Especialização em Computação Científica para a Indústria

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Hybrid Quantum Genetic Algorithm for Optimal Placement of Electric Vehicle Charging Stations: A Case Study on Hyderabad, India

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RESUMO The age of sustainability has forced us to incorporate electric vehicles into our daily life cycle. The one concern that arises with electric vehicles is their charging capacities. The growing demand for electric vehicles necessities the strategic placement of charging stations to ensure seamless mobility and widespread adoption. This study presents a method for determining the optimal locations for electric vehicle charging points using a hybrid quantum genetic algorithm. The proposed method involves partitioning the given region/target region into equal grid segments, considering the number of qubits. The algorithm then identifies the most suitable grid, instead of a specific point as it may collide with existing buildings or properties, for deploying new charging stations. It does so by utilizing a multi criterion fitness function, considering the data on existing charging stations, points that have infrastructure that can accommodate new charging stations and the power grids in the given region. Then, the set of solutions obtained from the algorithm are ranked based on fitness and land use. This hybrid approach leverages the power of quantum computing for generating new populations, while employing genetic algorithms to refine and optimize the solutions iteratively.

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I. INTRODUCTION

THE drive towards sustainable mode of transportation has made electric vehicles a popular alternative to Internal Combustion engine vehicles. The transition to electric vehicles is being aimed to increase by providing purchase incentives, tax rebates, investment or mandates to install charge station infrastructure, operational incentives, and corporative incentives. [1] [2] This transition has brought up a range of challenges, which includes the problem of placing new electric vehicle charge stations. Key reasons why this has become an essential problem in research include Infrastructure Demand, Environmental Impact, Economic and Urban Development, Grid efficiency and stability, Social Equity etc. [3] [4]

The placement of electric vehicle charge stations depends on various parameters, which can be categorized into environmental, economic-financial, socio-demographic behavior, technological, transportation planning, urban planning. [5] [6]

Considering some of these parameters, classical methods of solving the electrical vehicle charging station placement problem include Genetic algorithms [7] [8] [9] [10] [11], nature inspired metaheuristic optimization algorithms such as Particle Swarm Optimizations [12] [13] [14] [15] , Bee colony algorithm [16], Dove Based Recursive Deep Network [17], Sparrow Search Algorithm [18], Machine learning models [19], [20] grid partition method and some hybrid algorithms: Hybrid Genetic Algorithm Particle Swarm Optimization [21] Lion Pride and Bat Algorithm [22], Hybrid genetic algorithm-modified salp swarm algorithm (HGAMSSA) optimization [23], Graph Auto Encoder based Particle Swarm Optimization [24].

Quantum computing based methods of placing electric vehicle charge stations involve two different approaches: quantum annealing, and gate-based quantum computing. [25] integrates quantum annealing with a genetic algorithm, [26] uses D-Wave's Leap Hybrid Solver (a quantum-classical hybrid solver that uses quantum annealing). [27] integrates quantum rotation gates to a binary lightning search algorithm forming a Quantum Binary Lightning Search algorithm, [28] introduces a dragonfly algorithm with quantum rotation gates. A hybrid approach combining Eurasian Oystercatcher Optimizer and Quantum Neural Network is proposed in [29]. [30] employs Grover's Adaptive search. [31] uses an improved quantum genetic algorithm that performs crossover and mutation operations using updating rotation gates.

The proposed HQGA integrates the grid partition method in [20] and uses gate-based quantum computing to perform crossover and mutation operations of a genetic algorithm, since genetic algorithms have been performing well with the EV charging station placement problem. What sets it apart is that it is a multi-criterion algorithm based on [32] as it optimizes parameters such as the locations and load values of existing charge stations, locations and load capacities of power grids, and locations of existing infrastructure that can integrate charging stations to them, and outputs N possible grid locations that can be ranked. The ranking is done based on fitness and land use.

II. CURRENT WORK

A. PROBLEM STATEMENT

The parameters considered for the fitness function of the algorithm are as follows:

- Number of existing charge stations.
- Number of electrical sub stations
- Load values of existing charge stations.
- Load capacity of electrical sub stations, in Kwh
- Number and locations of points of interest, including petrol bunks, shopping malls, restaurants etc.

This paper introduces a hybrid quantum genetic algorithm to optimize the location for placement of electric vehicle charge stations. It integrates a gate-based method of quantum computing to a genetic algorithm, which optimizes the area of interest using grids, and proposes the best N number of grids as ideal places for establishing charge stations.

The area of interest is initially divided into grid possibilities, and an optimal grid configuration is chosen among them. The presence of existing charge stations, electric sub stations, and points of interest are listed, and the maximum power capacities are calculated for each of the grids. An initial set of possible solutions is randomly generated. The algorithm optimizes these solutions by encoding them into quantum circuits, performing quantum mutation and crossover operations and generating the next set of solutions (offspring). The quality of each solution is measured using a fitness function that checks how well it meets the parameters considered. The detailed process is outlined in flowchart in figure 1.

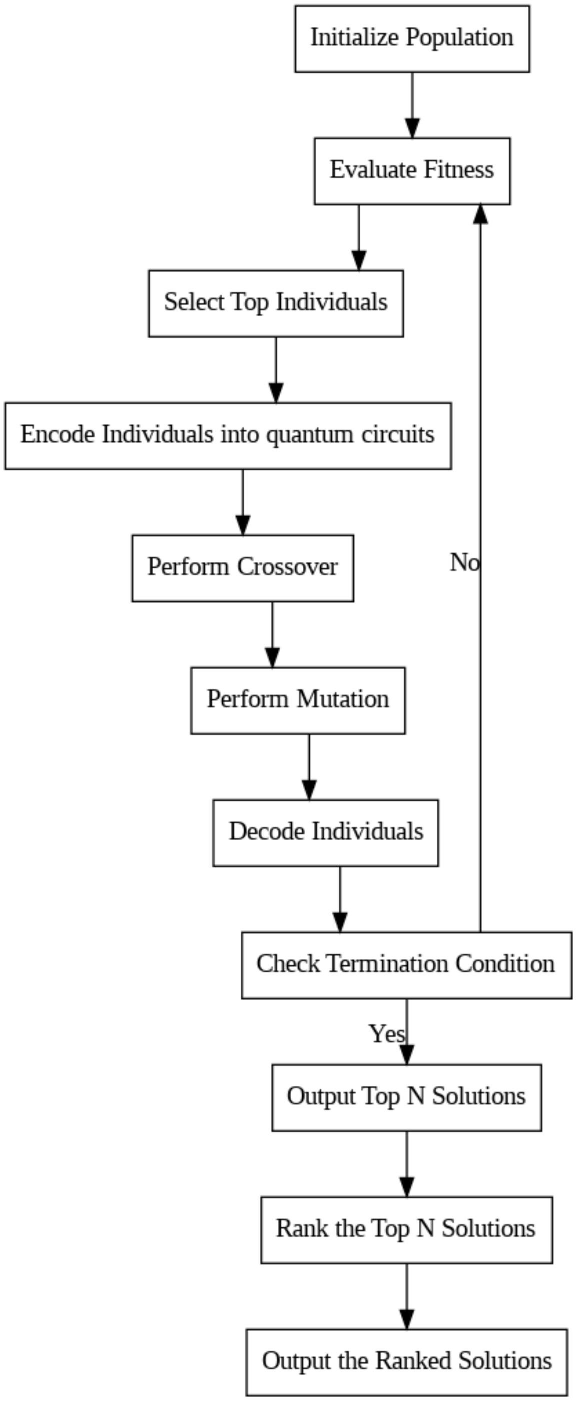


FIGURE 1: Flowchart of HGQA

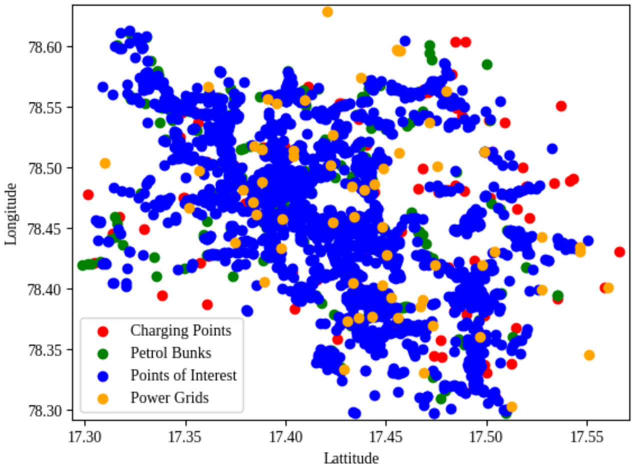


FIGURE 2: Data points in area of interest

B. DATA EXTRACTION

Data as input for the algorithm includes the coordinates (latitude-longitudes) of each of the existing charge stations, electric sub stations, and the points of interest. The load capacities and values of each of the electric sub stations and electric charge stations respectively are defined in Kwh. The points of interest are of two tiers: Tier 1 (petrol bunks) and Tier 2(hospitals, schools, colleges, etc.)

C. GRID PARTITIONING

The area of interest is divided into grids, and the algorithm generates possible grids, based on the number of qubits being used for encoding each of the solutions. For example, if the number of qubits is 7, it generates possibilities of 2^7 i.e. 128 grids, as shown in figure 3. One grid among these is to be chosen. The number of qubits is determined by the required level of granularity in dividing the area of interest.

D. FITNESS FUNCTION

The fitness function for a grid G is defined as follows:

1) Existing charging stations in G discouraged.
2) Existing charging stations in grids adjacent to G are discouraged.
3) Tier 1 point of interest is encouraged.
4) Tier 2 point of interest is encouraged, with 3/7th value of tier 1 point of interest.
5) Power grid in G is encouraged.
6) Power grids in grids adjacent to G are encouraged.
7) Negative penalty if the total power capacity of G is exceeded.

E. QUANTUM ENCODING, OPERATIONS AND DECODING

Each of the solutions is encoded into a quantum circuit, with each grid number represented in binary form based on the number of qubits. A Pauli X gate is applied to the qubits corresponding to each of the 1s in the binary representation.

The one-point crossover operation in the algorithm merges two parent quantum circuits by selecting a random crossover point. The first part of the parent circuits is inherited by one child, and the remaining portion is taken from the other parent, creating two new child circuits.

The mutation operation introduces randomness into the quantum circuits by applying either an X gate or a SWAP gate to randomly selected qubits in the circuit.

Once the evolutionary operations are performed, the resultant circuits are converted back into classical data by performing measurements and taking the result with the highest probability.

F. RANKING OF THE SOLUTIONS

Once the N number of solutions are obtained, they are given a ranking. The criteria that the ranking considers are as follows:

1) Fitness value
2) Number of T1 points of interest inside the grid
3) Percentage of Land use: Giving priority to residential and industrial areas, and less to restricted land.

III. CASE STUDY AND RESULTS

The city of Hyderabad, India was chosen to be the area of interest for the case study.

A. DATASETS USED

Google Maps was used to obtain the coordinates of existing charge stations, electrical sub stations and their capacities.

The Open Data Telangana [33] website was the source of obtaining the load values of the existing charge stations.

The locations of points of interest were obtained using the OpenStreetMap package on python.

The land use and land cover patterns of Hyderabad were obtained from the Centre for Environment, JNTU-Hyderabad [34]

B. EVALUATION METRICS

The algorithm was evaluated according to the following metrics:

- Fitness evolution: number of iterations taken for convergence.
- Distance values after convergence.

To compare performances, a classical counterpart was designed with classical mutation and crossover operations.

The algorithm was run using 10 qubits for each of the points, and the number of shots used was 256. The number of new charge stations was 5, and the algorithm was run for 500 iterations, checking the fitness value for each of the iterations. The HQGA had better fitness values compared to its classical counterparts.

The distance values of each of the solutions i.e. set of N grids chosen as ideal for placement of EV charge stations are calculated by averaging the distances of each of the existing charge stations, substations and T1 points of interest from the centroid of the grid. The HQGA and classical counterpart had similar performances in this metric.

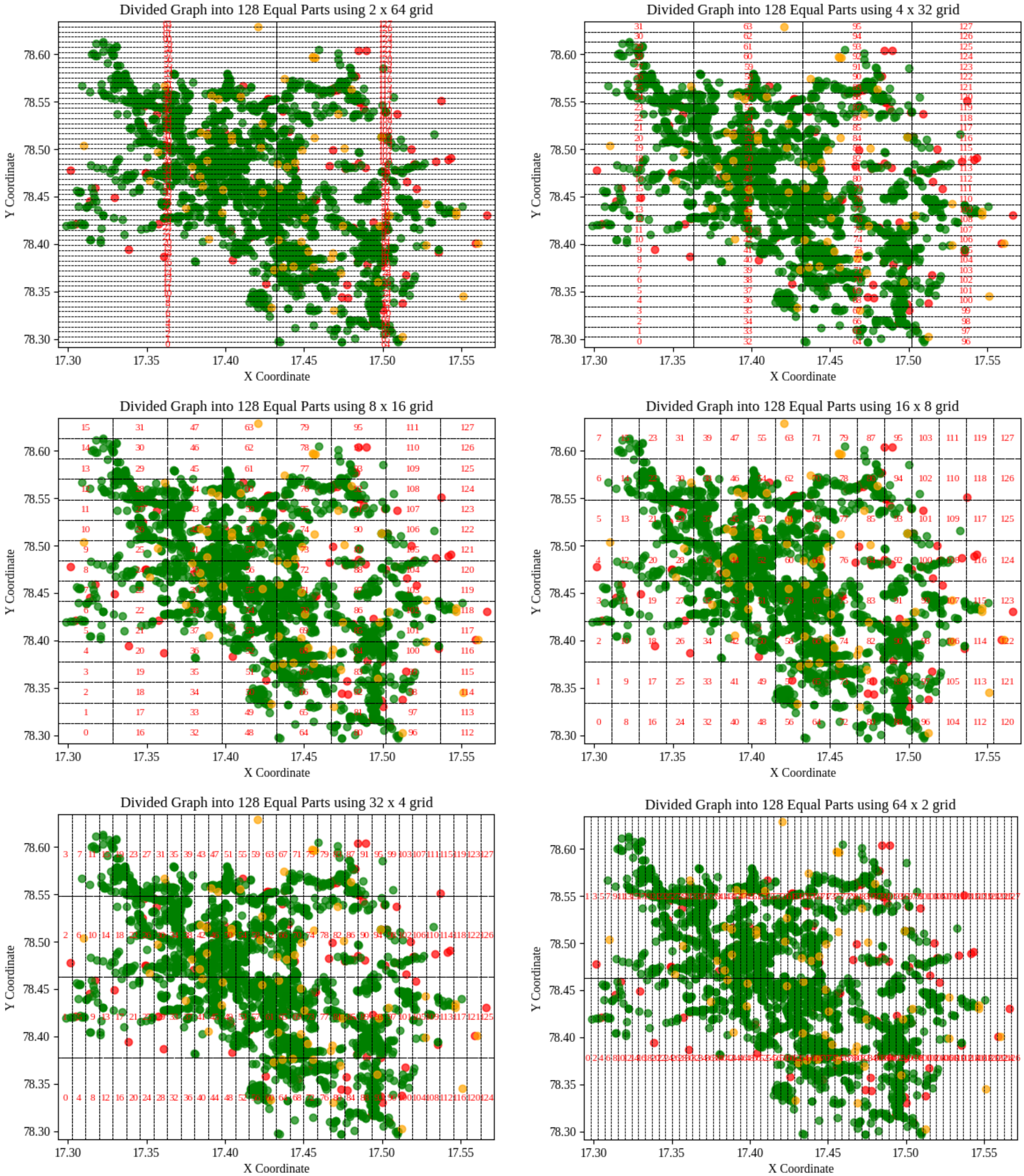
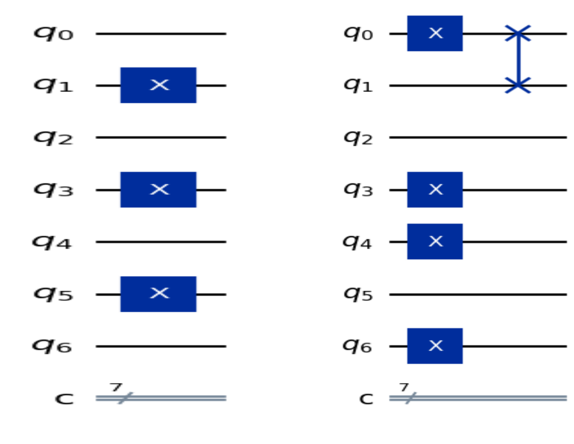


FIGURE 3: Grid partitioning for number of qubits=7

Grid Number	Adjacent Pairs	Charging Points	Tier 1 Points of Interest	Tier 2 Points of Interest	Power Grids	Load	Load Capacity
0	1, 8, 9	0	(0,)	(0,)	0	0	0
1	0, 2, 8, 9, 10	0	(0,)	(0,)	0	0	0
2	1, 3, 9, 10, 11	0	(2,)	(1,)	0	0	0
3	2, 4, 10, 11, 12	1	(2,)	(7,)	0	22.0	0
4	3, 5, 11, 12, 13	1	(0,)	(0,)	1	15.0	9000.0
5	4, 6, 12, 13, 14	0	(0,)	(0,)	0	0	0
6	5, 7, 13, 14, 15	0	(0,)	(1,)	0	0	0
7	6, 14, 15	0	(0,)	(0,)	0	0	0
8	0, 1, 9, 16, 17	0	(0,)	(0,)	0	0	0
9	0, 1, 2, 8, 10, 16, 17, 18	0	(0,)	(0,)	0	0	0
10	1, 2, 3, 9, 11, 17, 18, 19	0	(0,)	(5,)	0	0	0
11	2, 3, 4, 10, 12, 18, 19, 20	2	(5,)	(7,)	0	99.0	0
12	3, 4, 5, 11, 13, 19, 20, 21	0	(1,)	(4,)	0	0	0
13	4, 5, 6, 12, 14, 20, 21, 22	0	(0,)	(0,)	0	0	0
14	5, 6, 7, 13, 15, 21, 22, 23	0	(3,)	(9,)	0	0	0
15	6, 7, 14, 22, 23	0	(2,)	(11,)	0	0	0
16	8, 9, 17, 24, 25	0	(0,)	(0,)	0	0	0
17	8, 9, 10, 16, 18, 24, 25, 26	0	(0,)	(0,)	0	0	0
18	9, 10, 11, 17, 19, 25, 26, 27	1	(1,)	(0,)	0	54.0	0
19	10, 11, 12, 18, 20, 26, 27, 28	1	(1,)	(6,)	0	5.0	0
20	11, 12, 13, 19, 21, 27, 28, 29	0	(1,)	(16,)	0	0	0
21	12, 13, 14, 20, 22, 28, 29, 30	1	(5,)	(18,)	0	13.0	0
22	13, 14, 15, 21, 23, 29, 30, 31	1	(14,)	(59,)	0	54.0	0
23	14, 15, 22, 30, 31	0	(1,)	(2,)	0	0	0
24	16, 17, 25, 32, 33	0	(0,)	(0,)	0	0	0
25	16, 17, 18, 24, 26, 32, 33, 34	0	(0,)	(0,)	0	0	0
26	17, 18, 19, 25, 27, 33, 34, 35	1	(1,)	(2,)	0	18.0	0
27	18, 19, 20, 26, 28, 34, 35, 36	2	(5,)	(13,)	0	10.0	0
28	19, 20, 21, 27, 29, 35, 36, 37	4	(3,)	(23,)	2	38.0	18000.0
29	20, 21, 22, 28, 30, 36, 37, 38	5	(7,)	(62,)	0	157.0	0
30	21, 22, 23, 29, 31, 37, 38, 39	3	(3,)	(13,)	1	140.0	9000.0
31	22, 23, 30, 38, 39	0	(0,)	(0,)	0	0	0
32	24, 25, 33, 40, 41	0	(0,)	(0,)	0	0	0

FIGURE 4: Fitness table visualized



(a) Encoded parent (b) Mutation on offspring

FIGURE 5: Quantum Encoding and Operation

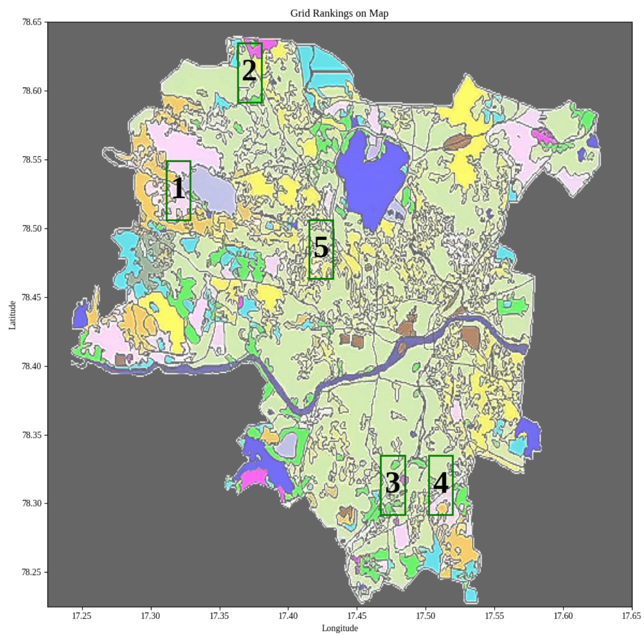


FIGURE 6: Ranking of the N=5 solutions

TABLE 1: Time Taken for Iterations in seconds

No. of Iterations	Classical	HQGA (5 Qubits)	HQGA (10 Qubits)
1	0.959	2.172	3.72
100	0.962	126.698	297.27
500	1.543	638.665	1479.15
1000	2.181	1274.647	2951.05

IV. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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Appendixes, if needed, appear before the acknowledgment.

ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments. Avoid expressions such as "One of us (S.B.A.) would like to thank . . . ." Instead, write "F. A. Author thanks . . . ." In most cases, sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.

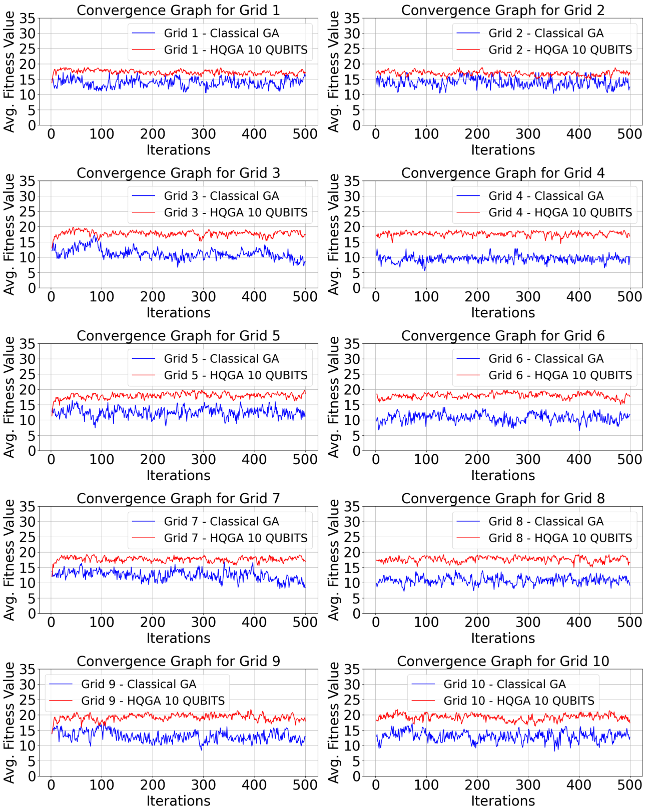

FIGURE 7: Evolution of the HQGA and classical GA fitness with iterations

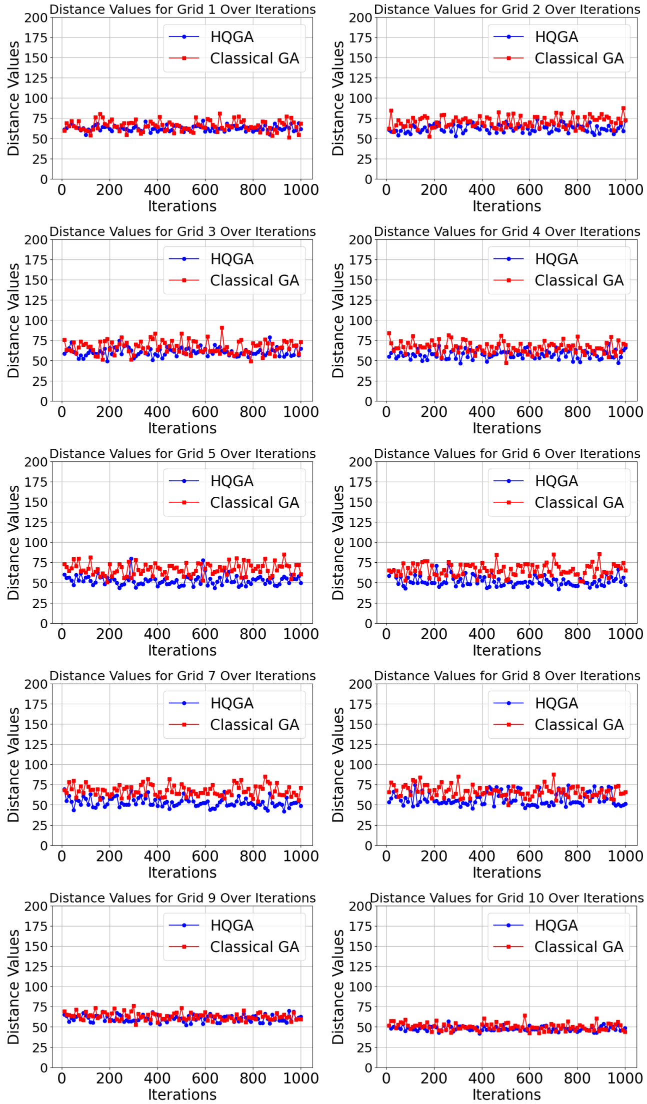

FIGURE 8: Distance values of HQGA and classical GA

REFERENCES AND FOOTNOTES

A. REFERENCES

References need not be cited in text. When they are, they appear on the line, in square brackets, inside the punctuation. Multiple references are each numbered with separate brackets. When citing a section in a book, please give the relevant page numbers. In text, refer simply to the reference number. Do not use "Ref." or "reference" except at the beginning of a sentence: "Reference [3] shows . . . ." Please do not use automatic endnotes in Word, rather, type the reference list at the end of the paper using the "References" style.

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APPENDIX A SUBMITTING YOUR PAPER FOR REVIEW

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FIRST A. AUTHOR (M'76–SM'81–F'87) and all authors may include biographies. Biographies are often not included in conference-related papers. This author became a Member (M) of IEEE in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year the degree was earned. The author's major field of study should be lower-cased.

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