1,24);
PD_50= (random_num_list/total_list)* demand_norm_list;
PD_list = [a;a;a;PD_50(1:2,:);a;PD_50(3,:);a;a;PD_50(4:5,:);a;PD_50(6:50,:)];


for hour = 1:24

    cvx_begin quiet
        variables PG_2(n) theta_2(n)
        dual variables lambda;
        minimize  indexer * PG_2(generator_index)+0.3*(PG_2(generator_index)' *PG_2(generator_index))
        subject to

            PG_2 .* (1 - indexer_PG) == 0;
            lambda: PG_2 - PD_list(:,hour) == L * theta_2;

            for  i = 1:n
                for j = 1:n
                    if sign(L) ~= 0
                        abs(theta_2(i) - theta_2(j)) <= pi/10;
                    end
                end
            end
            abs(theta_2(4) -  theta_2(6)) <= 0;
            abs(theta_2(8) -  theta_2(9)) <= 0;
            PG_2 >= 0;
     cvx_end

     PG_all(:,hour) = PG_2;
     cost_all(hour) = indexer * PG_2(generator_index)+0.3*(PG_2(generator_index)' *PG_2(generator_index));

     lambda_all =[lambda_all lambda];

end
Q2_PG = PG_2 * norm;
Q2_cost_all = cost_all;
Q2_lambda_all = lambda_all;
```

```
disp('The electricity prices at all buses at each of these times:')
lambda_all'
```

```
The electricity prices at all buses at each of these times:

ans =

  Columns 1 through 3

   1.859878702388815   1.446012334048007   0.149162064713171
   1.833720311823192   1.417741171477054   0.114270531042389
   1.807218654901687   1.389098268959902   0.078918035429861
   1.793739194188337   1.374530012509467   0.060938037526386
   1.796720622886822   1.377752263549698   0.064914905376884
   1.826704545479881   1.410158274640936   0.104910530801387
   1.889733502954397   1.478278997886620   0.188986302141948
   1.946549208251198   1.539683227345282   0.264768672107693
   1.926769953145112   1.518306548305079   0.238386465153957
   1.878064098540786   1.465669249130997   0.173429984381228
   1.802683503747434   1.384196793141486   0.072868681272633
   1.745492006726433   1.322385730064989  -0.003417792084964
   1.720208146990500   1.295059818847349  -0.037142471640954
   1.720838080302815   1.295740623020556  -0.036302263624632
   1.739233439663381   1.315621589700032  -0.011766146396494
   1.772323098499952   1.351384035488270   0.032371477331518
   1.825864398644363   1.409250226733181   0.103789714883101
   1.909678119162498   1.499834672097828   0.215590226622006
   2.006094393399659   1.604038148358691   0.344194900502014
   2.093228442047004   1.698210461191311   0.460421614229579
   2.128292039645080   1.736106316772166   0.507192350227795
   2.097091738657601   1.702385814960071   0.465574799106565
   2.048044781564569   1.649377066814645   0.400151778658842
   1.983544462435507   1.579666771649856   0.314116023534000

  Columns 4 through 6

  -1.668543816702811   2.297204454330797   4.219509679722501
  -1.712741350067481   2.278277985264615   4.212832777606147
  -1.757525225213126   2.259098954794577   4.206065106443702
  -1.780300972157219   2.249345639922334   4.202624115881569
  -1.775263369486306   2.251502904885409   4.203385203415253
  -1.724599334364461   2.273199453247551   4.211040429091491
  -1.618096216751993   2.318808519117780   4.227132504507642
  -1.522103032098631   2.359914455403169   4.241633110062438
  -1.555521321542699   2.345604126363733   4.236584925168835
  -1.637794516742878   2.310377376724197   4.224162857510224
  -1.765188106210778   2.255817461219801   4.204907389609617
  -1.861822089906628   2.214435859011280   4.190308108009849
  -1.904541255526508   2.196139000266722   4.183849400583533
  -1.903476979963154   2.196594855975143   4.184010338766575
  -1.872397307665653   2.209906937850819   4.188709990004643
  -1.816487029767144   2.233849578492663   4.197157054038469
  -1.726019228074983   2.272591358777188   4.210825835623884
  -1.584396170168582   2.333240079473868   4.232224109518929
  -1.421491667687880   2.402999522020742   4.256833627463164
  -1.274263963907921   2.466047275524105   4.279077086989556
  -1.215018162760854   2.491418269219702   4.288028047207808
  -1.267736280857258   2.468842641475314   4.280063298104715
  -1.350609547087323   2.433353560608384   4.267542610816822
  -1.459593350894769   2.386683152839047   4.251077187990903
```

Columns 7 through 9

1.816652173743808	-0.141905729899461	6.149231232021240
1.797420317512705	-0.170526225184790	6.144689517629144
1.777928880511592	-0.199533655175475	6.140096241343891
1.768017864400508	-0.214283103406710	6.137756758764445
1.770210007404786	-0.211020785634832	6.138274221864180
1.792258080362750	-0.178209141899154	6.143476532299102
1.838606988838814	-0.109232582643888	6.154408947253182
1.880374678652520	-0.047075042403804	6.164277688745371
1.865833889654021	-0.068714266327865	6.160842305716541
1.830048306220418	-0.121967545183399	6.152359515258417
1.774594327623975	-0.204496095844685	6.139309129171762
1.732543851798455	-0.267075112150286	6.129382542526718
1.713950604783022	-0.294743080878526	6.124991946615502
1.714413835453649	-0.294053786394400	6.125101395480355
1.727941463163094	-0.273924254942962	6.128296763589949
1.752271214473622	-0.237717075325047	6.134039891835765
1.791640012334953	-0.179128990699530	6.143331131182808
1.853272070663751	-0.087408169788236	6.157870053022560
1.924156415475625	0.018080390413768	6.174612214366343
1.988223805972186	0.113424749225593	6.189734464180913
2.014005079516755	0.151792134805841	6.195819899208880
1.991064375087928	0.117652051229504	6.190404957513251
1.955001289263645	0.063983356082363	6.181892959929606
1.907576268629977	-0.006593955125916	6.170698340930025

Columns 10 through 12

4.570141049294699	4.700989636095432	3.692999566045988
4.557707761282414	4.689213636431961	3.676137621741037
4.545116328211506	4.677288364361290	3.659057781471964
4.538709977273233	4.671220741949808	3.650369159806617
4.540126959445146	4.672562803381557	3.652290939798283
4.554376307554686	4.686058626947123	3.671617346117107
4.584327664767761	4.714425904614162	3.712241822364073
4.611335230515259	4.740005977084735	3.748867522249045
4.601933223723369	4.731100930467414	3.736117108519336
4.578766543723534	4.709157285205341	3.704709803857606
4.542960920585883	4.675246921746801	3.656134505228074
4.515779354820597	4.649502519568859	3.619269677094421
4.503761242227941	4.638119700091239	3.602971120030638
4.504060704402225	4.638403336111772	3.603377214920893
4.512805140202831	4.646685591938412	3.615235703433691
4.528531657381597	4.661580594932018	3.636564761855502
4.553977271486967	4.685680715853773	3.671075976570946
4.593806406081210	4.723403438733661	3.725097574415606
4.639635077202304	4.766809496371858	3.787249260045062
4.681046658776883	4.806031445916172	3.843414049324787
4.697711144354551	4.821814804904431	3.866015351741235
4.682882747960764	4.807770452898314	3.845904254806325
4.659572659688362	4.785692893896858	3.814289684901282
4.628917745303458	4.756658823022896	3.772713919726070

Columns 13 through 15

3.540651919957828	2.865614564039716	1.993450462741376
3.523054755901009	2.844641563534591	1.968012579156504
3.505229729936778	2.823395110444163	1.942241087184390
3.496162213796327	2.812587880490013	1.929132926664406
3.498167798485134	2.814978258988071	1.932032230285147
3.518337091307542	2.839017668043001	1.961190187079035

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  3.560733518449190   2.889549963661220   2.022482797215887
  3.598955941217770   2.935103988878762   2.077733676686157
  3.585649651440183   2.919245312121502   2.058499190111837
  3.552874437058351   2.880188652040284   2.011134223964406
  3.502178974860601   2.819759029685436   1.937830859739712
  3.463706569514696   2.773905336359622   1.882214727233327
  3.446697378396480   2.753633267712816   1.857627235047410
  3.447121176180423   2.754138348862627   1.858239820544866
  3.459496654581764   2.768887591844138   1.876128566026249
  3.481755826734591   2.795417430803205   1.908306753049905
  3.517772089843595   2.838344167466106   1.960373193313618
  3.574149912632727   2.905540565312013   2.041878014958759
  3.639011439189808   2.982844642686839   2.135638650312931
  3.697625507010314   3.052704688646727   2.220372519968273
  3.721212419546078   3.080817078406218   2.254470264362376
  3.700224306631488   3.055802103665263   2.224129399199120
  3.667231053337573   3.016478563841821   2.176433485493182
  3.623842247331925   2.964765085947369   2.113709867953684

Columns 16 through 18

  3.174105143331260   2.549437180035234  -1.302137835806087
  3.154611689990888   2.526775800200393  -1.344401510066433
  3.134864852575194   2.503818314138715  -1.387225549379172
  3.124820106656713   2.492141006107213  -1.409004711075988
  3.127041837303518   2.494723830565464  -1.404187535498008
  3.149385025474718   2.520698753619403  -1.355740440433286
  3.196351451444299   2.575299898027133  -1.253897795813168
  3.238692257959981   2.624520801654568  -1.162104615660386
  3.223952217326418   2.607385560511339  -1.194060740679830
  3.187648279134284   2.565186839179233  -1.272735134061483
  3.131485309143644   2.499889496168150  -1.394553129900325
  3.088866689578600   2.450344209024232  -1.486958773570340
  3.070024697689859   2.428440318255233  -1.527808847975587
  3.070494153655261   2.428986051073945  -1.526791134800885
  3.084203008879912   2.444922459254737  -1.497071242293563
  3.108861094909221   2.473588175361186  -1.443607392560514
  3.148759082198502   2.519970996761485  -1.357098187731137
  3.211213820815591   2.592577921719183  -1.221672360985099
  3.283064650826439   2.676105008982403  -1.065895648091080
  3.347995788403245   2.751589462795740  -0.925110129128061
  3.374124744447000   2.781965163668731  -0.868456719414151
  3.350874669472342   2.754936248658248  -0.918868074865012
  3.314325581246229   2.712446769912340  -0.998115080783976
  3.266260651376146   2.656569897735708  -1.102330143227930

Columns 19 through 21

  0.242374363287419   1.202271962894379   2.459450417289480
  0.208262490945389   1.173226347133846   2.437040080772593
  0.173699753330666   1.143797919027465   2.414336060868425
  0.156121500331050   1.128830485273548   2.402788018626016
  0.160009508941793   1.132141026680077   2.405342250893368
  0.199111530122882   1.165435185680269   2.431029849357405
  0.281308869356298   1.235423180438901   2.485027258430363
  0.355397758297684   1.298509044187907   2.533702453571917
  0.329605099238555   1.276546912452575   2.516757165739957
  0.266100745650545   1.222470574255061   2.475028704880076
  0.167785565885268   1.138762140066969   2.410450734020560
  0.093203656248833   1.075257488042943   2.361453972848440
  0.060232367487732   1.047182779206605   2.339792317637986
  0.061053806089852   1.047882235288164   2.340332013140159
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```
 0.085041814884819   1.068307940450989   2.356092167127344
 0.128193228842364   1.105050287291538   2.384440554971061
 0.198015748779478   1.164502213339605   2.430310108064000
 0.307318368954602   1.257569543630858   2.502114069584232
 0.433049289631313   1.364627329938925   2.584715640756543
 0.546679048160976   1.461380077545153   2.659364557166378
 0.592404742711674   1.500314315504888   2.689404020408879
 0.551717090563186   1.465669839619245   2.662674296051809
 0.487755870301640   1.411208569548623   2.620655116369522
 0.403642497224797   1.339588178646255   2.565396791616004

Columns 22 through 24

 2.712871252724868   2.700610213318600   2.494650927801973
 2.691798449478133   2.679588704471843   2.474491055364719
 2.670449929374694   2.658292016090329   2.454065029254234
 2.659591164816371   2.647459668454265   2.443676429513744
 2.661992941007794   2.649855601547993   2.445974211040817
 2.686147216243834   2.673951148429492   2.469083246947172
 2.736921258284533   2.724601776087522   2.517660776457932
 2.782691564573660   2.770260602198704   2.561446973582441
 2.766757567357440   2.754365410809876   2.546203637245909
 2.727518179850525   2.715221971926148   2.508671930387785
 2.666796509567944   2.654647484197177   2.450569795334433
 2.620724235215687   2.608687304042454   2.406492558384553
 2.600355317247016   2.588367898639316   2.387004858376321
 2.600862808363761   2.588874155862888   2.387490388828887
 2.615682484988672   2.603657807558084   2.401668898615706
 2.642338826572646   2.630249299764222   2.427171059723311
 2.685470457861843   2.673276030140466   2.468435678718475
 2.752988169757541   2.740629608560631   2.533032165163807
 2.830659880376146   2.818112223188427   2.607338370853441
 2.900853127546242   2.888134715740382   2.674492550370472
 2.929099590573085   2.916312464006547   2.701516037358694
 2.903965314290727   2.891239331447413   2.677469988811954
 2.864454199338432   2.851824330021153   2.639669489427034
 2.812494124295124   2.799990662116218   2.589959191575877

Columns 25 through 27

 2.570438090106766   2.460506209831136   2.210524730471575
 2.550319219186659   2.440459876875210   2.191309646657388
 2.529935214784781   2.420148531255208   2.171837903774442
 2.519567796786395   2.409818399646903   2.161935831059223
 2.521860893718858   2.412103248698911   2.164125998431589
 2.544922695422230   2.435082313935383   2.186153517945572
 2.593400789670111   2.483386731625376   2.232458420013721
 2.637098179082270   2.526926144077669   2.274191064066390
 2.621885772773048   2.511768711207907   2.259662550601490
 2.584428842811167   2.474449542382497   2.223899422504936
 2.526447107582400   2.416672968792138   2.168506360654550
 2.482459704814208   2.372843831796815   2.126493621548998
 2.463011830886298   2.353465706835277   2.107917721174489
 2.463496370583751   2.353948506446411   2.108380527655743
 2.477645919295887   2.368047289029611   2.121895608703538
 2.503096085814694   2.393405919828132   2.146203420484351
 2.544276470506897   2.434438373385159   2.185536136479303
 2.608740808094747   2.498671630362212   2.247110105425195
 2.682896001909472   2.572559263134231   2.317933267808127
 2.749913222505797   2.639335517882890   2.381942646790963
 2.776881601013778   2.666206920564212   2.407700604632629
 2.752884589327566   2.642296199553568   2.384780648216977
```

```
 2.715161192564857   2.604708423647525   2.348750270734582
 2.665552251010146   2.555277900607641   2.301368044630972

Columns 28 through 30

 2.116788892737638   2.055560557996011   2.607180227608461
 2.097885503353239   2.036860767697571   2.587081234505849
 2.078728587257155   2.017909496745943   2.566717602517302
 2.068987024268679   2.008272778857441   2.556360453573164
 2.071141688744661   2.010404252809109   2.558651279381941
 2.092812406084067   2.031841906642500   2.581690181618860
 2.138367547520525   2.076907303750181   2.630120068967445
 2.179422705585176   2.117519927349255   2.673774403789893
 2.165130018740044   2.103381282667346   2.658576992570628
 2.129950360993538   2.068582748285907   2.621156314962313
 2.075451047233080   2.014667231593335   2.563232950396540
 2.034119404896344   1.973780482287490   2.519289099857453
 2.015844315581553   1.955701883031396   2.499860533887181
 2.016299625216309   1.956152295719179   2.500344593259743
 2.029595835039931   1.969305538659452   2.514480101443696
 2.053509620026504   1.992961944984478   2.539905060628268
 2.092204983507514   2.031240989221797   2.581044607951085
 2.152781796216011   2.091166458566123   2.645444878863991
 2.222455870675038   2.160089947744714   2.719526861083194
 2.285427751126064   2.222384133208047   2.786477683052844
 2.310768199298281   2.247451863683203   2.813419344590605
 2.288219751002138   2.225146084829722   2.789446106311620
 2.252773352966140   2.190081142700993   2.751760089430422
 2.206159179078805   2.143968661222174   2.702200286105294

Columns 31 through 33

 2.696555868928705   2.834291967880169   2.834291967880170
 2.676505228829144   2.814315844213883   2.814315844213884
 2.656191152953292   2.794078138874132   2.794078138874132
 2.645858983593127   2.783784465354657   2.783784465354658
 2.648144284869320   2.786061252817070   2.786061252817071
 2.671127483909874   2.808958608099155   2.808958608099155
 2.719440107461803   2.857090517334956   2.857090517334957
 2.762989711535610   2.900478721674507   2.900478721674508
 2.747828776032585   2.885373998611330   2.885373998611330
 2.710496282660945   2.848177405274297   2.848177405274298
 2.652714905355415   2.790614843420469   2.790614843420470
 2.608876996078101   2.746940199389693   2.746940199389694
 2.589495396920700   2.727630980418767   2.727630980418768
 2.589978287897839   2.728112070790896   2.728112070790897
 2.604079642347251   2.742160791188221   2.742160791188222
 2.629443284422464   2.767429937947738   2.767429937947739
 2.670483494408727   2.808317059944758   2.808317059944759
 2.734727922451575   2.872321319764429   2.872321319764430
 2.808631816683886   2.945950763998706   2.945950763998707
 2.875421123286021   3.012491160536380   3.012491160536380
 2.902297795508786   3.039267678236182   3.039267678236182
 2.878382386296423   3.015441388944244   3.015441388944244
 2.840787296375648   2.977986425848108   2.977986425848109
 2.791347022318027   2.928730357405951   2.928730357405952

Columns 34 through 36

 2.951120219652243   2.965286172997581   2.976367305148244
 2.931207301091185   2.945380918341085   2.956468045481085
 2.911034373513308   2.925215845359495   2.936309116654944
```

2.900773352303595	2.914958783389860	2.926055151749196
2.903042918318708	2.917227473771863	2.928323157178624
2.925867460617821	2.940043187167829	2.951131964280313
2.973846087324322	2.988003227675138	2.999077465975838
3.017097391831999	3.031237932459700	3.042299185843606
3.002040348361355	3.016186670355062	3.027252446137085
2.964959025919751	2.979119325030311	2.990196034229602
2.907582064114694	2.921764868069690	2.932859181389872
2.864045902249984	2.878245497793263	2.889352946114263
2.844798076412108	2.859005116150137	2.870118387595341
2.845277639504628	2.859484494053104	2.870597620636196
2.859281715510716	2.873483156725056	2.884592048798160
2.884470711005478	2.898662433516852	2.909763723261381
2.925227983222471	2.939403960861369	2.950492934384861
2.989028531496232	3.003179808189841	3.014249459721206
3.062425186260550	3.076548236179207	3.087595807684203
3.128754456391270	3.142851906279236	3.153879452494283
3.155446022666470	3.169533171810402	3.180552660402844
3.131695325209793	3.145791640205266	3.156818298665470
3.094359218187509	3.108469945018916	3.119507876949716
3.045259393607238	3.059389065712793	3.070441817337075

Columns 37 through 39

2.944772380780823	2.801830509869577	2.969667280430907
2.924693404841017	2.781002176930379	2.949706291601627
2.904352362636150	2.759901705283893	2.929484838909412
2.894005785533757	2.749168957566777	2.919199066642809
2.896294275164538	2.751542861325555	2.921474107331721
2.919309097320142	2.775416735652682	2.944353662641651
2.967687680849063	2.825601228995072	2.992447881696451
3.011299721779339	2.870840739158447	3.035803684190668
2.996117098505528	2.855091538303761	3.020710266719110
2.958726189791687	2.816306140393163	2.983538868375262
2.900871268060884	2.756290683847511	2.926024202087704
2.856972093831451	2.710753054543977	2.882383010976401
2.837563845151882	2.690620543176048	2.863088805224346
2.838047405173709	2.691122145850874	2.863569524285544
2.852168194867915	2.705769842644066	2.877607347253600
2.877567214838966	2.732116838350015	2.902857102957200
2.918664292997822	2.774747849662807	2.943712650907377
2.982996708543127	2.841481660018733	3.007666937576064
3.057005456118361	2.918252375087393	3.081240814127916
3.123887768871428	2.987630995071883	3.147730067400207
3.150801886168709	3.015549648130070	3.174486014315816
3.126853158363090	2.990707063961727	3.150678029742131
3.089205751032452	2.951654502797007	3.113251873167279
3.039696534533550	2.900297428537836	3.064033612744724

Columns 40 through 42

3.019609332074867	4.347819428412897	4.061602563403214
2.999913382180588	4.334377375952773	4.046810305297143
2.979960526686753	4.320763412843824	4.031827790015793
2.969811338044211	4.313837186346706	4.024205731978186
2.972056168840874	4.315369155631222	4.025891606742467
2.994631889384078	4.330775038368103	4.042845443231132
3.042087384592697	4.363157737716412	4.078482328182586
3.084867567801026	4.392356053550868	4.110612947620022
3.069974542929221	4.382191366157219	4.099427419775527
3.033296373125271	4.357148132040475	4.071872211020196
2.976545843338485	4.318433093353738	4.029263358384018

```
 2.933484153230382   4.289045801540713   3.996923789090464
 2.914446109057037   4.276052618867080   3.982625532841942
 2.914920446671823   4.276376371138049   3.982981796200139
 2.928771909856513   4.285830172892203   3.993385044411827
 2.953686378602839   4.302832884991977   4.012095890095920
 2.993999394825874   4.330343572908465   4.042370576141083
 3.057104342654896   4.373405733437929   4.089759933788911
 3.129701342130969   4.422952442933918   4.144283161931206
 3.195307683668259   4.467724650487579   4.193553420036341
 3.221708339170670   4.485741479022954   4.213380301169480
 3.198216500124829   4.469709740250893   4.195737940670728
 3.161287328288699   4.444507975045120   4.168004250387510
 3.112722631602580   4.411365413907966   4.131532078831706

Columns 43 through 45

 4.608315129188807   2.622377841839610   2.238823195597893
 4.596101944796695   2.600526232577939   2.214784478213607
 4.583733547553272   2.578388838925728   2.190430810724667
 4.577440621000802   2.567128772199859   2.178043674348182
 4.578832515675078   2.569619309721861   2.180783500009972
 4.592829553069029   2.594666200008647   2.208337545673057
 4.622250507451259   2.647316589438695   2.266258438528626
 4.648780034072611   2.694778528197553   2.318470503452204
 4.639544448283846   2.678255627121719   2.300293927800909
 4.616787447697710   2.637565646810659   2.255533172522461
 4.581616301483622   2.574600401370525   2.186263171358539
 4.554915977788793   2.526825440386273   2.133706230976913
 4.543110586950722   2.505703965724840   2.110470987429512
 4.543404749775745   2.506230205528820   2.111049885605534
 4.551994428025875   2.521597384249327   2.127954854982141
 4.567442509670707   2.549238848866865   2.158363063448659
 4.592437588908970   2.593964435503807   2.207565508001956
 4.631561420207882   2.663977269624318   2.284586790722596
 4.676578830872542   2.744519585112463   2.373190367603739
 4.717257209676836   2.817306924215504   2.453263360745841
 4.733626647797667   2.846597276674449   2.485485526279419
 4.719060790623335   2.820534126514131   2.456813589287421
 4.696163416520941   2.779562823441128   2.411741247305718
 4.666051247039029   2.725682484876784   2.352467788881025

Columns 46 through 48

 2.884674958587814   2.906509962168435   2.917319873759875
 2.863910995340435   2.885985465594204   2.896913930569722
 2.842876245621601   2.865193236766796   2.876241767186119
 2.832176724103636   2.854617102730865   2.865726718909452
 2.834543279262934   2.856956366603729   2.868052471614686
 2.858343121622612   2.880481768702716   2.891442005865325
 2.908371839804119   2.929933604012990   2.940608242283269
 2.953471799953149   2.974513401141690   2.984930520962652
 2.937771194751263   2.958993877866983   2.969500646385111
 2.899104001636954   2.920772846168465   2.931500496970509
 2.839276403257768   2.861634907997042   2.872703990658557
 2.793879709294468   2.816761738491315   2.828090003757559
 2.773809617191809   2.796923024524796   2.808365838762220
 2.774309666328563   2.797417309141678   2.808857269523368
 2.788911965804933   2.811851274644014   2.823207897490611
 2.815177400159311   2.837813815190216   2.849020483617254
 2.857676330897995   2.879822664579139   2.890786707167168
 2.924203077693291   2.945582279663127   2.956166536374428
 3.000736655099097   3.021233195928842   3.031380471310858
```

```
 3.069900456337025   3.089599400560956   3.099351807732273
 3.097732669633807   3.117110652292592   3.126704160193265
 3.072967001545733   3.092630582262030   3.102365481930330
 3.034035370112970   3.054147909065264   3.064105075646481
 2.982837285853294   3.003540243951027   3.013789710862790

Columns 49 through 51

 3.278892783397359   3.695823651323034   4.415151675304400
 3.260194520074065   3.679148284496826   4.401966398207471
 3.241253237517102   3.662257303440619   4.388612788549172
 3.231618245607488   3.653664806702503   4.381818901723182
 3.233749345596678   3.655565325347096   4.383321599923825
 3.255181098428068   3.674677953101176   4.398433056770300
 3.300231589935833   3.714853088465066   4.430196772949452
 3.340845220341835   3.751073459652880   4.458837483537945
 3.326706459663503   3.738464148392744   4.448866921078648
 3.291883353155569   3.707404782870403   4.424301112580313
 3.238011555472669   3.659366368303811   4.386326994694503
 3.197131476276852   3.622909399089803   4.357501187401644
 3.179057908893021   3.606791076168596   4.344756234609395
 3.179508221103337   3.607192680444033   4.345073803412178
 3.192658032359410   3.618920040990434   4.354347019310359
 3.216310248108631   3.640013129675426   4.371024863272915
 3.254580692016694   3.674142567115674   4.398009850088513
 3.314487680031502   3.727566621465589   4.440248942562203
 3.383407535504794   3.789030569513749   4.488849263645557
 3.445689940558005   3.844573998974823   4.532765983814351
 3.470753020138973   3.866925258389498   4.550438558123946
 3.448451383584680   3.847036654703189   4.534713143825279
 3.413393241830296   3.815771839347796   4.509992929008766
 3.367289018218645   3.774656039786638   4.477483623931635

Columns 52 through 54

 2.986099279352082   3.477302279679806   4.675662951398616
 2.970617783562369   3.463519623371293   4.666024859395440
 2.954930250967337   3.449554918678261   4.656263242225328
 2.946952279117447   3.442452548253920   4.651297027955936
 2.948716869723089   3.444023472334783   4.652395474575200
 2.966464042106018   3.459822552156365   4.663441901198754
 3.003770617340017   3.493033482044399   4.686660912664797
 3.037394800728991   3.522968681063320   4.707596301453107
 3.025689131292549   3.512547305029042   4.700308144684743
 2.996872470064051   3.486888292131420   4.682352671000674
 2.952246070501336   3.447165334091193   4.654592366838179
 2.918396924478569   3.417031124124741   4.633521279989600
 2.903429766797704   3.403706401521560   4.624203515001973
 2.903802674462469   3.404038396649347   4.624435698086141
 2.914692377208569   3.413733245587408   4.631215528567368
 2.934276888111012   3.431168327129535   4.643406766708048
 2.965966668813120   3.459379836649410   4.663132531255719
 3.015575250638953   3.503542448321801   4.694008912088954
 3.072637320092171   3.554343236193142   4.729534399122817
 3.124208778649060   3.600254494365823   4.761636780863642
 3.144961613681867   3.618729627741793   4.774555132042355
 3.126495317596561   3.602290077467436   4.763060120929589
 3.097466167067287   3.576447037171905   4.744990056770868
 3.059290919843799   3.542461613747303   4.721226313707882

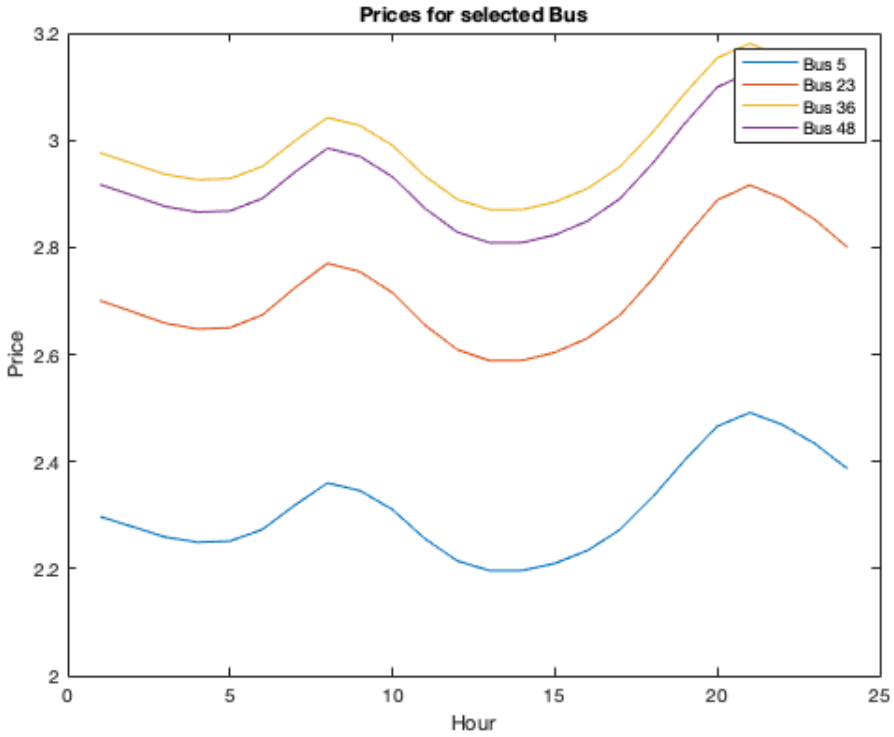
Columns 55 through 57
```

```
5.795765244381192   3.770655043640764   3.593737483755565
5.790001057865221   3.754490263395424   3.576734218841254
5.784168047568759   3.738116576212966   3.559510659393245
5.781198488783642   3.729787185779435   3.550749154617888
5.781855312859202   3.731629509806818   3.552687054607097
5.788459456061334   3.750156884964393   3.572175714228806
5.802339066627551   3.789101741408203   3.613141429145103
5.814862373549675   3.824213130201939   3.650073796512504
5.810502822640125   3.811989889233035   3.637216607502678
5.799747812172863   3.781881187374569   3.605547937957070
5.783168946416041   3.735314162982968   3.556562861530607
5.770569119702657   3.699973520322970   3.519388841576768
5.764996639852456   3.684348619958941   3.502953486190152
5.765135529071460   3.684737931754714   3.503362987495800
5.769190705001980   3.696106319082006   3.515320984379600
5.776480546462495   3.716553530754738   3.536828954293853
5.788274723613029   3.749637898892324   3.571629775831879
5.806732524648673   3.801425974516011   3.626105054019691
5.827980257165178   3.861007974289901   3.688777498880846
5.847175544639757   3.914850627706791   3.745413460373126
5.854899996663031   3.936517478381700   3.768204361289848
5.848026623912860   3.917237875449177   3.747924555524047
5.837221925348667   3.886930411878764   3.716044756078151
5.823012340629978   3.847073597377306   3.674120239365214
```

Q2 -- selected bus 5,23,36 and 48 and plot the prices over time

```
selected_buses = [5,23,36,48];
price_seleted_buses = Q2_lambda_all(selected_buses,:);
x =  1:24;
for i = 1:4
    yi = price_seleted_buses(i,:);
    plot(x,yi)
    hold on
end

xlabel('Hour');
ylabel('Price');
legend('Bus 5','Bus 23','Bus 36','Bus 48')
title('Prices for selected Bus')
hold off
figure()
```



Q2 -- max and min price

```
[max_price, max_index] = max(Q2_lambda_all(:));
[max_row,max_col] = ind2sub(size(Q2_lambda_all),max_index);
max_price_bus = max_row;

[min_price, min_index] = min(Q2_lambda_all(:));
[min_row,min_col] = ind2sub(size(Q2_lambda_all),min_index);
min_price_bus = min_row;
```

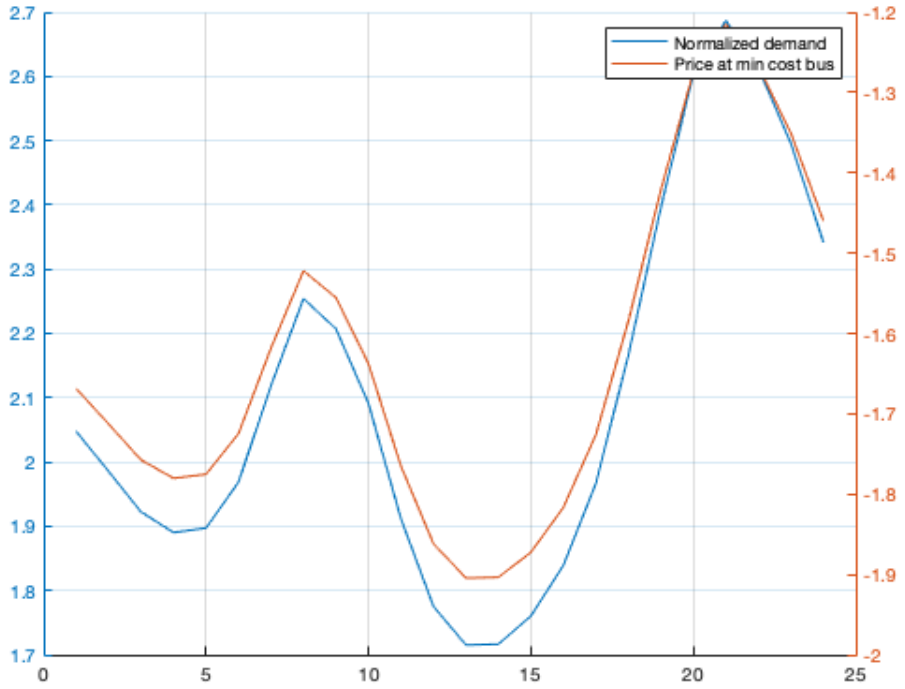
```
min_p = sprintf('The buses %d with the lowest prices %d',min_row  ,round(min_price,3));
max_p = sprintf('The buses %d with the highest prices %d',max_row  ,round(max_price,3) );
disp(min_p);
disp(max_p);

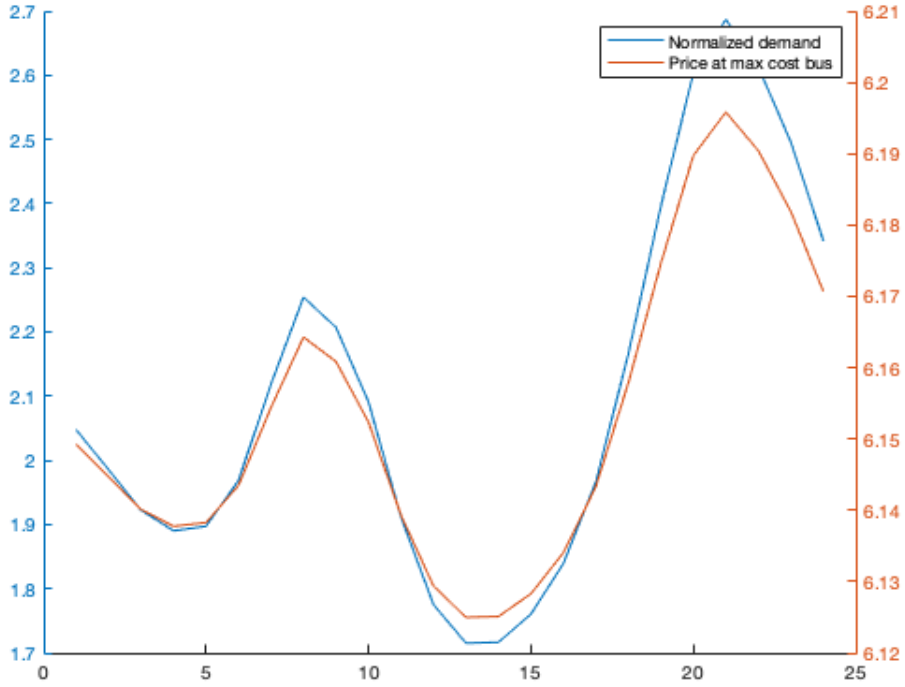

mean_prices = mean(Q2_lambda_all, 2);
min_index = find(mean_prices == min(mean_prices)); % Bus 4 -> it is connected to the edge with capacity 0
max_index = find(mean_prices == max(mean_prices)); % Bus 9 -> it is connected to the edge with capacity 0

hold on
yyaxis left
plot(demand_norm_list)
yyaxis right
plot(Q2_lambda_all(min_index, :))
grid
legend("Normalized demand", "Price at min cost bus")
hold off
figure()
hold on
yyaxis left
plot(demand_norm_list)
yyaxis right
plot(Q2_lambda_all(max_index, :))
legend("Normalized demand", "Price at max cost bus")
hold off


disp('The min and max price of the buses connected to an edge with capacity zero. ')
disp(['Prices of both the min and max cost bus seems to vary directly ' ...
    'proportionately with the current demand.'])
disp('Interesting to note that the price of the min cost bus is always negative.')
```

```
The buses 4 with the lowest prices -1.905000e+00
The buses 9 with the highest prices 6.196000e+00
The min and max price of the buses connected to an edge with capacity zero.
Prices of both the min and max cost bus seems to vary directly proportionately with the current demand.
Interesting to note that the price of the min cost bus is always negative.
```





Q3

```
P = zeros(n,n);

x_ij = zeros(n,n);
for i = 1:n
    for j = 1:n
        if L(i,j) ~= 0
            x_ij(i,j) = -1/L(i,j);
```

```
        end
    end
end

x_ij(x_ij == diag(x_ij)) == 0;

for row = 1:n
    for col = 1:n
        if L(row,col) ~= 0
            P(row,col) = (theta(row) - theta(col)) ./ (x_ij(row,col));
        end
    end
end

bus_err_all = zeros(n,3);
edge_err_all = zeros(n,3*n);

for z = 1:3

    PG_hat = PG;
    rand_idx = randi(n,1,z);
    PG_hat(rand_idx) = PG_hat(rand_idx) + randi([101 10000],1,z)';
    injections_idx = rand_idx;

    cvx_begin quiet
        variables e(n) theta_3(n) edge_err(n,n)
        minimize (sum(abs(e)) + sum(sum(abs(edge_err))))
        subject to

            PG_hat + e  == sum(P,2);  % P_hat + e  = P

            for  i = 1:n
                for j = 1:n
                    if sign(L) ~= 0
                        P(i,j) + edge_err(i,j) == abs(theta_3(i) -theta_3(j)) ./ x_ij;
                    end
                end
            end

     cvx_end

     round_error = round(e,0);

     disp('The attact nodes');
     rand_idx'
     disp('All buses error');
     round_error

     bus_err_all(:,z) = e;
     edge_err_all(:,z*(1:57)) =edge_err;

     if any(edge_err ~= 0)
         disp('non-zero edge error detected');
         [row_att, col_att] = find(edge_err);
     else
         disp('All edge errors are zero');
     end


end
```

```
The attact nodes

ans =

    17

All buses error

round_error =

           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
       -5483
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
```

```
           0
           0
           0
           0
           0
           0

All edge errors are zero
The attact nodes

ans =

    57
    41

All buses error

round_error =

           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
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           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
           0
       -4390
           0
           0
```

```
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
        -8406

All edge errors are zero
The attact nodes

ans =

    27
    32
    16

All buses error

round_error =

            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
        -6504
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
            0
        -7516
            0
            0
            0
            0
        -5089
            0
            0
```

```
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0
     0

All edge errors are zero
```

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