POWER GRID OPTIMIZATION

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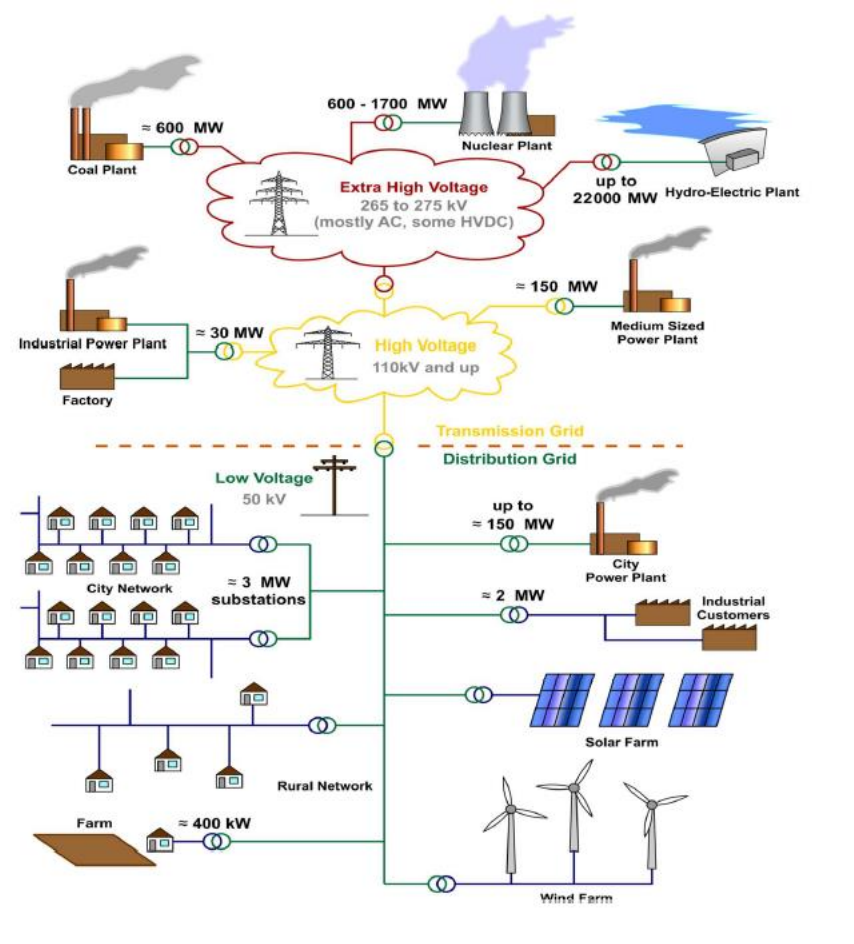
TEAM ENTRY NUMBER: **02556224**

FINAL DEFENCE – TCS QUANTUM COMPUTING CHALLENGE

CONTENTS

- City power distribution network and equivalent engineered model to solve
- Problem statement and the KPIs
- Quantum solution for scenario 1 and scenario 2
- Classical vs quantum solution – speed, accuracy.
- Scalability, cost advantage in quantum

Unit Commitment (UC) Problem and Finding Optimal Toplogy:



City power distribution network

BUSINESS VALUE AND MOTIVATION

- Solution to such problem help reduce energy losses and improve efficiency leading to cost saving in energy companies.
- Classical approaches requires lots of time and resources as we increase the complexity in the power grid network, classical algorithms are not good at finding optimal solution for large networks.
- Quantum approaches shows exponential advantage for solving many optimization problems. Our question is to investigate quantum approaches can effectively find solution for such large power grid networks?

The problem is to find the optimal solution with minimum generation cost for the unit commitment problem:

(1) Amount of energy production in each generators,

(2) which transmission lines the power has to be transferred, and

(3) How the policy changes if some of the genertors, transmission lines goes under maintenance or faulty in the city power distribution network.

OPTIMIZATION PROBLEM motivated from Business Perspective :

Part I: Power Generation:

$$\min \sum_{i\in U} f_i$$

$$s.t.\quad f_i = A_i y_i + B_i p_i + C_i p_i^2$$

$$\sum_{i\in U} p_i = L$$

$$P_{\min,i} y_i \le p_i \le P_{\max,i} y_i \qquad \forall i \in U$$

$$y_i \in \{0,1\}$$

(1) p_i is the power

(2) y_i is the status of the generator

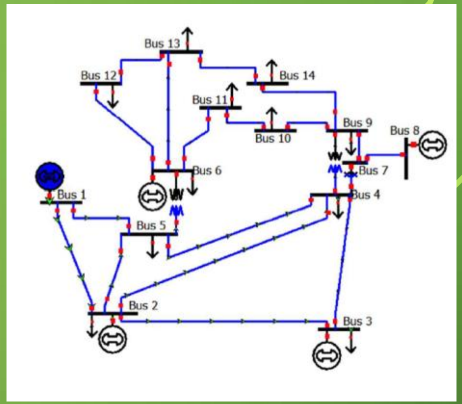
(3) L is total demand

(4) A_i, B_i *and* C_i are the cost coefficients

cost of pushing the reactor beyond its limit

cost of producing power within limits

generator maintenance cost



- The goal is to minimize the cost function (Budget allocated on producing energy)
- **Can be applied for IEEE8, 14, 30, 118, and higher number of bus systems.**

Part II: find the optimal topology:

- Constructed a network problem to connect the buses from source to destination, based on the demand.
- This can be achieved by implementing Multi Depot Vehicle Routing Optimization (MDVRP)

The cost function is

$$C = \sum_{i,j} (\text{line cost}) \times x_{i,j},$$

where $i \neq j$.

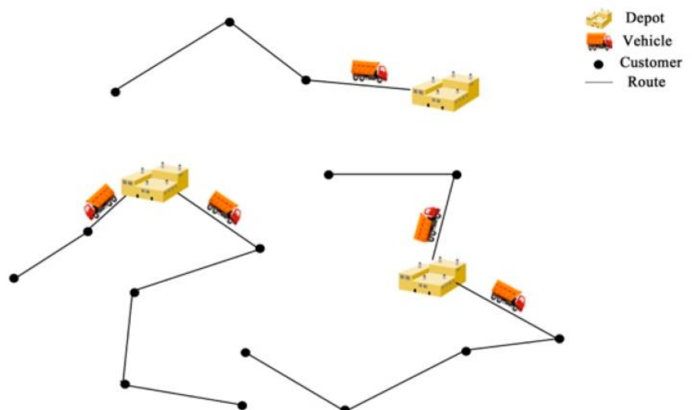
The constraints are

$$x_{ij} = 1 \ \ \forall i = generator$$

$$x_{ij} = 1 \ \ \forall j = destination$$

where d is the destination.

$$line\ capacities_{(i,j)} - line\ resistance_{(i,j)} \geq total\ demand$$



QUANTUM APPROACH:

- Discretize the continuous variables

$$\min \sum_{i \in U} f_i$$

$$s.t. \quad h_i = \left(\frac{P_{\max,i} - P_{\min,i}}{N} \right)$$

$$p_i = \sum_{k=1}^{N+1} \left(P_{\min,i} + (k-1) h_i \right) z_{ik}$$

$$f_i = A_i (1 - v_i) + B_i p_i + C_i p_i^2$$

$$v_i + \sum_{k=1}^{N+1} z_{ik} = 1 \qquad \forall i \in U$$

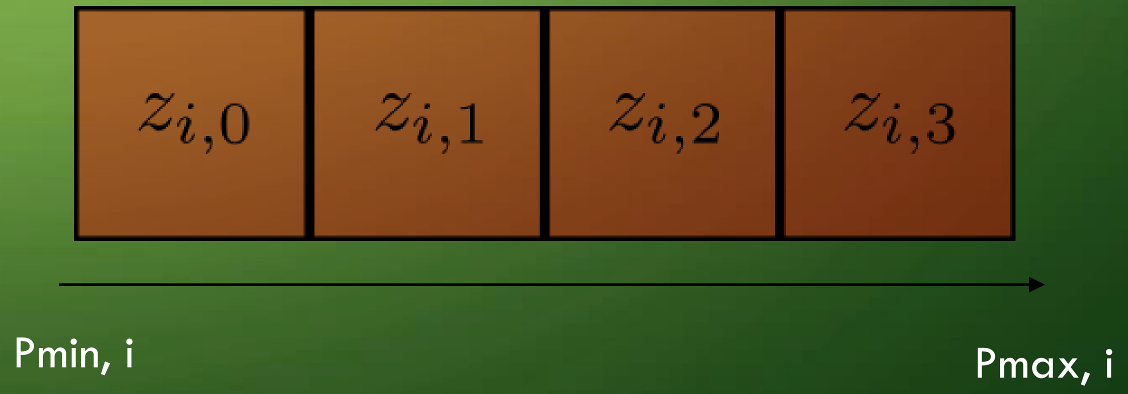
$$\sum_{i \in U} p_i = L$$

$$v_i, z_{ik} \in \{0,1\}$$

N is the number of bins

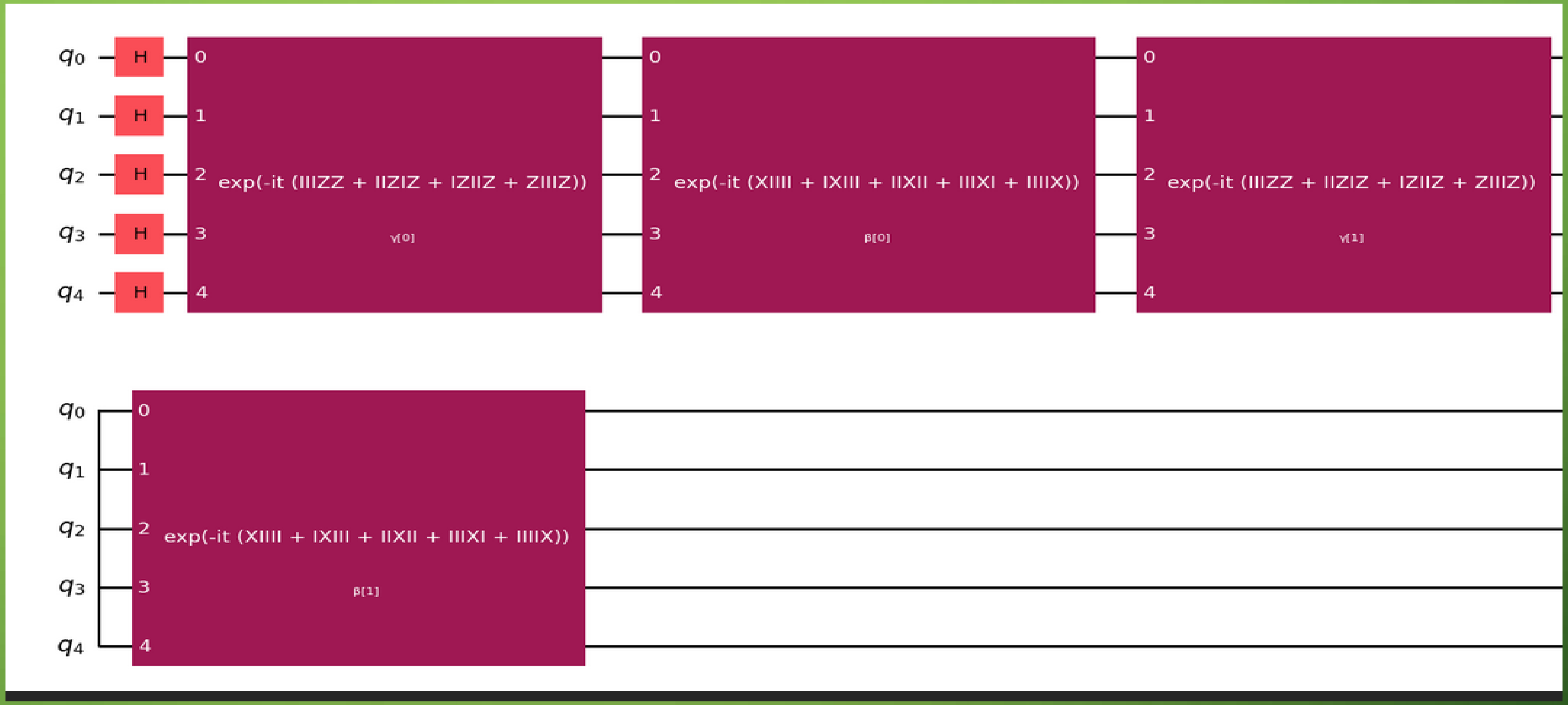
NOVELTY IN APPROACH

- For combinatorial problem, the best approach is QAOA, but it works only with binary variables.
- With our novel approach we can implement QAOA for combinatorial problems with continuous variables.
- This way of discretizing reduces the number of variables. Effectively reduce the decision variables for corrective actions in scenario 2.
- Helpful in solving large number of variables and scalability of the problem.



Accuracy of the model can be improved in increasing the bins

FULL APPROACH:



Circuit representation of QAOA ansatz

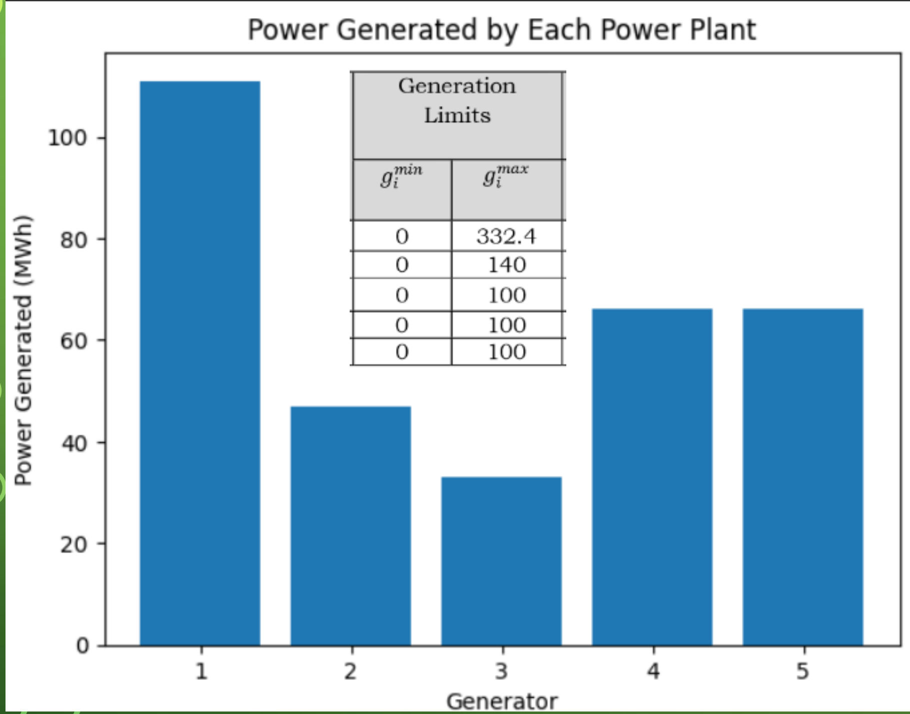
UC Problem + MDVRP

↓

Binary Quadratic Model → Quantum Ising Hamiltonian → Quadratic Approximate Optimization Algorithm ansatz → Finding the ground state of the Hamiltonian

SCENARIO 1:

```
The power generated by power plant 1 is 111.0 MWh
The power generated by power plant 2 is 47.0 MWh
The power generated by power plant 3 is 33.0 MWh
The power generated by power plant 4 is 66.0 MWh
The power generated by power plant 5 is 66.0 MWh
total power generated is  323.0 MWh, and the demand is 323 MWh
the total cost is 9960.0
Time taken: 7.36 seconds
```



TWO STEP STRATEGY

- First step is to get power generation from generators using quantum algorithm.
- Second step running a second algorithm for finding possible lines connecting generators and destination using same quantum algorithm.

Current Limitations of the algorithm:

- We assumed the lines can carry more power than power generators
- The direction in which the flow can also be not implemented by doable.

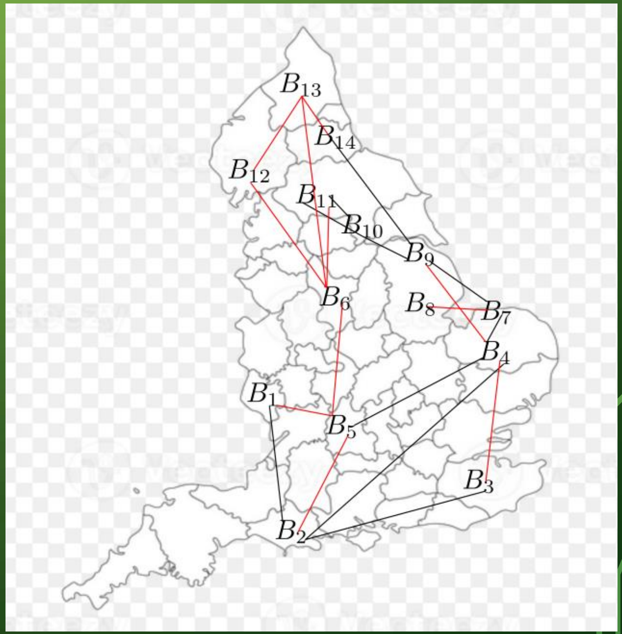
More merits in our algorithm:

- Variable sources of energy such as windmills, solar power plants can can also be incorporated in our model.

Generators are B1, B2, B3, B4, B5

Destination buses {11:40 ,12:30,13:30}

```
(1, 5)
(2, 5)
(3, 4)
(4, 9)
(5, 6)
(6, 11)
(6, 12)
(6, 13)
(7, 8)
(12, 13)
(13, 14)
```



SCENARIO 2:

- Generator re-dispatch constraint [9]:

$$p_i(new) = p_i + (r_{i,up}\Delta g_{i,up}) - (r_{i,down}\Delta g_{i,down}). \quad (9)$$

where $r_{i,up/down} \in \{0,1\}$ is the re-dispatch status and $r_{i,up} + r_{i,down} = 1$ should satisfy.

- The new powers should satisfy the demand constraint

$$\sum_{i \in U} p_i(new) = L. \quad (10)$$

This ensures that the even beyond the generator is running its limits, the total power equals the demand.

Generator Number	Bus Number	Generation Limits		Ramp up/Ramp down limits		a_i ($/(MWhr)²)	b_i ($/MWhr)	c_i ($/hr)
		g_i^{min}	g_i^{max}	g_i^{up}	g_i^{down}			
G1	1	0	332.4	50	-50	0.043	20	0
G2	2	0	140	20	-20	0.25	20	0
G3	3	0	100	10	-10	0.01	40	0
G4	6	0	100	10	-10	0.01	40	0
G5	8	0	100	10	-10	0.01	40	0

- ➢ A generator can not be simultaneously ramped up or ramped down.
- ➢ The generators will produce energy based on the demands after re-dispatching.
- ➢ Transmission line switching scenario can be realized by switching off certain lines, the optimization will find an alternate way of transmitting power from generators to destination.

- For a 14 bus system, bus split requires 196 additional variables.

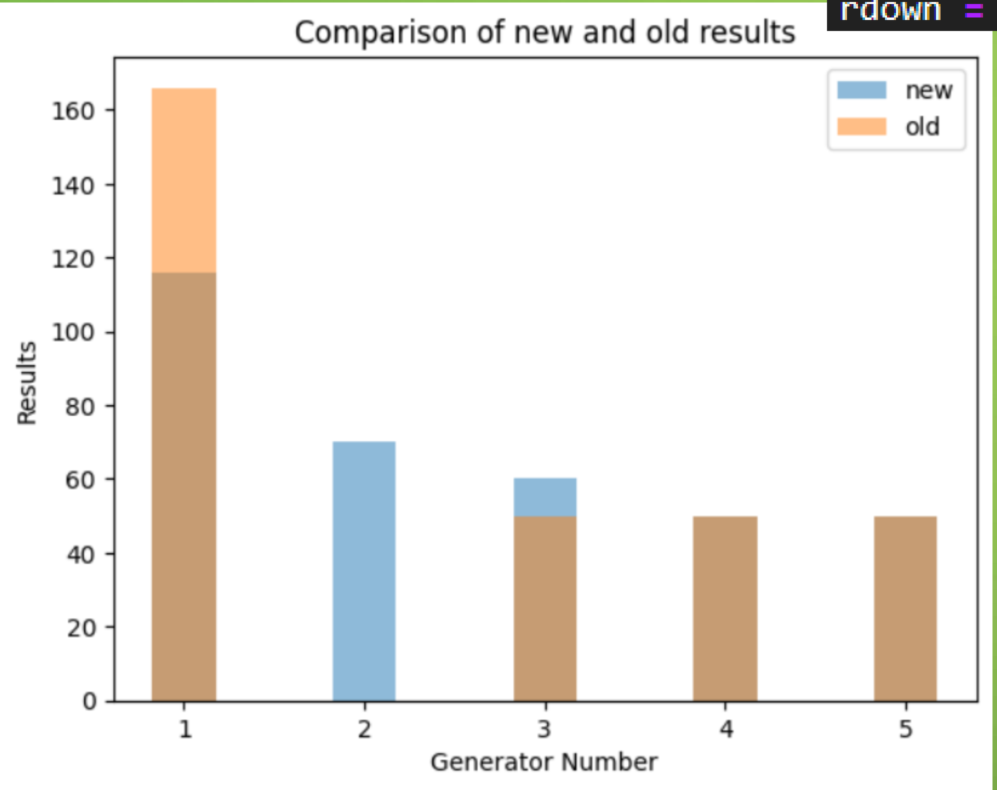
- Transmission line switching constraint:

$$y_{n,m} = 0, \forall (m,n) \in \text{Faultyline}$$

GENERATOR REDIPSATCHING:

```
rup =[0,0,1,0,0]
rdown = [1,0,0,0,0]
```

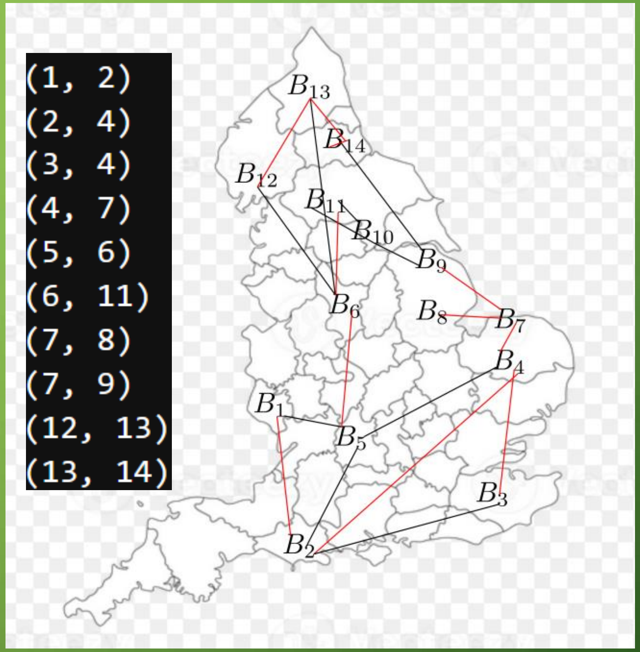
Accuracy depends on noise in the hardware and number of measurements



Destination is 7,8,9

Ramp up/Ramp down limits	
g_i^{up}	g_i^{down}
50	-50
20	-20
10	-10
10	-10
10	-10

```
(1, 2)
(2, 4)
(3, 4)
(4, 7)
(5, 6)
(6, 11)
(7, 8)
(7, 9)
(12, 13)
(13, 14)
```




```
total power generated is  346.0 MWh, and the demand is 323 MWh
total power generated in old case  316.0 MWh, and the demand is 323 MWh
```

```
The power generated by power plant 1 is 116.0 MWh
The power generated by power plant 2 is 70.0 MWh
The power generated by power plant 3 is 60.0 MWh
The power generated by power plant 4 is 50.0 MWh
The power generated by power plant 5 is 50.0 MWh
total power generated is  346.0 MWh, and the demand is 323 MWh
total power generated in old case  316.0 MWh, and the demand is 323 MWh
```

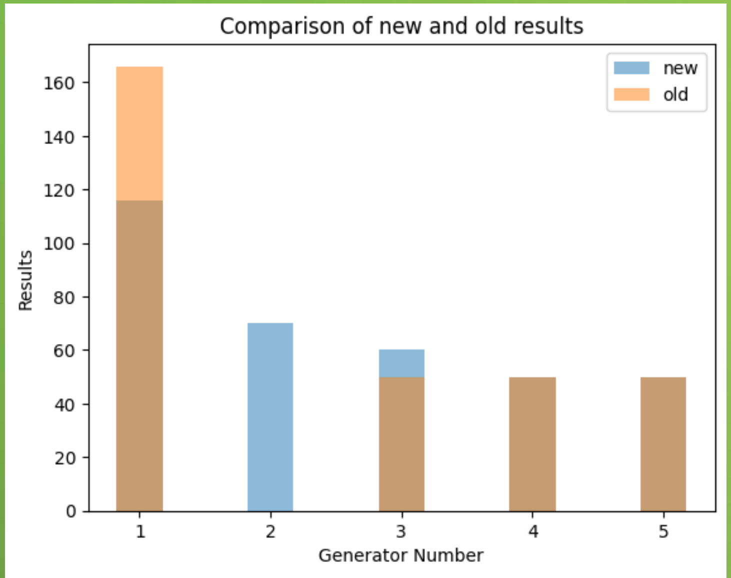
Nobody :

Reactor four on 26 april 1986:

- Generator re-dispatching is running certain generators above or below its allowed limit.
- **Generator1 is ramped up and generator 2 is ramped down.**

Line Switching:

Line connecting 2 and 4 buses is faulty !!!

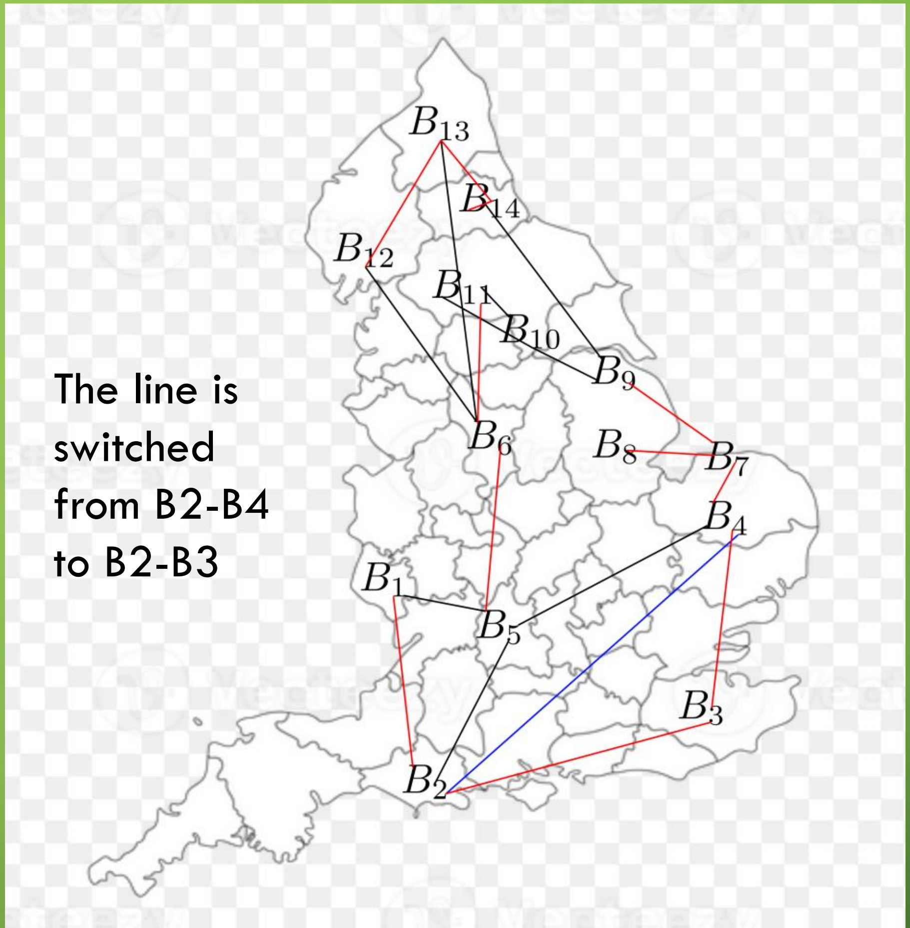


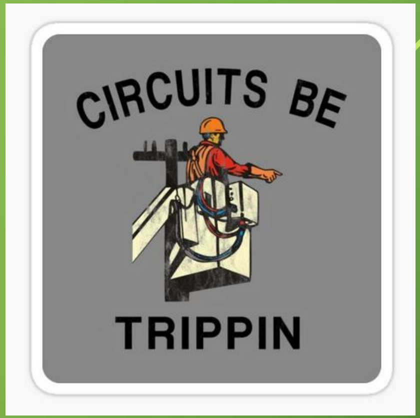
The generated power is same as before!!!

```
(1, 2)
(2, 4)
(3, 4)
(4, 7)
(5, 6)
(6, 11)
(7, 8)
(7, 9)
(12, 13)
(13, 14)
```

```
(1, 5)
(2, 3)
(3, 4)
(4, 5)
(5, 6)
(6, 11)
(6, 12)
(7, 8)
(10, 11)
(12, 13)
(13, 14)
```

The line is switched from B2-B4 to B2-B3





Two corrective actions are implemented

(1) Redispatching

(2) Line switching

- Line switching is about changing the power transmission to a new line due to scheduled maintenance of a particular line(s) or closed due to accident.
- We can observe that the re-dispatch status also gets modified due to line switching based on demand from the circuit.
- In order to implement bus split scenario, we need 196 additional binary variables to be introduced. **BUT CAN BE IMPLEMENTED IN OUR MODEL**

	CLASSICAL	QUANTUM
Number of bits	Scenario1 can be solved as it requires less number of bits	Scenario 1 can be solved using quantum algorithm
Speed	For small number of decision variables, classical solution is faster (**Scenario 1 took 1.51 seconds on local computer**)	For smaller number of decision variables, quantum algorithm takes more time than classical algorithm (**Scenario 1 took 17 minutes on qpu**)
Hardware Requirement	**As we increase the number of decision variables to 15 (more than 15) classical solver is unable to obtain a solution**	**Quantum algorithm can solve more than 15 decision variables** (we went upto 24 variables, solved on IONQ Aria 1)
Quantum Advantage	Hence scenario 2 can't be solved classically using BQM formalism	BQM can be solved for higher number of decision variables. Hence we obtained solution for scenario 2 using quantum algorithm.
Scalability	Classically more number of bits with high computing power is required to solve higher bus systems	**It's a matter of qpus in quantum algorithm, scalability is possible, IEEE 8, 30, 118 can also be implemented in our model by slightly modifying our problem statement. (approximately 3N^2 qubits are required for arbitrary N bus system)**

CONCLUSION:

- Our model is general enough to include variants of the problems in terms of number of generators, buses and the lines.
- Bus split can be implemented, but can not be executed on braket device due to shortage of the qubits.
- Speed up is possible if QAOA is implemented in annealers (which is available on Amazon bracket system). It usually comes with 1000s of qubits.
- Reason to choose QAOA approach is that we can write efficient ansatz to escape Barren Plateau problem.
- With better qpus in future, our model can be more generalized including more real world scenarios by slight modifications (add reactive constraints, power losses in lines, bus split, etc can be implemented).
- Less computational space is actually required as compared to classical counterpart as demonstrated by our model.
- **For large network problems, classical algorithm needs access to HPCs, which is costly. With a quantum annealer access, the same problem can be solved within few 100s of dollars with less time.**

THANK YOU AND QUESTIONS

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