

Code

## Data Pre-processing

```
In [20]: #Customized data set bases on IEEE MATPOWER case33bw – 37 LINES
import numpy as np
#          fbus, tbus,   r   ,   x
#          (0) (1)   (2)   (3)
LData = np.array([[1,  2, 0.0575, 0.0293],
                  [2,  3, 0.3076, 0.1567],
                  [3,  4, 0.2284, 0.1163],
                  [4,  5, 0.2378, 0.1211],
                  [5,  6,  0.511, 0.4411],
                  [6,  7, 0.1168, 0.3861],
                  [7,  8, 0.4439, 0.1467],
                  [8,  9, 0.6426, 0.4617],
                  [9, 10, 0.6514, 0.4617],
                  [10, 11, 0.1227, 0.0406],
                  [11, 12, 0.2336, 0.0772],
                  [12, 13, 0.9159, 0.7206],
                  [13, 14, 0.3379, 0.4448],
                  [14, 15, 0.3687, 0.3282],
                  [15, 16, 0.4656, 0.34],
                  [16, 17, 0.8042, 1.0738],
                  [17, 18, 0.4567, 0.3581],
                  [ 2, 19, 0.1023, 0.0976],
                  [19, 20, 0.9385, 0.8457],
                  [20, 21, 0.2555, 0.2985],
                  [21, 22, 0.4423, 0.5848],
                  [ 3, 23, 0.2815, 0.1924],
                  [23, 24, 0.5603, 0.4424],
                  [24, 25, 0.559, 0.4374],
                  [ 6, 26, 0.1267, 0.0645],
                  [26, 27, 0.1773, 0.0903],
                  [27, 28, 0.6607, 0.5826],
                  [28, 29, 0.5018, 0.4371],
                  [29, 30, 0.3166, 0.1613],
                  [30, 31, 0.608, 0.6008],
                  [31, 32, 0.1937, 0.2258],
                  [32, 33, 0.2128, 0.3308],
                  [21,  8, 1.2479, 1.2479],
                  [ 9, 15, 1.2479, 1.2479],
                  [12, 22, 1.2479, 1.2479],
                  [18, 33, 0.312, 0.312],
                  [10, 30, 0.312, 0.312],
                  [25, 29, 0.312, 0.312]])

#L = len(LData)
#print(L)
#MVALim for 37 lines
MVALim = np.array([270, 270, 270, 270, 270, 270, 270, 270, 270, 270,
```

```
In [21]: #Read bus data from MATPOWER
#CVXPY, MOSEK and GUROBI
import cvxpy as cvx
import numpy as np
import math
import gurobipy
# to run the following commands, please follow https://www.instruct
import matlab.engine
eng = matlab.engine.start_matlab()

#case = "case141"
case = "case33bw"
#case = "case22"
#case = "case18"
#case = "case33qiskit5"
#case = "case33qiskit3"
#case = "case4_dist"
#case = "case33bw_qiskit_13line"

ret = eng.Read_RadialNet_Matpower(case) #case33bw, case123 # these
import scipy.io as spio #Reading Matlab mat data as Python dictionary
data = spio.loadmat('Radial_Netdata', squeeze_me=True) #taken from I
#data contains the following parameters
# 'Sbase', 'Pgmax', 'Pgmin', 'Qgmax', 'Qgmin', 'GenVarCost0', 'GenVa
#r = data['r']
#x = data['x']
slack_bus = 0
#slack_bus = 55 #case 123 slackbus is 56 (Python index count from 0)
#slack_bus = 113
I = len(data['Pd'])
G = data['G']
B = -data['B']
MVAlim = data['MVAlim']
status = data['status']
```

```
In [22]: def connex(i,j,LData): #return 1 of (i,j) or (j,i) is a "connected"
temp = False
for line in range(L):
    z1= (i== fr_bus[line]-1) and (j== to_bus[line]-1)
    z2= (j== fr_bus[line]-1) and (i== to_bus[line]-1)
    #z3= (data['status'][line]==1) #some lines are open switch.
    #z= (z1 or z2) and z3
    z= (z1 or z2)
    temp = temp or z
return temp
```

Normalize the data from MATPOWER

```
In [23]: print(MVAlim)
if case == "case18":
    scale = 10
else:
    scale = 1
data['Sbase'] = scale*data['Sbase']
r = r*scale
x = x*scale
data['gs'] = data['gs']/scale
data['bs'] = data['bs']/scale
```

```
[270 270 270 270 270 270 270 270 270 270 270 270 270 270 270 270 270
270
270 270 270 270 270 270 270 270 270 270 270 270 270 270]
```

## Network reconfiguration model - Classical computing

```
In [24]: #Cplex
import sys
import docplex.mp
from docplex.mp.model import Model
mdl = Model(name='Reconfiguration')

#Qiskit
from src.qiskit_optimization import QuadraticProgram
from src.qiskit_optimization.translators import from_docplex_mp
```

```
In [29]: #Branch flow model of Farivar and S. Low (Cleaner version)

data = spio.loadmat('Radial_Netdata', squeeze_me=True)
mdl.clear()
#Power flow variables
P = mdl.continuous_var_matrix(keys1=I, keys2=I, name='P')
Q = mdl.continuous_var_matrix(keys1=I, keys2=I, name='Q')
v = mdl.continuous_var_list(I, ub=1, name='v') #Remember to remove
Isq = mdl.continuous_var_list(L, lb=0, name='Isq')

#Variables for relaxation of Demand satisfaction. In case some demand
Pds = mdl.continuous_var_list(I, lb=0, name='Pds')
Pc = mdl.continuous_var_list(I, lb=0, name='Pc')
Qds = mdl.continuous_var_list(I, lb=0, name='Qds')
Qc = mdl.continuous_var_list(I, lb=0, name='Qc')

#Network reconfiguration setting
vl = mdl.continuous_var_matrix(keys1=L, keys2=I, lb=0, name='vl')
alpha = mdl.binary_var_list(L, name='alpha')
beta = mdl.continuous_var_matrix(keys1=I, keys2=I, lb=0, name='beta')

### CONSTRAINTS
#Faulted lines scenario
```

```

# faultline = [19, 25] #Case 1
# faultline = [8, 11, 19] #Case 2          # TEST 3
# faultline = [7, 11] #Case 3
# faultline = [3, 18] #Case 4
# faultline = [21, 26] #Case 5
faultline = [10, 20] #Case 6          # TEST 2
# faultline = [22] #Case 7          # TEST 1
# faultline = []

Delta = [1 for line in range(L)]
for line in faultline:
    Delta[line] = 0

#Power balance
P_outflow_of = [0 for i in range(I)]
Q_outflow_of = [0 for i in range(I)]
P_inflow_of = [data['gs'][i]*v[i] for i in range(I)]
Q_inflow_of = [data['bs'][i]*v[i] for i in range(I)]

for j in range(I):
    for k in range(I):
        for line in range(L):
            if Delta[line]==1:
                if (j==fr_bus[line]-1) and (k==to_bus[line]-1):
                    P_outflow_of[j] += P[j,k]
                    Q_outflow_of[j] += Q[j,k]
for j in range(I):
    for i in range(I):
        for line in range(L):
            if Delta[line]==1:
                if (i==fr_bus[line]-1) and (j==to_bus[line]-1):
                    P_inflow_of[j] += (P[i,j] - r[line]*Isq[line])
                    Q_inflow_of[j] += (Q[i,j] - x[line]*Isq[line])

#Demand = Curtailment + Demand served
mdl.add_constraints(data['Pd'][j]/data['Sbase'] == Pc[j] + Pds[j] for j in range(I))
mdl.add_constraints(data['Qd'][j]/data['Sbase'] == Qc[j] + Qds[j] for j in range(I))

mdl.add_constraints(-(P_outflow_of[j] - P_inflow_of[j]) == Pds[j] for j in range(I))
mdl.add_constraints(-(Q_outflow_of[j] - Q_inflow_of[j]) == Qds[j] for j in range(I))

#Radiality constraints
#Beta(i,j) = 1 for all j connected to node i
for i in range(I):
    mdl.add_constraint(mdl.sum(beta[i,j] for j in range(I) if connex(i,j)) == 1)

mdl.add_constraints(beta[0,j] == 0 for j in range(I) if connex(0,j))

#Sectionalizing switches + Tie switches
SW = [L-1, L-2, L-3, L-4, L-5, L-6]
print(L)

#Switching operation
for line in range(L):
    i = int(fr_bus[line]-1)

```

```

j = int(to_bus[line]-1)
mdl.add_constraint(beta[i,j] <= 1) #Already set ub = 1
mdl.add_constraint(beta[j,i] <= 1)
if line in SW:
    mdl.add_constraint(alpha[line] == (beta[j,i] + beta[i,j]))
    mdl.add_constraint(alpha[line] <= Delta[line])
else:
    mdl.add_constraint(Delta[line] == (beta[j,i]+beta[i,j]))

if line in SW:
    #For sectionalizing switches and tie switches
    mdl.add_constraint(vl[line,i] <= ((data['Vmax'][i])**2)*alpha[line])
    mdl.add_constraint(vl[line,j] <= ((data['Vmax'][j])**2)*alpha[line])
    mdl.add_constraint((v[i]-vl[line,i]) >= 0)
    mdl.add_constraint((v[i]-vl[line,i]) <=((data['Vmax'][i])**2)*alpha[line])
    mdl.add_constraint((v[j]-vl[line,j]) >= 0)
    mdl.add_constraint((v[j]-vl[line,j]) <=((data['Vmax'][j])**2)*alpha[line])
else:
    #For non-sectionalizing switches
    mdl.add_constraint(vl[line,i] <= ((data['Vmax'][i])**2)*Delta[line])
    mdl.add_constraint(vl[line,j] <= ((data['Vmax'][j])**2)*Delta[line])
    mdl.add_constraint((v[i]-vl[line,i]) >= 0)
    mdl.add_constraint((v[i]-vl[line,i]) <=((data['Vmax'][i])**2)*Delta[line])
    mdl.add_constraint((v[j]-vl[line,j]) >= 0)
    mdl.add_constraint((v[j]-vl[line,j]) <=((data['Vmax'][j])**2)*Delta[line])

#=====

#""
aux1 = mdl.continuous_var_list(L, name='aux1')
aux2 = mdl.continuous_var_list(L, name='aux2')

for line in range(L):
    i = int(fr_bus[line]-1)
    j = int(to_bus[line]-1)
    if Delta[line] == 1:
        mdl.add_constraint(aux1[line] == 0.5*(vl[line,i] - Isq[line])
        mdl.add_constraint(aux2[line] == 0.5*(vl[line,i] + Isq[line])
#""

#Voltage drop and Conic constraint
for line in range(L):
    if Delta[line] == 1:
        i = int(fr_bus[line]-1)
        j = int(to_bus[line]-1)
        mdl.add_constraint(vl[line,j] == vl[line,i] - 2*(r[line]*P[i,j])
        #mdl.add_constraint(P[i,j]**2 + Q[i,j]**2 <= vl[line,i] * I
        mdl.add_constraint((P[i,j]**2 + Q[i,j]**2 + (aux1[line])**2

#Voltage limit constraint
#mdl.add_constraints(v[i] >= (data['Vmin'][i])**2 for i in range(I)
#mdl.add_constraints(v[i] <= (data['Vmax'][i])**2 for i in range(I)
for i in range(I):
    if i!=slack_bus:
        mdl.add_constraint(v[i] >= (data['Vmin'][i])**2)
        mdl.add_constraint(v[i] <= (data['Vmax'][i])**2)

```

```

if case == "case18":
    mdl.add_constraint(v[slack_bus] == 1.1)
else:
    mdl.add_constraint(v[slack_bus] == 1)

#Objective function
Pgrid = P_outflow_of[slack_bus]*data['Sbase']
Qgrid = Q_outflow_of[slack_bus]*data['Sbase']

VOLL= 1000
ENS = data['Sbase']*(mdl.sum(Pc[j] for j in range(I) if j != slack_

mdl.minimize(Pgrid + ENS*VOLL)

mdl.print_information()
mdl.solve(clean_before_solve=True, log_output=True)
# mdl.report()
# mdl.print_solution()

# """
print('Pgrid = ',Pgrid.solution_value)
print('Bus \t sum_Vl \t \t Vsq')
for i in range(I):
    print(i+1,'\t',sum(vl[line,i].solution_value for line in range(

print('L# \t Fr \t To \t Del \t Al \t Isq')
for line in range(L):
    print(str(line+1)+'\t'+str(fr_bus[line])+'\t'+str(to_bus[line])).
# """

```

38

Model: Reconfiguration

- number of variables: 4838
  - binary=38, integer=0, continuous=4800
- number of constraints: 719
  - linear=683, quadratic=36
- parameters: defaults
- objective: minimize
- problem type is: MIQCP

Version identifier: 22.1.0.0 | 2022-03-09 | 1a383f8ce

CPXPARAM\_Read\_DataCheck

1

Tried aggregator 4 times.

MIQCP Presolve eliminated 439 rows and 4515 columns.

MIQCP Presolve modified 18 coefficients.

Aggregator did 76 substitutions.

Reduced MIQCP has 169 rows, 249 columns, and 611 nonzeros.

Reduced MIQCP has 3 binaries, 0 generals, 0 SOSs, and 0 indicators.

Reduced MIQCP has 33 quadratic constraints.

Presolve time = 0.00 sec. (3.44 ticks)

Probing fixed 0 vars, tightened 6 bounds.

Probing time = 0.00 sec. (0.02 ticks)

Clique table members: 1.

MIP emphasis: balance optimality and feasibility.

MIP search method: dynamic search.

Parallel mode: deterministic, using up to 8 threads.

Root relaxation solution time = 0.00 sec. (0.73 ticks)

nt	Node	Nodes Left Gap	Objective	IInf	Best Integer	Cuts/ Best Bound	ItC
	0	0	33003.3850	0		33000.0000	
88	0	0	33003.4835	1		Cone: 18	1
13	0	0	33003.4835	1		33003.4835	1
13	0+	0			33003.4299	33003.4835	
							-0.00%
	0	0	cutoff		33003.4299	33003.4835	1
13							-0.00%

Elapsed time = 0.03 sec. (14.67 ticks, tree = 0.01 MB, solutions = 1)

Cone linearizations applied: 17

Root node processing (before b&c):

Real time = 0.03 sec. (14.81 ticks)

Parallel b&c, 8 threads:

Real time = 0.00 sec. (0.00 ticks)

Sync time (average) = 0.00 sec.

Wait time (average) = 0.00 sec.

Total (root+branch&cut) = 0.03 sec. (14.81 ticks)

Pgrid = 3.4885853103994973

Bus	sum_Vl	Vsq
1	1.0	1.0
2	2.9871851216194387	0.9957283738731463
3	2.926903487417765	0.9756344958059217
4	1.9314499047267868	0.9657249523633934
5	1.9121327228707177	0.9560663614353588
6	2.8063210850818434	0.9354403616939477
7	1.8655722424044452	0.9327861212022226
8	1.8537547941427834	0.9268773970713917
9	2.7618093686876906	0.9206031228958969
10	1.8380414170182224	0.9190207085091112
11	0.9188978805965379	0.9188978805965379
12	0.9128466793987593	0.9128466793987593
13	1.8256933588013353	0.9128466794006677
14	1.8256933588013353	0.9128466794006677
15	2.7385415884750763	0.9128471961583587
16	1.8213114860102253	0.9106557430051127
17	1.815358986064805	0.9076794930324025
18	0.9067301387527443	0.9067301387527443
19	1.990047345458861	0.9950236727294305
20	1.9814106378863396	0.9907053189431698
21	0.9900676835589075	0.9900676835589075
22	0	0.81
23	1.940172540362206	0.970086270181103
24	1.9203335856298833	0.9601667928149417
25	0.9551859460048608	0.9551859460048608

26	1.8659052859328225	0.9329526429664112			
27	1.8594067440782347	0.9297033720391173			
28	1.8362280506217723	0.9181140253108862			
29	1.8200984432718814	0.9100492216359407			
30	1.8118414201186603	0.9059207100593302			
31	1.8006433750767907	0.9003216875383954			
32	1.7982788352667538	0.8991394176333769			
33	0.8987629125588741	0.8987629125588741			
L#	Fr	To	Del	Al	Isq
1	1.0	2.0	1	0	0.0012416665253911496
2	2.0	3.0	1	0	0.000984117119601584
3	3.0	4.0	1	0	0.0004383186673162823
4	4.0	5.0	1	0	0.00038860252384516613
5	5.0	6.0	1	0	0.00036403102733747464
6	6.0	7.0	1	0	7.962704554281015e-05
7	7.0	8.0	1	0	4.5288217268784484e-05
8	8.0	9.0	1	0	2.1760195405626326e-05
9	9.0	10.0	1	0	1.948931366156661e-06
10	10.0	11.0	1	0	7.312109396115082e-06
11	11.0	12.0	0	0	0
12	12.0	13.0	1	0	0
13	13.0	14.0	1	0	0
14	14.0	15.0	1	0	2.120158412351343e-06
15	15.0	16.0	1	0	5.8670820028283125e-06
16	16.0	17.0	1	0	3.05614646524622e-06
17	17.0	18.0	1	0	2.3777901211310813e-06
18	2.0	19.0	1	0	1.3711019533544993e-05
19	19.0	20.0	1	0	4.068018745718773e-06
20	20.0	21.0	1	0	6.071846157605738e-06
21	21.0	22.0	0	0	0
22	3.0	23.0	1	0	9.172710068691583e-05
23	23.0	24.0	1	0	7.435931887568777e-05
24	24.0	25.0	1	0	1.9310082597335136e-05
25	6.0	26.0	1	0	9.703948746676372e-05
26	26.0	27.0	1	0	8.440294681765941e-05
27	27.0	28.0	1	0	7.173619280779462e-05
28	28.0	29.0	1	0	6.171569766671798e-05
29	29.0	30.0	1	0	4.4200297201387534e-05
30	30.0	31.0	1	0	2.0342820253277806e-05
31	31.0	32.0	1	0	1.0092965973592447e-05
32	32.0	33.0	1	0	4.784162386096606e-06
33	21.0	8.0	1	0	0
34	9.0	15.0	1	1.0	8.476807189401394e-06
35	12.0	22.0	1	0	0
36	18.0	33.0	1	0	0
37	10.0	30.0	1	0	0
38	25.0	29.0	1	0	0

```
In [7]: # To be used for benchmarking plotting
type(Isq[line].solution_value)
Isq[1].solution_value
isq_cm = np.array([Isq[line].solution_value for line in range(L)])

for i in range(len(isq_cm)):
    print(isq_cm[i])
```



```

0.0012158277335322376
0.0009706177382479093
0.000430846776558987
0.00038169091579920607
0.00035811719294654164
7.528401745119455e-05
4.36927191939292e-05
2.0590537449850874e-05
1.1956641020891793e-06
2.415139243175489e-07
0.0
0.0
0.0
1.1334042337090009e-08
4.8238275404328845e-06
2.4638590061866268e-06
8.899886004503831e-07
7.360913684933318e-06
3.271988100173341e-06
8.246526905919835e-07
0.0
9.003060333265096e-05
7.353374502126076e-05
1.843061604094058e-05
9.272404220046677e-05
8.116666028486712e-05
7.035778115084766e-05
6.0270729191697533e-05
4.23700046017739e-05
1.9484301234447687e-05
8.062210698738306e-06
4.061477584075913e-07
0.0
7.96292903759424e-06
0.0
0.0
0.0
0.0

```

```

In [8]: # To be used for benchmarking plotting
# type(v[i].solution_value)
v[1].solution_value
v_cm = np.array([v[i].solution_value for i in range(33)])

for j in range(len(v_cm)):
    print(v_cm[j])

```

```

1.0
0.9959494123700599
0.9767310216387267
0.9672864872981752
0.9580811934476632
0.939009973548052
0.936999590010527
0.9313155538937068
0.9256658869033378
0.9242926959446076
0.9241820009659901
0.9188608388850938
0.9188608386386132
0.9188608386386132
0.9188608414981845
0.9168952592002021
0.914466533438035
0.9136418925561068
0.9953818594682914
0.991915212520596
0.9914364317628923
0.81
0.9714357318345964
0.9619595377829452
0.957250698744657
0.9366330989347709
0.9335257939301799
0.922758992418854
0.9152535608789208
0.9113071460279901
0.9061743578264612
0.905125511660737
0.9048681134900398

```

## Quantum computing

### Check conflicted constraints

Make sure there is no SOS1, SOS2 constraints in the model

```

In [9]: import docplex.mp.conflict_refiner as cr
        solve_status = mdl.get_solve_status()
        if solve_status.name == 'INFEASIBLE_SOLUTION': # or also 'INFEASIBLE'
            cref = cr.ConflictRefiner()
            print('show some of the constraints that can be removed to arrive at a feasible solution')
            cref.refine_conflict(mdl, display=True) # display flag is to show

```

```

In [10]: #print(mdl.export_as_lp_string())
        print('Pgrid = ', Pgrid.solution_value)
        print('Bus \t sum_Vl \t \t Vsq')
        for i in range(I):
            print(i+1, '\t', sum(vl[line, i].solution_value for line in range(

```

```
print('L# \t Fr \t To \t Del \t Al \t Isq')
for line in range(L):
    print(str(line+1)+'\t'+str(fr_bus[line])+'\t'+str(to_bus[line])).
```

```
Pgrid = 3.485810444771447
Bus      sum_Vl      Vsq
1        1.0        1.0
2        2.9878482371101796      0.9959494123700599
3        2.93019306491618      0.9767310216387267
4        1.9345729745963505      0.9672864872981752
5        1.9161623868953264      0.9580811934476632
6        2.8170299206441562      0.939009973548052
7        1.873999180021054      0.936999590010527
8        1.8626311077874136      0.9313155538937068
9        2.7769976607100135      0.9256658869033378
10       1.8485853918892152      0.9242926959446076
11       0.9241820009659901      0.9241820009659901
12       0.9188608388850938      0.9188608388850938
13       1.8377216772772265      0.9188608386386132
14       1.8377216772772265      0.9188608386386132
15       2.7565825244945534      0.9188608414981845
16       1.8337905184004042      0.9168952592002021
17       1.82893306687607      0.914466533438035
18       0.9136418925561068      0.9136418925561068
19       1.9907637189365828      0.9953818594682914
20       1.983830425041192      0.991915212520596
21       0.9914364317628923      0.9914364317628923
22       0          0.81
23       1.9428714636691928      0.9714357318345964
24       1.9239190755658904      0.9619595377829452
25       0.957250698744657      0.957250698744657
26       1.8732661978695417      0.9366330989347709
27       1.8670515878603597      0.9335257939301799
28       1.845517984837708      0.922758992418854
29       1.8305071217578417      0.9152535608789208
30       1.8226142920559802      0.9113071460279901
31       1.8123487156529223      0.9061743578264612
32       1.810251023321474      0.905125511660737
33       0.9048681134900398      0.9048681134900398
L#      Fr      To      Del      Al      Isq
1        1.0      2.0      1        0        0.0012158277335322376
2        2.0      3.0      1        0        0.0009706177382479093
3        3.0      4.0      1        0        0.000430846776558987
4        4.0      5.0      1        0        0.00038169091579920607
5        5.0      6.0      1        0        0.00035811719294654164
6        6.0      7.0      1        0        7.528401745119455e-05
7        7.0      8.0      1        0        4.36927191939292e-05
8        8.0      9.0      1        0        2.0590537449850874e-05
9        9.0      10.0     1        0        1.1956641020891793e-06
10       10.0     11.0     1        0        2.415139243175489e-07
11       11.0     12.0     0        0        0
12       12.0     13.0     1        0        0
13       13.0     14.0     1        0        0
14       14.0     15.0     1        0        1.1334042337090009e-08
15       15.0     16.0     1        0        4.8238275404328845e-06
```

16	16.0	17.0	1	0	2.4638590061866268e-06
17	17.0	18.0	1	0	8.899886004503831e-07
18	2.0	19.0	1	0	7.360913684933318e-06
19	19.0	20.0	1	0	3.271988100173341e-06
20	20.0	21.0	1	0	8.246526905919835e-07
21	21.0	22.0	0	0	0
22	3.0	23.0	1	0	9.003060333265096e-05
23	23.0	24.0	1	0	7.353374502126076e-05
24	24.0	25.0	1	0	1.843061604094058e-05
25	6.0	26.0	1	0	9.272404220046677e-05
26	26.0	27.0	1	0	8.116666028486712e-05
27	27.0	28.0	1	0	7.035778115084766e-05
28	28.0	29.0	1	0	6.0270729191697533e-05
29	29.0	30.0	1	0	4.23700046017739e-05
30	30.0	31.0	1	0	1.9484301234447687e-05
31	31.0	32.0	1	0	8.062210698738306e-06
32	32.0	33.0	1	0	4.061477584075913e-07
33	21.0	8.0	1	0	0
34	9.0	15.0	1	1.0	7.96292903759424e-06
35	12.0	22.0	1	0	0
36	18.0	33.0	1	0	0
37	10.0	30.0	1	0	0
38	25.0	29.0	1	0	0

## Set up connect to IBMQ Cloud service

```
In [11]: # Import Qiskit libraries
# Import Qiskit libraries from the modified version in .src
from src.qiskit import IBMQ, Aer
from src.qiskit.algorithms import QAOA, VQE, NumPyMinimumEigensolve
from src.qiskit.algorithms.optimizers import COBYLA
from src.qiskit.utils import QuantumInstance, algorithm_globals
from src.qiskit.providers.aer.noise.noise_model import NoiseModel

# Import optimization-related modules from the modified version in
from src.qiskit_optimization import QuadraticProgram
from src.qiskit_optimization.algorithms import MinimumEigenOptimizer
from src.qiskit_optimization.converters import QuadraticProgramToQuadraticModel
```

C:\Users\ango1\AppData\Local\Temp\ipykernel\_14780\2270211978.py:3: DeprecationWarning: ``qiskit.algorithms`` has been migrated to an independent package: <https://github.com/qiskit-community/qiskit-algorithms>. The ``qiskit.algorithms`` import path is deprecated as of qiskit-terra 0.25.0 and will be removed no earlier than 3 months after the release date. Please run ``pip install qiskit\_algorithms`` and use ``import qiskit\_algorithms`` instead.

```
from qiskit.algorithms import QAOA, VQE, NumPyMinimumEigensolver
```

```
In [12]: #Run this command only once when receiving it from IBMQ. This command
# IBMQ.save_account('449340a846e733ba9acd11130b2ae2aebbc21ff321b5cc')
```

```
In [13]: #Check loading status and current active account
# IBMQ.active_account()
```

```
In [14]: #Run directly, the token is not saved in local PC. This kind of pro
# provider = IBMQ.enable_account('449340a846e733ba9acd11130b2ae2aeb
# backend_real = provider.get_backend('ibm_kyoto')
```

```
In [15]: from qiskit import IBMQ
# IBMQ.update_account()
```

## Choose a real quantum computer

Maxium number of qubits for free usage is 7. If your problem has many binary variables, you should consider to use a simulator, instead.

```
In [16]: #Load account and specify the server we want to use. Check the onli
#Current available FREE servers: 7qubits: ibm_nairobi, ibm_oslo; 5q
provider = IBMQ.load_account()
#backend_real = provider.get_backend('ibm_nairobi') # The system wa

provider = IBMQ.get_provider(hub='ibm-q', group='open', project='ma
# device = provider.get_backend('QC NAME')
cloud_server = provider.get_backend("ibm_kyoto")
# backend_real = provider.get_backend('simulator_stabilizer')
```

```
C:\Users\ango1\AppData\Local\Temp\ipykernel_14780\3613560080.py:3: D
eprecationWarning: The package qiskit.providers.ibmq is being deprec
ated. Please see https://ibm.biz/provider_migration_guide to get ins
tructions on how to migrate to qiskit-ibm-provider (https://github.c
om/Qiskit/qiskit-ibm-provider) and qiskit-ibm-runtime (https://githu
b.com/Qiskit/qiskit-ibm-runtime).
```

```
provider = IBMQ.load_account()
C:\Users\ango1\AppData\Local\Temp\ipykernel_14780\3613560080.py:3: D
eprecationWarning: The qiskit.IBMQ entrypoint and the qiskit-ibmq-pr
ovider package (accessible from 'qiskit.providers.ibmq') are depreca
ted and will be removed in a future release. Instead you should use
the qiskit-ibm-provider package which is accessible from 'qiskit_ibm
_provider'. You can install it with 'pip install qiskit_ibm_provide
r'. Just replace 'qiskit.IBMQ' with 'qiskit_ibm_provider.IBMProvide
r'
```

```
provider = IBMQ.load_account()
```

## Choose a simulator

```
In [17]: #This links with IBM Circuit online
# from qiskit import IBMQ, assemble, transpile
# from qiskit.circuit.random import random_circuit
# provider = IBMQ.load_account()
# backend_real = provider.backend.ibmq_qasm_simulator
# backend_real = provider.backend.simulator_stabilizer
```

## Using ADMM - Grover

ADMM algorithm is employed to decompose the Mixed-integer Convex Program into

- Quadratic Unconstrained Binary Optimization Subproblem (QUBO). QUBO is solved by QAOA algorithm or Grover algorithm
- Convex Program is solved by a classical solver such as Gurobi or CPLEX

```
In [61]: print('ADMMOptimizer')
import time
from typing import List, Optional, Any
from docplex.mp.model import Model

# Importing modified Qiskit libraries from .src
from src.qiskit.algorithms import import QAOA, NumPyMinimumEigensolver
from src.qiskit_optimization.algorithms import (
    CobylaOptimizer,
    MinimumEigenOptimizer,
    GroverOptimizer,
    ADMMParameters,
    ADMMOptimizer,
    CplexOptimizer # Uncomment to use CPLEX instead
    # GurobiOptimizer, # Uncomment to use GUR0BI instead
)
from src.qiskit_optimization.problems import QuadraticProgram
from src.qiskit_optimization.translators import import from_docplex_mp

# Define solver for QUBO subproblems

## Using QAOA
# qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=BasicAer.get_b
# Using Quantum computer
backend_real = cloud_server
# qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=backend_real))
# quantum_instance_real = QuantumInstance(backend_real, shots=2048)
# qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=quantum_instan

## Using Grover
from qiskit.primitives import import Sampler
from qiskit.primitives import import BackendSampler
# samplerGrover = Sampler(backend=backend_real)
samplerGrover = BackendSampler(backend_real)
grover = GroverOptimizer(6, num_iterations = 10**5, sampler=samplerGrover)

# Define solver for Continuous subproblems
#cobyla = CobylaOptimizer()
cplex = CplexOptimizer() # uncomment to use CPLEX instead
# gurobi = GurobiOptimizer()

# Convert mdl to MICP for ADMM optimizers
mod = from_docplex_mp(mdl)
#print(mod.export_as_lp_string())
```

```

# Set up parameters for ADMM
#admm_params = ADMMParameters(rho_initial=1001, beta=1000, factor_c=
admm_params = ADMMParameters(
    rho_initial=100000, beta=10000000, factor_c=90000, maxiter=10000

# Select solver for QUBO subproblems
# qubo_optimizer = qaoa
qubo_optimizer = grover
#qubo_optimizer = cplex # uncomment to use CPLEX instead (If CPLEX

# Select solver for Continuous subproblems
# convex_optimizer = cobyla
convex_optimizer = cplex
# convex_optimizer = gurobi
# convex_optimizer = spsa

# initialize ADMM with classical QUBO and convex optimizer
admm = ADMMOptimizer(params=admm_params, qubo_optimizer=qubo_optimi

# =====
# run ADMM to solve problem
start_time = time.time()
result_Grover = admm.solve(mod)
print(result_Grover)
print("fval={:.2f}".format(result_Grover.fval))
#print("x={}".format(result))
print(result_Grover.variables_dict)
print("---- %s seconds ----" % (time.time() - start_time))

```

ADMMOptimizer

```

fval=528.2763512101841, P_0_0=0.0, P_0_1=0.032817112661909134, P_0_2=
0.0, P_0_3=0.0, P_0_4=0.0, P_0_5=0.0, P_0_6=0.0, P_0_7=0.0, P_0_8=
0.0, P_0_9=0.0, P_0_10=0.0, P_0_11=0.0, P_0_12=0.0, P_0_13=0.0, P_0_
14=0.0, P_0_15=0.0, P_0_16=0.0, P_0_17=0.0, P_0_18=0.0, P_0_19=0.0,
P_0_20=0.0, P_0_21=0.0, P_0_22=0.0, P_0_23=0.0, P_0_24=0.0, P_0_25=
0.0, P_0_26=0.0, P_0_27=0.0, P_0_28=0.0, P_0_29=0.0, P_0_30=0.0, P_0_
31=0.0, P_0_32=0.0, P_1_0=0.0, P_1_1=0.0, P_1_2=0.0299536987016619
4, P_1_3=0.0, P_1_4=0.0, P_1_5=0.0, P_1_6=0.0, P_1_7=0.0, P_1_8=0.0,
P_1_9=0.0, P_1_10=0.0, P_1_11=0.0, P_1_12=0.0, P_1_13=0.0, P_1_14=0.
0, P_1_15=0.0, P_1_16=0.0, P_1_17=0.0, P_1_18=0.0018012622248443425,
P_1_19=0.0, P_1_20=0.0, P_1_21=0.0, P_1_22=0.0, P_1_23=0.0, P_1_24=
0.0, P_1_25=0.0, P_1_26=0.0, P_1_27=0.0, P_1_28=0.0, P_1_29=0.0, P_1_
30=0.0, P_1_31=0.0, P_1_32=0.0, P_2_0=0.0, P_2_1=0.0, P_2_2=0.0, P_
2_3=0.01939912620872301, P_2_4=0.0, P_2_5=0.0, P_2_6=0.0, P_2_7=0.0,
P_2_8=0.0, P_2_9=0.0, P_2_10=0.0, P_2_11=0.0, P_2_12=0.0, P_2_13=0.
0, P_2_14=0.0, P_2_15=0.0, P_2_16=0.0, P_2_17=0.0, P_2_18=0.0, P_2_1
9=0.0, P_2_20=0.0, P_2_21=0.0, P_2_22=0.009376937942474815, P_2_23=
0.0, P_2_24=0.0, P_2_25=0.0, P_2_26=0.0, P_2_27=0.0, P_2_28=0.0, P_2_
29=0.0, P_2_30=0.0, P_2_31=0.0, P_2_32=0.0, P_3_0=0.0, P_3_1=0.0, P_
3_2=0.0, P_3_3=0.0, P_3_4=0.01811098906859784, P_3_5=0.0, P_3_6=0.
0, P_3_7=0.0, P_3_8=0.0, P_3_9=0.0, P_3_10=0.0, P_3_11=0.0, P_3_12=
0.0, P_3_13=0.0, P_3_14=0.0, P_3_15=0.0, P_3_16=0.0, P_3_17=0.0, P_3_
18=0.0, P_3_19=0.0, P_3_20=0.0, P_3_21=0.0, P_3_22=0.0, P_3_23=0.0,
P_3_24=0.0, P_3_25=0.0, P_3_26=0.0, P_3_27=0.0, P_3_28=0.0, P_3_29=

```

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```

## Using ADMM - QAOA

```

In [62]: print('ADMMOptimizer')
import time
from typing import List, Optional, Any
from docplex.mp.model import Model

# Importing modified Qiskit libraries from .src
from src.qiskit.algorithms import QAOA, NumPyMinimumEigensolver
from src.qiskit_optimization.algorithms import (
    CobylaOptimizer,
    MinimumEigenOptimizer,
    GroverOptimizer,
    ADMMParameters,
    ADMMOptimizer,
    CplexOptimizer # Uncomment to use CPLEX instead
    # GurobiOptimizer, # Uncomment to use GUROBI instead
)
from src.qiskit_optimization.problems import QuadraticProgram
from src.qiskit_optimization.translators import from_docplex_mp

```



```

# Define solver for QUBO subproblems
from qiskit.primitives import Sampler
from qiskit.primitives import BackendSampler
backend_real = cloud_server

## Using QAOA
# qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=BasicAer.get_backend('qasm_simulator')))
# Using Quantum computer
backend_real = cloud_server
# samplerGrover = BackendSampler(backend_real)

# qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=backend_real))
quantum_instance_real = QuantumInstance(backend_real, shots=2048, optimization_level=1)
qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=quantum_instance_real))

## Using Grover
# from qiskit.primitives import Sampler
# from qiskit.primitives import BackendSampler
# samplerGrover = Sampler(backend=backend_real)
# samplerGrover = BackendSampler(backend_real)
# grover = GroverOptimizer(5, num_iterations = 10*5, sampler=samplerGrover)

# Define solver for Continuous subproblems
#cobyla = CobylaOptimizer()
cplex = CplexOptimizer() # uncomment to use CPLEX instead
# gurobi = GurobiOptimizer()

# Convert mdl to MICP for ADMM optimizers
mod = from_docplex_mp(mdl)
#print(mod.export_as_lp_string())

# Set up parameters for ADMM
#admm_params = ADMMParameters(rho_initial=1001, beta=1000, factor_c=1000)
admm_params = ADMMParameters(
    rho_initial=100000, beta=10000000, factor_c=90000, maxiter=10000)

# Select solver for QUBO subproblems
qubo_optimizer = qaoa
# qubo_optimizer = grover
#qubo_optimizer = cplex # uncomment to use CPLEX instead (If CPLEX is available)

# Select solver for Continuous subproblems
#convex_optimizer = cobyla
convex_optimizer = cplex
# convex_optimizer = gurobi
# convex_optimizer = spsa

# initialize ADMM with classical QUBO and convex optimizer
admm = ADMMOptimizer(params=admm_params, qubo_optimizer=qubo_optimizer, convex_optimizer=convex_optimizer)

# =====

```

```
# run ADMM to solve problem
start_time = time.time()
result_QAOA = admm.solve(mod)
print(result_QAOA)
print("fval={:.2f}".format(result_QAOA.fval))
#print("x={}".format(result))
print(result_QAOA.variables_dict)
print("---- %s seconds ----" % (time.time() - start_time))
```

#### ADMMOptimizer

C:\Users\ango1\AppData\Local\Temp\ipykernel\_46392\2779394475.py:28:  
DeprecationWarning: The class ``qiskit.utils.quantum\_instance.QuantumInstance`` is deprecated as of qiskit-terra 0.24.0. It will be removed no earlier than 3 months after the release date. For code migration guidelines, visit [https://qiskit.it/qi\\_migration](https://qiskit.it/qi_migration).

```
quantum_instance_real = QuantumInstance(backend_real, shots=2048,
optimization_level = 3)
```

C:\Users\ango1\AppData\Local\Temp\ipykernel\_46392\2779394475.py:29:  
DeprecationWarning: The class ``qiskit.algorithms.minimum\_eigen\_solvers.qaoa.QAOA`` is deprecated as of qiskit-terra 0.24.0. It will be removed no earlier than 3 months after the release date. Instead, use the class ``qiskit.algorithms.minimum\_eigensolvers.QAOA``. See [https://qiskit.it/algo\\_migration](https://qiskit.it/algo_migration) for a migration guide.

```
qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=quantum_instance_real, optimizer=COBYLA()))
```

```
fval=528.2763512101841, P_0_0=0.0, P_0_1=0.032817112661909134, P_0_2=0.0, P_0_3=0.0, P_0_4=0.0, P_0_5=0.0, P_0_6=0.0, P_0_7=0.0, P_0_8=0.0, P_0_9=0.0, P_0_10=0.0, P_0_11=0.0, P_0_12=0.0, P_0_13=0.0, P_0_14=0.0, P_0_15=0.0, P_0_16=0.0, P_0_17=0.0, P_0_18=0.0, P_0_19=0.0, P_0_20=0.0, P_0_21=0.0, P_0_22=0.0, P_0_23=0.0, P_0_24=0.0, P_0_25=0.0, P_0_26=0.0, P_0_27=0.0, P_0_28=0.0, P_0_29=0.0, P_0_30=0.0, P_0_31=0.0, P_0_32=0.0, P_1_0=0.0, P_1_1=0.0, P_1_2=0.02995369870166194, P_1_3=0.0, P_1_4=0.0, P_1_5=0.0, P_1_6=0.0, P_1_7=0.0, P_1_8=0.0, P_1_9=0.0, P_1_10=0.0, P_1_11=0.0, P_1_12=0.0, P_1_13=0.0, P_1_14=0.0, P_1_15=0.0, P_1_16=0.0, P_1_17=0.0, P_1_18=0.0018012622248443425, P_1_19=0.0, P_1_20=0.0, P_1_21=0.0, P_1_22=0.0, P_1_23=0.0, P_1_24=0.0, P_1_25=0.0, P_1_26=0.0, P_1_27=0.0, P_1_28=0.0, P_1_29=0.0, P_1_30=0.0, P_1_31=0.0, P_1_32=0.0, P_2_0=0.0, P_2_1=0.0, P_2_2=0.0, P_2_3=0.01939912620872301, P_2_4=0.0, P_2_5=0.0, P_2_6=0.0, P_2_7=0.0, P_2_8=0.0, P_2_9=0.0, P_2_10=0.0, P_2_11=0.0, P_2_12=0.0, P_2_13=0.0, P_2_14=0.0, P_2_15=0.0, P_2_16=0.0, P_2_17=0.0, P_2_18=0.0, P_2_19=0.0, P_2_20=0.0, P_2_21=0.0, P_2_22=0.009376937942474815, P_2_23=0.0, P_2_24=0.0, P_2_25=0.0, P_2_26=0.0, P_2_27=0.0, P_2_28=0.0, P_2_29=0.0, P_2_30=0.0, P_2_31=0.0, P_2_32=0.0, P_3_0=0.0, P_3_1=0.0, P_3_2=0.0, P_3_3=0.0, P_3_4=0.01811098906859784, P_3_5=0.0, P_3_6=0.0, P_3_7=0.0, P_3_8=0.0, P_3_9=0.0, P_3_10=0.0, P_3_11=0.0, P_3_12=0.0, P_3_13=0.0, P_3_14=0.0, P_3_15=0.0, P_3_16=0.0, P_3_17=0.0, P_3_18=0.0, P_3_19=0.0, P_3_20=0.0, P_3_21=0.0, P_3_22=0.0, P_3_23=0.0, P_3_24=0.0, P_3_25=0.0, P_3_26=0.0, P_3_27=0.0, P_3_28=0.0, P_3_29=0.0, P_3_30=0.0, P_3_31=0.0, P_3_32=0.0, P_4_0=0.0, P_4_1=0.0, P_4_2=0.0, P_4_3=0.0, P_4_4=0.0, P_4_5=0.017430263745264858, P_4_6=0.0, P_4_7=0.0, P_4_8=0.0, P_4_9=0.0, P_4_10=0.0, P_4_11=0.0, P_4_12=0.0, P_4_13=0.0, P_4_14=0.0, P_4_15=0.0, P_4_16=0.0, P_4_17=0.0, P_4_18=0.0, P_4_19=0.0, P_4_20=0.0, P_4_21=0.0, P_4_22=0.0, P_4_23=0.0, P_4_24=0.0, P_4_25=0.0, P_4_26=0.0, P_4_27=0.0, P_4_28=0.0, P_4_29=0.0, P_4_30=0.0, P_4_31=0.0, P_4_32=0.0, P_5_0=0.0, P_5_1=0.0, P_5_2=0.0,
```

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## Using Quantum Random Access Optimization (Compress binaries to qubit)

```
In [18]: from src.qiskit.utils import QuantumInstance
from src.qiskit.algorithms.minimum_eigen_solvers import VQE
from src.qiskit.circuit.library import RealAmplitudes
from src.qiskit.algorithms.optimizers import SPSA
from src.qiskit_aer import Aer

from src.qrao import (
    QuantumRandomAccessOptimizer,
    QuantumRandomAccessEncoding,
    SemideterministicRounding,
    MagicRounding,
)
from qrao.utils import get_random_maxcut_qp

## ADMM-----
print('ADMMOptimizer')
import time
from typing import List, Optional, Any
from docplex.mp.model import Model

# Importing modified Qiskit libraries from .src
from src.qiskit.algorithms import QAOA, NumPyMinimumEigensolver
from src.qiskit_optimization.algorithms import (
```

```

    CobylaOptimizer,
    MinimumEigenOptimizer,
    GroverOptimizer,
    ADMMParameters,
    ADMMOptimizer,
    CplexOptimizer # Uncomment to use CPLEX instead
    # GurobiOptimizer, # Uncomment to use GUROBI instead
)
from src.qiskit_optimization.problems import QuadraticProgram
from src.qiskit_optimization.translators import from_docplex_mp

# Define solver for QUBO subproblems using modified Qiskit libraries
from src.qiskit.primitives import Sampler, BackendSampler
backend_real = cloud_server

#-----
## Using QAOA
## Using Quantum computer
# backend_real = cloud_server
quantum_instance_real = QuantumInstance(backend_real, shots=2048, op
qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=quantum_instance

#-----
"""
## Using Random access
from qrao import (
    QuantumRandomAccessOptimizer,
    QuantumRandomAccessEncoding,
    SemideterministicRounding,
    MagicRounding,
)

# Create fake model
problem = get_random_maxcut_qp(degree=3, num_nodes=6, seed=1, draw=
# Create and encode the problem using the (3,1,p)-QRAC
encoding = QuantumRandomAccessEncoding(max_vars_per_qubit=3)
encoding.encode(problem)

## Create and encode the problem using the (3,1,p)-QRAC
# encoding = QuantumRandomAccessEncoding(max_vars_per_qubit=3)
# mod = from_docplex_mp mdl)
# encoding.encode(mod)
## Create a QuantumInstance for solving the relaxed Hamiltonian using
relaxed_qi = QuantumInstance(backend=backend_real, shots=500)

## Create a QuantumInstance for magic rounding
rounding_qi = QuantumInstance(backend=backend_real, shots=1000)

# Set up the variational quantum eigensolver (ansatz width is determined)
vqe = VQE(
    ansatz=RealAmplitudes(encoding.num_qubits),
    optimizer=SPSA(maxiter=50),
    quantum_instance=relaxed_qi,

```

```

)

# Use magic rounding
rounding_scheme = MagicRounding(rounding_qi)

# Construct the optimizer
from qrao.utils import get_random_maxcut_qp
problem = get_random_maxcut_qp(degree=3, num_nodes=6, seed=1, draw=
encoding.encode(problem)
qrao = QuantumRandomAccessOptimizer(encoding=encoding, min_eigen_so
"""

#-----

# Define solver for Continuous subproblems
cplex = CplexOptimizer() # uncomment to use CPLEX instead
# gurobi = GurobiOptimizer()

# Convert mdl to MICP for ADMM optimizers
mod = from_docplex_mp(mdl)
#print(mod.export_as_lp_string())

# Set up parameters for ADMM
#admm_params = ADMMParameters(rho_initial=1001, beta=1000, factor_c
admm_params = ADMMParameters(
    rho_initial=100000, beta=10000000, factor_c=90000, maxiter=1000

# Select solver for QUBO subproblems
qubo_optimizer = qaoa
# qubo_optimizer = qrao

# Select solver for Continuous subproblems
convex_optimizer = cplex
# convex_optimizer = gurobi

# initialize ADMM with classical QUBO and convex optimizer
admm = ADMMOptimizer(params=admm_params, qubo_optimizer=qubo_optimi

# =====
# run ADMM to solve problem
start_time = time.time()
result_QRAO = admm.solve(mod)
print(result_QRAO)
print("fval={:.2f}".format(result_QRAO.fval))
#print("x={}".format(result))
print(result_QRAO.variables_dict)
print("--- %s seconds ---" % (time.time() - start_time))

```

ADMMOptimizer

C:\Users\ango1\AppData\Local\Temp\ipykernel\_14780\887322793.py:41: DeprecationWarning: The class ``qiskit.utils.quantum\_instance.QuantumInstance`` is deprecated as of qiskit-terra 0.24.0. It will be removed no earlier than 3 months after the release date. For code migration guidelines, visit [https://qiskit.it/qi\\_migration](https://qiskit.it/qi_migration).

```
quantum_instance_real = QuantumInstance(backend_real, shots=2048,
optimization_level = 3)
```

C:\Users\ango1\AppData\Local\Temp\ipykernel\_14780\887322793.py:42: DeprecationWarning: The class ``qiskit.algorithms.minimum\_eigensolvers.qaoa.QAOA`` is deprecated as of qiskit-terra 0.24.0. It will be removed no earlier than 3 months after the release date. Instead, use the class ``qiskit.algorithms.minimum\_eigensolvers.QAOA``. See [https://qiskit.it/algo\\_migration](https://qiskit.it/algo_migration) for a migration guide.

```
qaoa = MinimumEigenOptimizer(QAOA(quantum_instance=quantum_instance_real, optimizer=COBYLA()))
```

```
fval=333.69371014542287, P_0_0=0.0, P_0_1=0.036937825701041246, P_0_2=0.0, P_0_3=0.0, P_0_4=0.0, P_0_5=0.0, P_0_6=0.0, P_0_7=0.0, P_0_8=0.0, P_0_9=0.0, P_0_10=0.0, P_0_11=0.0, P_0_12=0.0, P_0_13=0.0, P_0_14=0.0, P_0_15=0.0, P_0_16=0.0, P_0_17=0.0, P_0_18=0.0, P_0_19=0.0, P_0_20=0.0, P_0_21=0.0, P_0_22=0.0, P_0_23=0.0, P_0_24=0.0, P_0_25=0.0, P_0_26=0.0, P_0_27=0.0, P_0_28=0.0, P_0_29=0.0, P_0_30=0.0, P_0_31=0.0, P_0_32=0.0, P_1_0=0.0, P_1_1=0.0, P_1_2=0.033154918315579505, P_1_3=0.0, P_1_4=0.0, P_1_5=0.0, P_1_6=0.0, P_1_7=0.0, P_1_8=0.0, P_1_9=0.0, P_1_10=0.0, P_1_11=0.0, P_1_12=0.0, P_1_13=0.0, P_1_14=0.0, P_1_15=0.0, P_1_16=0.0, P_1_17=0.0, P_1_18=0.0027040292825913576, P_1_19=0.0, P_1_20=0.0, P_1_21=0.0, P_1_22=0.0, P_1_23=0.0, P_1_24=0.0, P_1_25=0.0, P_1_26=0.0, P_1_27=0.0, P_1_28=0.0, P_1_29=0.0, P_1_30=0.0, P_1_31=0.0, P_1_32=0.0, P_2_0=0.0, P_2_1=0.0, P_2_2=0.0, P_2_3=0.02253610305222722, P_2_4=0.0, P_2_5=0.0, P_2_6=0.0, P_2_7=0.0, P_2_8=0.0, P_2_9=0.0, P_2_10=0.0, P_2_11=0.0, P_2_12=0.0, P_2_13=0.0, P_2_14=0.0, P_2_15=0.0, P_2_16=0.0, P_2_17=0.0, P_2_18=0.0, P_2_19=0.0, P_2_20=0.0, P_2_21=0.0, P_2_22=0.009377022567943497, P_2_23=0.0, P_2_24=0.0, P_2_25=0.0, P_2_26=0.0, P_2_27=0.0, P_2_28=0.0, P_2_29=0.0, P_2_30=0.0, P_2_31=0.0, P_2_32=0.0, P_3_0=0.0, P_3_1=0.0, P_3_2=0.0, P_3_3=0.0, P_3_4=0.021215701739839953, P_3_5=0.0, P_3_6=0.0, P_3_7=0.0, P_3_8=0.0, P_3_9=0.0, P_3_10=0.0, P_3_11=0.0, P_3_12=0.0, P_3_13=0.0, P_3_14=0.0, P_3_15=0.0, P_3_16=0.0, P_3_17=0.0, P_3_18=0.0, P_3_19=0.0, P_3_20=0.0, P_3_21=0.0, P_3_22=0.0, P_3_23=0.0, P_3_24=0.0, P_3_25=0.0, P_3_26=0.0, P_3_27=0.0, P_3_28=0.0, P_3_29=0.0, P_3_30=0.0, P_3_31=0.0, P_3_32=0.0, P_4_0=0.0, P_4_1=0.0, P_4_2=0.0, P_4_3=0.0, P_4_4=0.0, P_4_5=0.020503265628403735, P_4_6=0.0, P_4_7=0.0, P_4_8=0.0, P_4_9=0.0, P_4_10=0.0, P_4_11=0.0, P_4_12=0.0, P_4_13=0.0, P_4_14=0.0, P_4_15=0.0, P_4_16=0.0, P_4_17=0.0, P_4_18=0.0, P_4_19=0.0, P_4_20=0.0, P_4_21=0.0, P_4_22=0.0, P_4_23=0.0, P_4_24=0.0, P_4_25=0.0, P_4_26=0.0, P_4_27=0.0, P_4_28=0.0, P_4_29=0.0, P_4_30=0.0, P_4_31=0.0, P_4_32=0.0, P_5_0=0.0, P_5_1=0.0, P_5_2=0.0, P_5_3=0.0, P_5_4=0.0, P_5_5=0.0, P_5_6=0.01034401436168689, P_5_7=0.0, P_5_8=0.0, P_5_9=0.0, P_5_10=0.0, P_5_11=0.0, P_5_12=0.0, P_5_13=0.0, P_5_14=0.0, P_5_15=0.0, P_5_16=0.0, P_5_17=0.0, P_5_18=0.0, P_5_19=0.0, P_5_20=0.0, P_5_21=0.0, P_5_22=0.0, P_5_23=0.0, P_5_24=0.0, P_5_25=0.009331027911214497, P_5_26=0.0, P_5_27=0.0, P_5_28=0.0, P_5_29=0.0, P_5_30=0.0, P_5_31=0.0, P_5_32=0.0, P_6_0=0.0, P_6_1=0.0, P_6_2=0.0, P_6_3=0.0, P_6_4=0.0, P_6_5=0.0, P_6_6=0.0, P_6_7=0.008330080030195416, P_6_8=0.0, P_6_9=0.0, P_6_10=0.0, P_6_11=0.0, P_6_12=0.0, P_6_13=0.0, P_6_14=0.0, P_6_15=0.0, P_6_16=0.0, P_6_17=0.0, P_6_18=0.0, P_6_19=0.0, P_6_20=0.0, P_6_21=0.0, P_6_22=0.0, P_6_23=0.0,
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## Visualization

```

In [ ]: import pandas as pd

admm_dict = result_QRA0.variables_dict
# admm_dict = result_QA0A.variables_dict

admm_df = pd.DataFrame(list(admm_dict.values()), index=admm_dict.keys())
# Current magnitude results:
# Note: Use the Boolean array from .str.contains('Isq') to filter the
isq_filter = admm_df.index.str.contains('Isq')
isq_data = admm_df[isq_filter]
# Note: Now, convert the filtered DataFrame's values to a NumPy array
isq_qm = isq_data['Value'].to_numpy()
print(isq_qm)

```

```

In [64]: # Voltage results

v_filter = admm_df.index.str.contains('v_')
v_data = admm_df[v_filter]
# Now, convert the filtered DataFrame's values to a NumPy array
v_qm = v_data['Value'].to_numpy()
print(v_qm)
len(v_qm)

[1.          0.99611837  0.97739453  0.96835502  0.95957197  0.94125768
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 0.91072055  0.90986158  0.90981935]

```

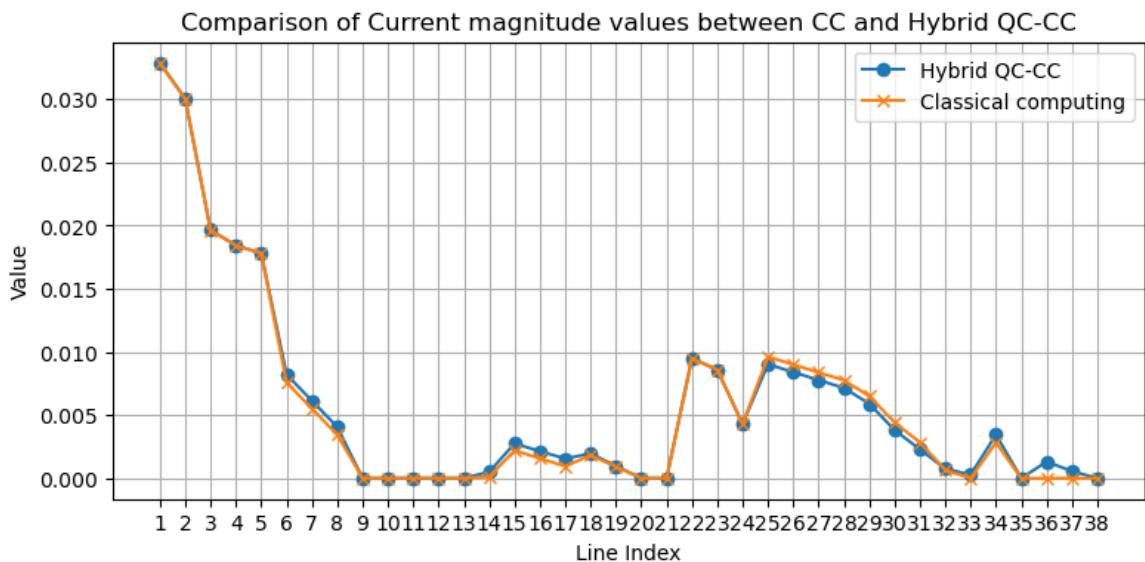
Out[64]: 33

```
In [65]: import matplotlib.pyplot as plt

# Plotting the data
plt.figure(figsize=(9, 4)) # Set the figure size for better readability
x_axis = np.arange(1, len(isq_qm) + 1)
plt.plot(x_axis, np.sqrt(isq_qm), label='Hybrid QC-CC', marker='o')
plt.plot(x_axis, np.sqrt(isq_cm), label='Classical computing', marker='x')

# Adding some plot decorations
plt.title('Comparison of Current magnitude values between CC and Hybrid QC-CC')
plt.xlabel('Line Index')
plt.ylabel('Value')
plt.xticks(x_axis)
plt.legend() # Show legend to identify the lines
plt.grid(True) # Show grid for better readability

# Show the plot
plt.savefig('Isq.png')
plt.show()
# Save the plot
plt.close()
```



```
In [66]: # Export data
for i in range(len(isq_qm)):
    print(np.sqrt(isq_qm[i]))

# for i in range(len(isq_cm)):
#     print(np.sqrt(isq_cm[i]))
```



```

0.03287678236536136
0.030042982511389198
0.019643980557965977
0.018424549961419217
0.01780990373429281
0.008207905858205904
0.006130128430918539
0.004061205065865669
0.0
0.0
0.0
0.0
0.0
0.0005085085644007153
0.0027470830769185774
0.002133123309986929
0.001546677094904626
0.0019533192786164977
0.0009633570924027844
0.0
0.0
0.009493650433546687
0.008577688180145527
0.004300833829387891
0.009018431850545265
0.008394830805420372
0.007765343575035675
0.0071429997883527396
0.005896116228844544
0.0038032291705394207
0.0022792455842341017
0.0007449133317131749
0.0002768198575247548
0.0034403819153466454
0.0
0.0013090099601697953
0.0005490420366926293
0.0

```

In [67]: `import matplotlib.pyplot as plt`

```

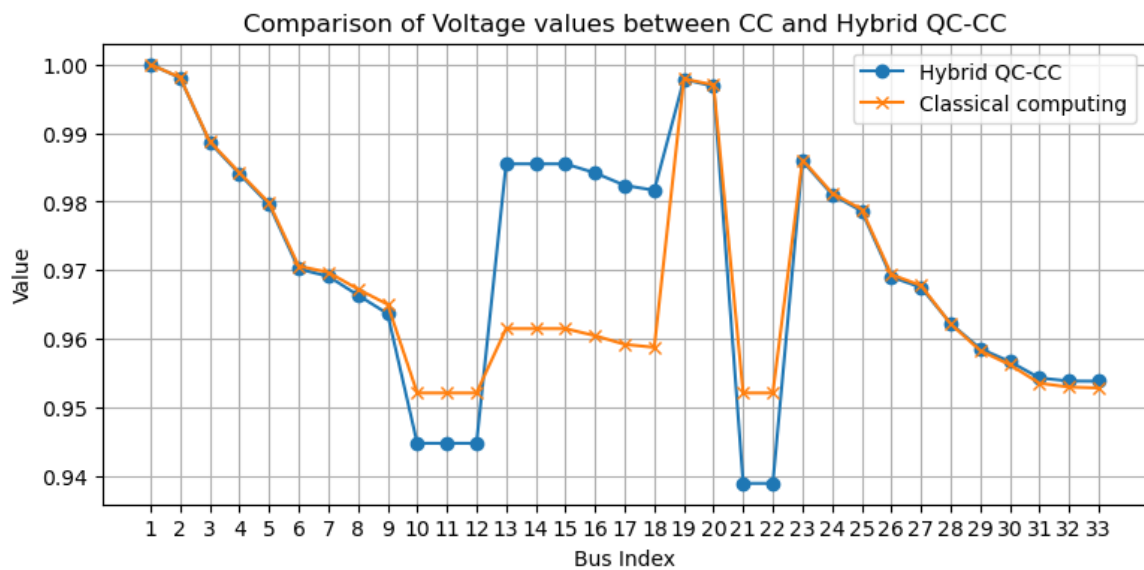
# Plotting the data
plt.figure(figsize=(9, 4)) # Set the figure size for better readability
x_axis = np.arange(1, len(v_qm) + 1)
plt.plot(x_axis, np.sqrt(v_qm), label='Hybrid QC-CC', marker='o')
plt.plot(x_axis, np.sqrt(v_cm), label='Classical computing', marker='o')

# Adding some plot decorations
plt.title('Comparison of Voltage values between CC and Hybrid QC-CC')
plt.xlabel('Bus Index')
plt.ylabel('Value')
plt.xticks(x_axis)
plt.legend() # Show legend to identify the lines
plt.grid(True) # Show grid for better readability

# Show the plot

```

```
plt.savefig('voltage.png')
plt.show()
# Save the plot
plt.close()
```



```
In [68]: # Export data
for i in range(len(v_qm)):
    print(np.sqrt(v_qm[i]))

# for i in range(len(v_cm)):
#     print(np.sqrt(v_cm[i]))
```

```

1.0
0.9980572961528726
0.9886326570624351
0.9840503139016279
0.9795774430260404
0.9701843560208949
0.9691271616719072
0.9663771329186233
0.9636822685966729
0.9447921449151246
0.9447921449150922
0.9447921449150922
0.9855130561616953
0.9855130561616953
0.9855130890078392
0.9841973505328453
0.9823782345040981
0.9816609775869763
0.9978333149884211
0.9968036168877187
0.9389585166486474
0.9389585166486474
0.9859192660781413
0.9810467594460903
0.9786090438148751
0.9690243910095836
0.9675133426308715
0.9622468561379401
0.9585824083385064
0.9566941563471993
0.9543167967574757
0.9538666446156854
0.9538445114190668

```

## Circuit

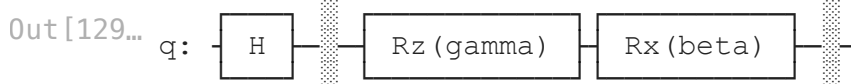
### Try 01

```

In [129... from src.qiskit import Aer, execute, QuantumCircuit
from src.qiskit.circuit import Parameter
gamma, beta = Parameter('gamma'), Parameter('beta')

qc = QuantumCircuit(1)
qc.h(0)
qc.barrier()
qc.rz(gamma, 0)
qc.rx(beta, 0)
qc.barrier()
qc.draw()

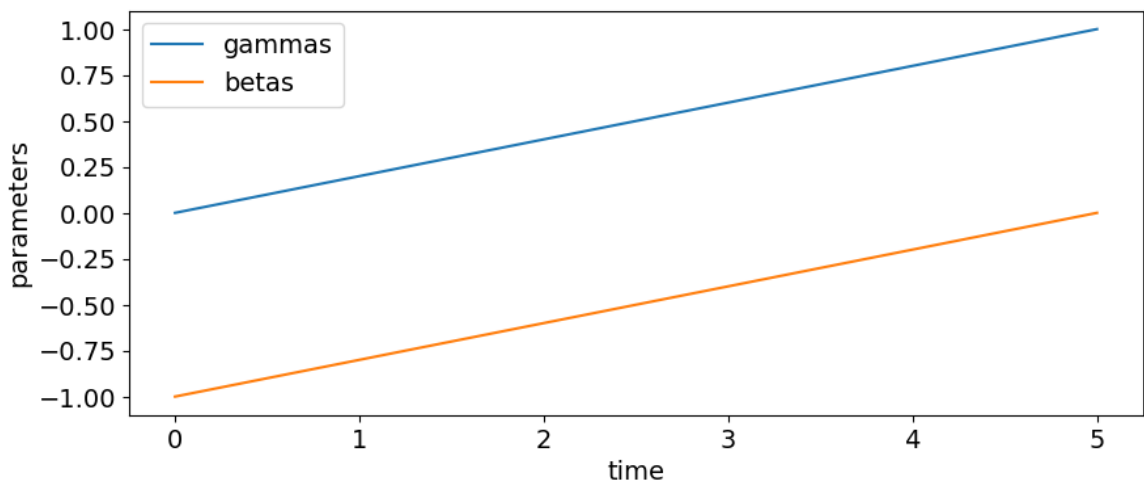
```



```
In [130... def construct_schedule(T, N):
    delta_t = T/N
    gammas, betas = [], [] # H_C, H_X parameters
    for i in range(N+1):
        t = i * delta_t
        gammas += [ 2 * delta_t * t/T ] # H_C
        betas += [ -2 * delta_t * (1 - t/T) ] # H_X
    return gammas, betas
```

```
In [131... T = 5
N = 10
gammas, betas = construct_schedule(T, N)
```

```
In [132... plt.figure(figsize=(10, 4))
plt.plot(np.linspace(0, T, N+1), gammas, label='gammas')
plt.plot(np.linspace(0, T, N+1), betas, label='betas')
plt.legend(fontsize=14)
plt.xticks(fontsize=14)
plt.xlabel('time', fontsize=14)
plt.yticks(fontsize=14)
plt.ylabel('parameters', fontsize=14);
```



```
In [133... from src.qiskit import QuantumCircuit
from src.qiskit.quantum_info import Statevector
import numpy as np

# Example definitions of gammas and betas
gammas = np.linspace(0, np.pi, 10) # Replace with your actual values
betas = np.linspace(0, np.pi/2, 10) # Replace with your actual values

N = 17 # Number of qubits
num_steps = len(gammas) # Assuming gammas and betas have the same length

# Adjust the probabilities array to have the right shape
probabilities = np.zeros((2**N, num_steps))

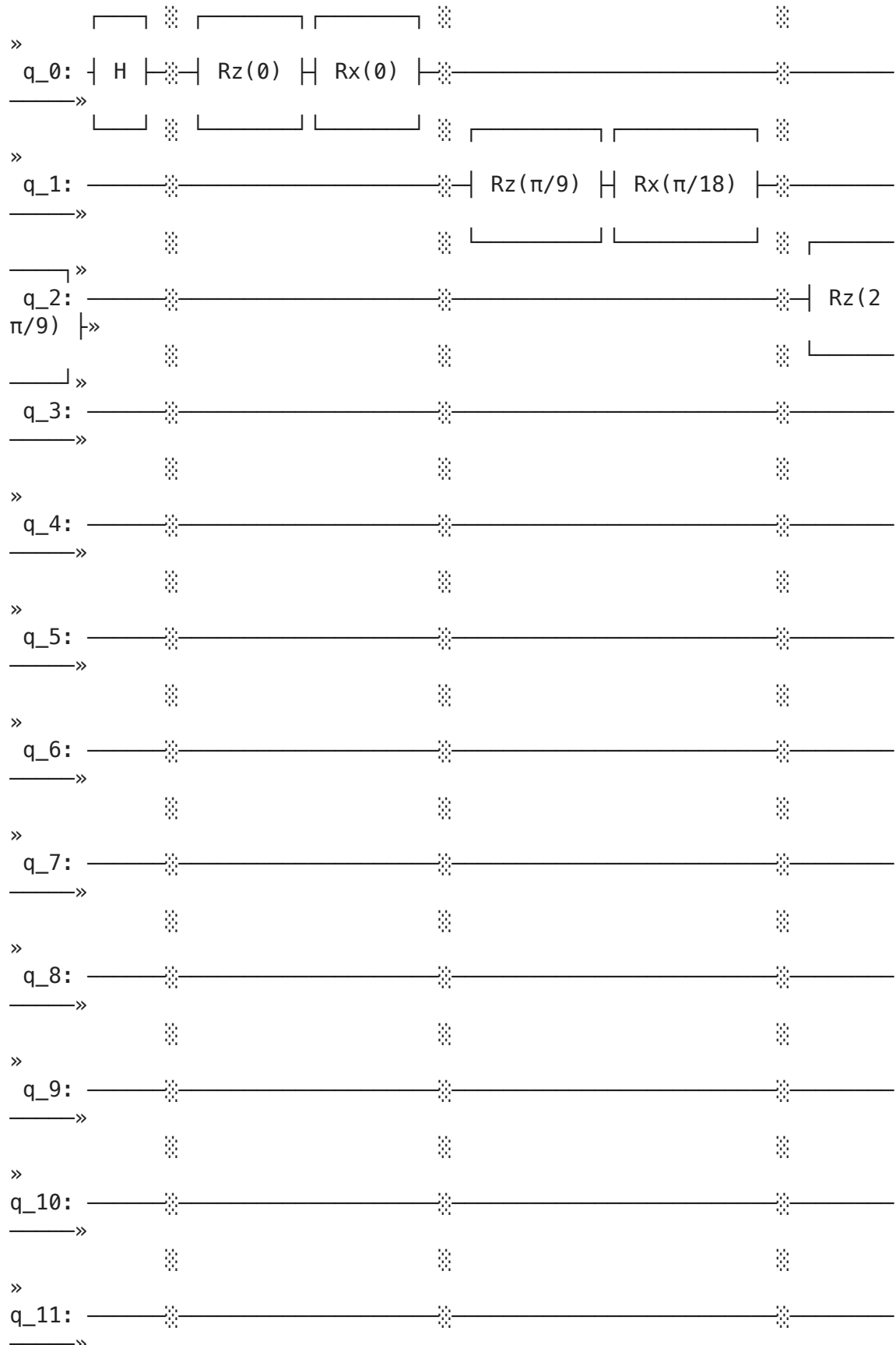
qc = QuantumCircuit(N)
qc.h(0)
qc.barrier()
for i, (gamma, beta) in enumerate(zip(gammas, betas)):
    qc.rz(gamma, i)
```

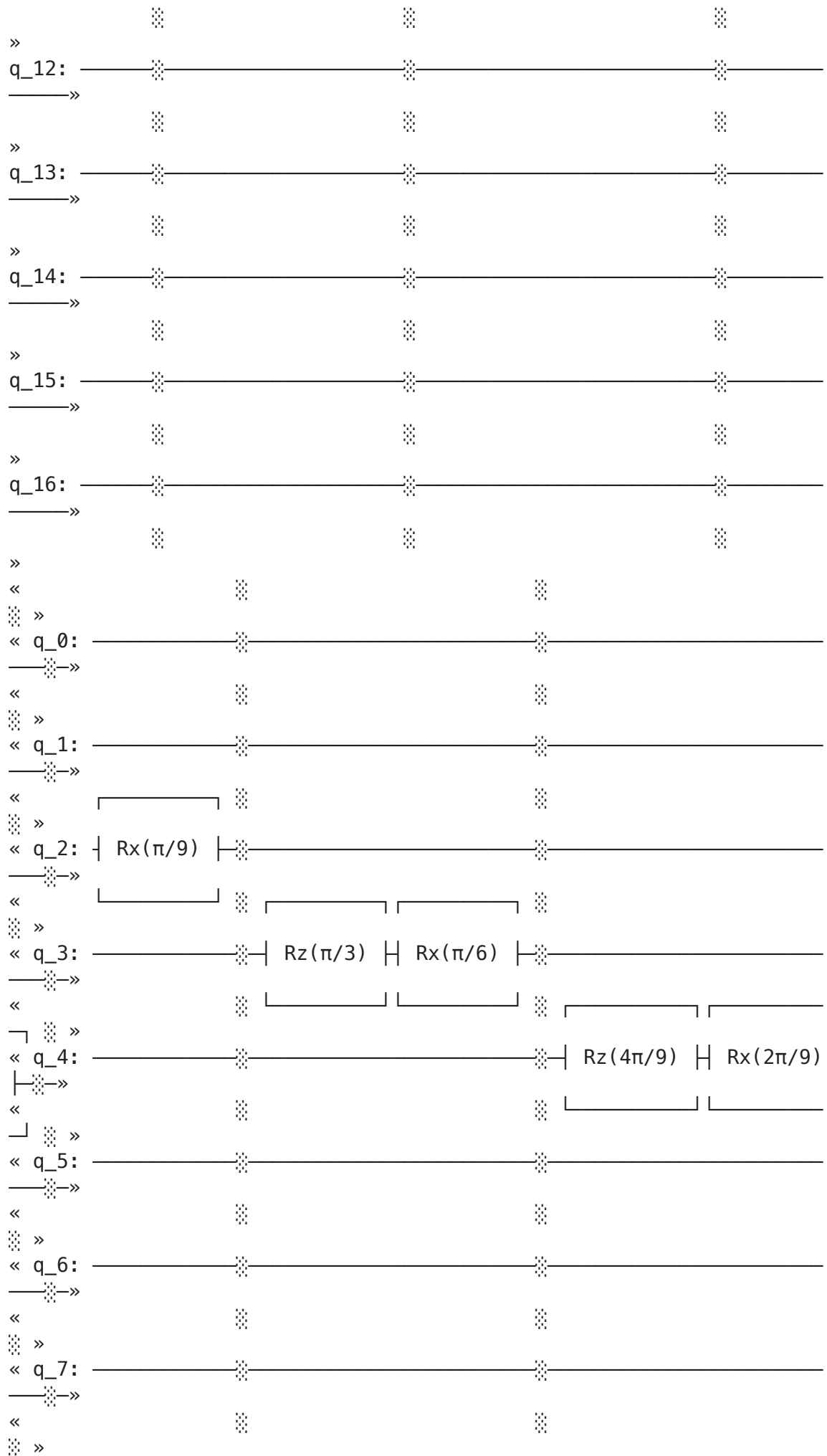
```

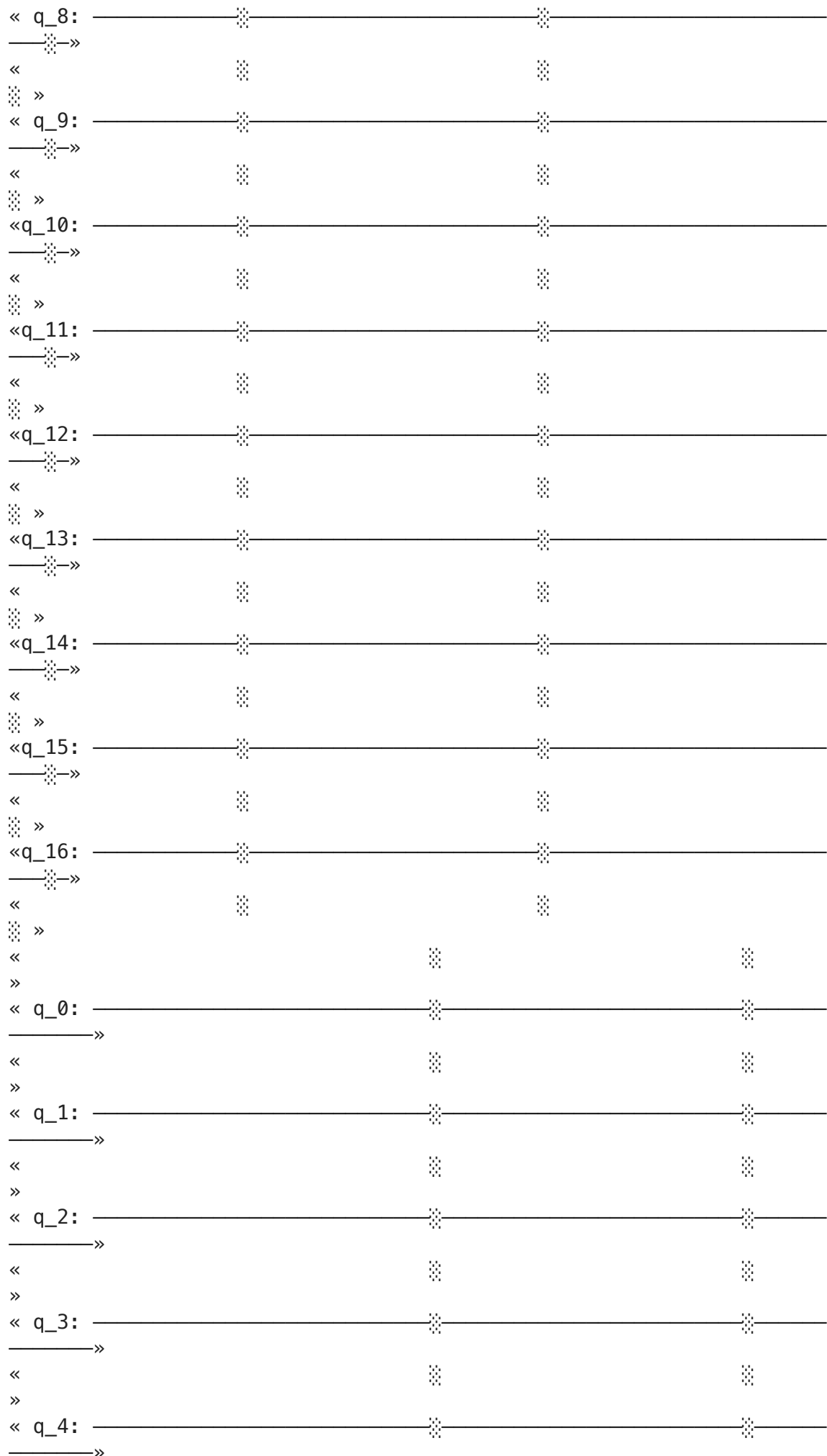
qc.rx(beta, i)
qc.barrier()
# Update to fill the correct column in probabilities
probabilities[:, i] = Statevector.from_instruction(qc).probabil

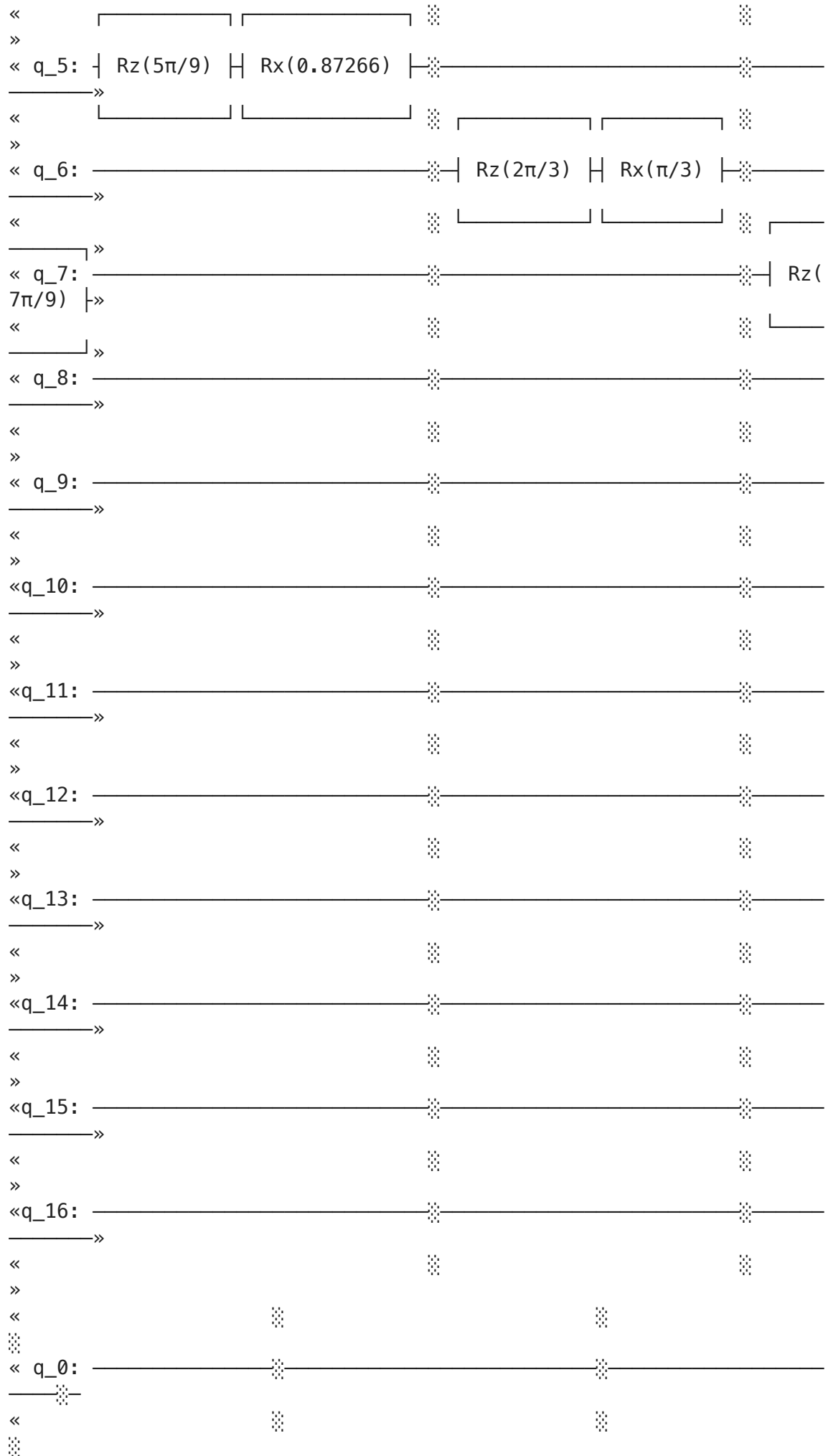
# If you want to visualize the circuit, use the draw method
print(qc.draw()) # Or qc.draw('mpl') for a matplotlib drawing if y

```

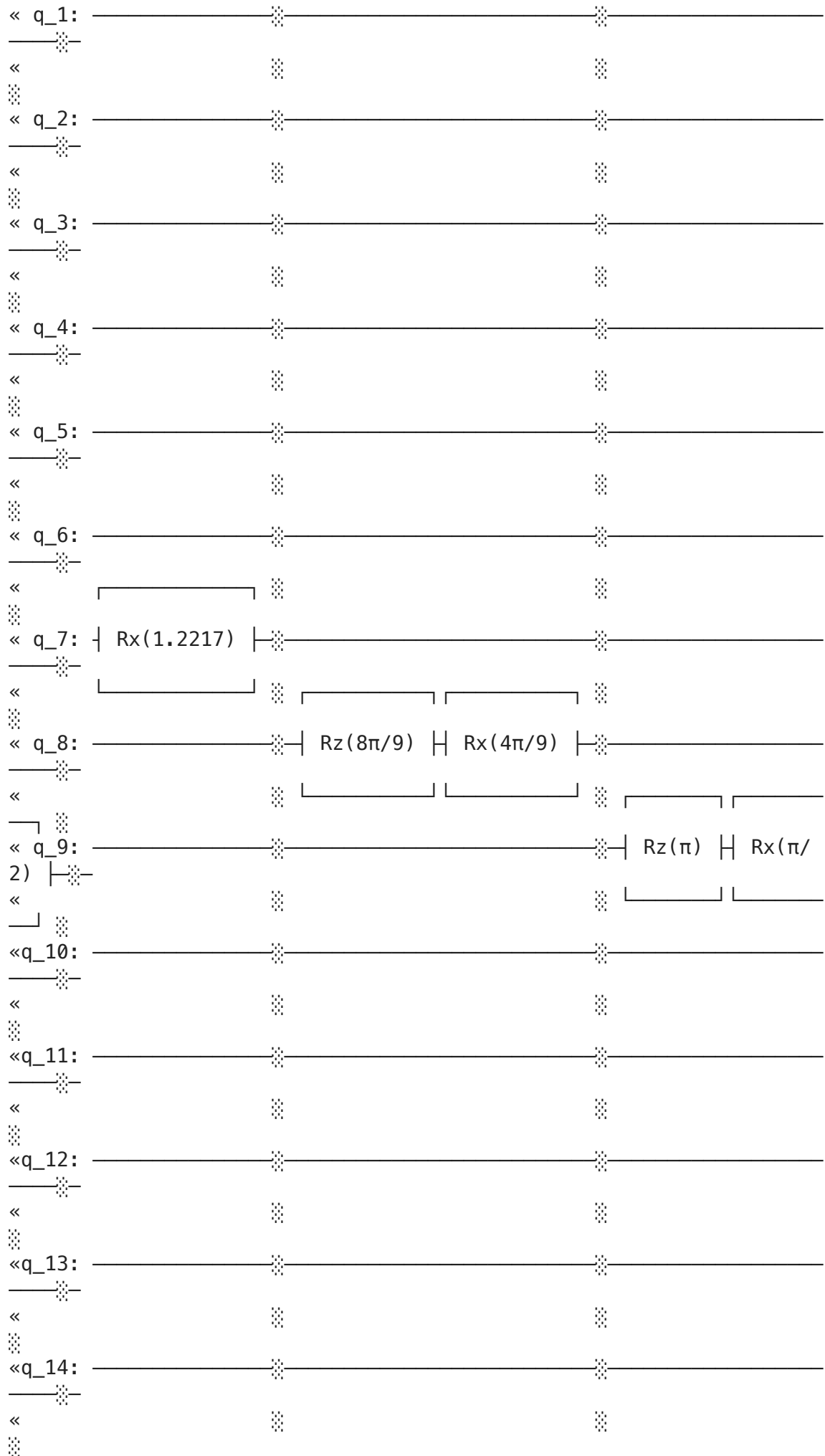


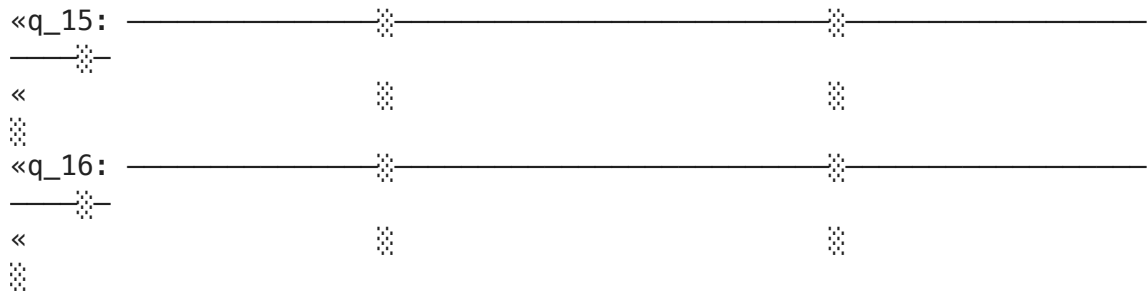












## Try 02

```
In [134... # Built-in modules
import math
import warnings
warnings.filterwarnings("ignore")

# Imports from Qiskit
from src.qiskit import QuantumCircuit
from src.qiskit.circuit.library import GroverOperator, MCMT, ZGate
from src.qiskit.visualization import plot_distribution

# Imports from Qiskit Runtime
# from qiskit_ibm_runtime import QiskitRuntimeService, Sampler, Bat
```

```
In [135... def grover_oracle(marked_states):
    """Build a Grover oracle for multiple marked states

    Here we assume all input marked states have the same number of

    Parameters:
        marked_states (str or list): Marked states of oracle

    Returns:
        QuantumCircuit: Quantum circuit representing Grover oracle
    """
    if not isinstance(marked_states, list):
        marked_states = [marked_states]
    # Compute the number of qubits in circuit
    num_qubits = len(marked_states[0])

    qc = QuantumCircuit(num_qubits)
    # Mark each target state in the input list
    for target in marked_states:
        # Flip target bit-string to match Qiskit bit-ordering
        rev_target = target[::-1]
        # Find the indices of all the '0' elements in bit-string
        zero_inds = [ind for ind in range(num_qubits) if rev_target[ind] == '0']
        # Add a multi-controlled Z-gate with pre- and post-applied X-gates
        # where the target bit-string has a '0' entry
        qc.x(zero_inds)
        qc.compose(MCMT(ZGate(), num_qubits - 1, 1), inplace=True)
        qc.x(zero_inds)
    return qc
```

```
In [136... marked_states = ["00011", "00100"]

oracle = grover_oracle(marked_states)
grover_op = GroverOperator(oracle)
optimal_num_iterations = math.floor(
    math.pi / (4 * math.asin(math.sqrt(len(marked_states) / 2**grover_op.num_qubits)))
```

```
In [137... qc = QuantumCircuit(grover_op.num_qubits)
# Create even superposition of all basis states
qc.h(range(grover_op.num_qubits))
# Apply Grover operator the optimal number of times
qc.compose(grover_op.power(optimal_num_iterations), inplace=True)
# Measure all qubits
qc.measure_all()
```

## Try 03

```
In [138... import numpy as np
from src.qiskit.visualization import plot_bloch_vector

# Use spherical coordinates to define the vector on the Bloch sphere
bloch_vector = [np.pi/3, np.pi/3, np.pi/2]

# Create the Bloch vector plot
fig = plot_bloch_vector(bloch_vector, coord_type='cartesian')

# Save the plot as a PNG file
fig.savefig('bloch_vector.png', dpi=300)
```

```
In [139... ## Multiple block
from src.qiskit.visualization import plot_bloch_vector
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

fig = plt.figure(figsize = [3, 4])

states = [
    [1, 0, 0],
    [0, 1, 0],
    [0, 0, 1],
    [0.6, 0.8, 0],
    [0.6, 0, 0.8],
    [0, 0.6, 0.8],
]

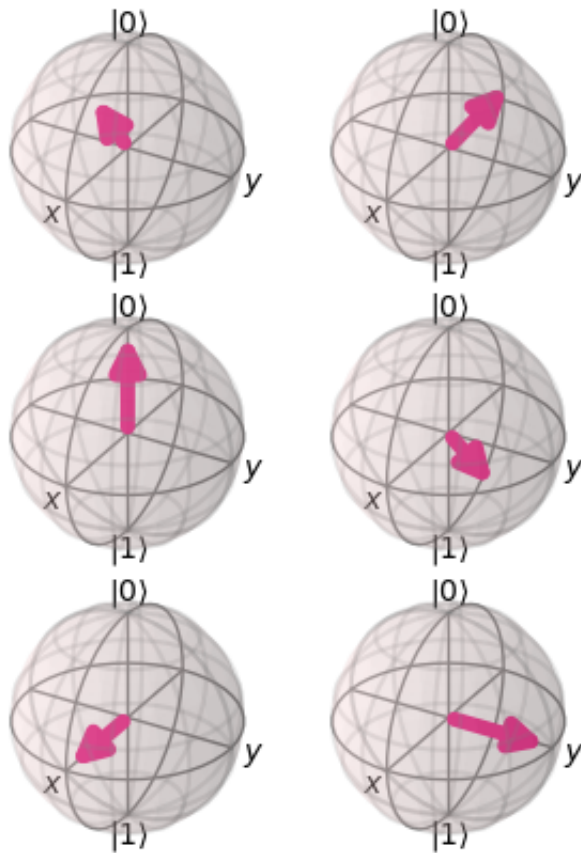
# Values are in fractions of figure width and height:
positions = [
    [0, 0],
    [0.5, 0],
    [0, 0.333],
    [0.5, 0.333],
    [0, 0.667],
    [0.5, 0.667],
]
```

```

]

for m in range(len(states)):
    ax = fig.add_axes([positions[m][0], positions[m][1], 0.5, 0.333])
    plot_bloch_vector(states[m], ax = ax)

```



```

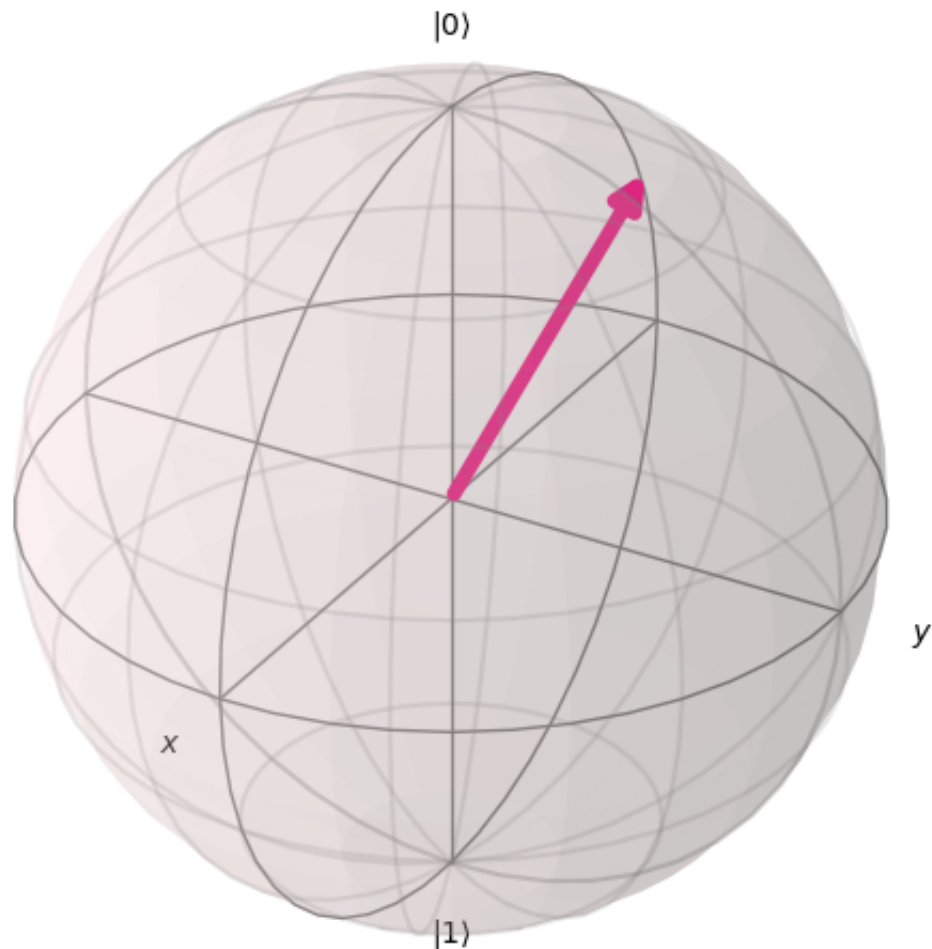
In [140... from src.qiskit.visualization import plot_bloch_vector
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

fig = plt.figure(figsize = [1, 2])

# ax = fig.add_axes(axes_class = Axes3D)
plot_bloch_vector([np.pi/3, np.pi/3, np.pi/2])

```

Out [140...



&lt;Figure size 100x200 with 0 Axes&gt;

## Try 04

```
In [141... jid = "crtjgskdbt40008jr q2g"
job = provider.backend.retrieve_job(jid)
```

```
In [142... # jobRes = job.result()
# resL=jobRes.results
# nqc=len(resL) # number of circuit in the job
# counts=jobRes.get_counts()
# if nqc==1: counts=[counts] # this is poor design
# print('M: got %d circ+results'%nqc, 'JID=',jid)
# for ic in range(nqc):
#     qc=job.circuits()[ic] # transpiled circuit
#     resHead=resL[ic].header # auxiliary info about used hardware
#     print('\nM: circ=%d %s'%(ic,qc.name))
#     print('counts:',counts[ic])
#     q2_depth=qc.depth(filter_function=lambda x: x.operation.num_q
#     print('circuit q2_depth=%d , gate count:%'q2_depth,dict(qc.co
#     print(qc.draw(output="text", idle_wires=False,fold=120))
#     print('result header: ',end=''); print(resHead)
```

In [ ]: