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Quantum Inspired Evolutionary Algorithm based on Day Ahead Market of the Polish Electricity Power Exchange

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Abstract. The paper discusses the essence of the method and selected results of the quantum-inspired implementation of the so-called System Evolutionary Algorithm on the example of the neural model of the Day-Ahead Market of the Polish Electricity Exchange Market S.A. First, the appropriate Perceptron Artificial Neural Network was designed and implemented in the MATLAB and Simulink environment, in which the Day-Ahead Market model was taught. Then it was assumed that the obtained parameters of the neural model, i.e. weights and biases, are quantum-encoded numbers, the values of which were corrected by the quantum-inspired Evolutionary Algorithm. Finally, a hybrid model was obtained in the form of an Artificial Neural Network with weights and biases corrected by a quantum inspired Evolutionary Algorithm. As a result of the conducted research, the relative error improvement was obtained from the level for different hours of the day from -0.11% ÷ 0.12% to the level from 0.04% ÷ 0.05%, i.e. by an order of magnitude. Moreover, the improvement of the quantum-inspired evolutionary algorithm measured by the fitness metric formulated as MSE error was achieved from a value of 0.990366 to a value of 0.990375.

Keywords: Evolutionary Algorithm, quantum inspirations, qudit, Day Ahead Market, Artificial Neural Network, Polish Electricity Exchange.

1 Introduction

In recent years, a very important issue that can be used in calculations carried out on classical computers is the quantum inspiration of artificial intelligence methods [15], especially among them evolutionary algorithms [8, 11, 20, 21, 38], as well as artificial neural networks [14, 17, 25].

Quantum inspirations introduce new sources of uncertainty into the methods of artificial intelligence, hence, on the one hand, they increase the scope of the diversity of solutions, but on the other hand, they increase the factors resulting from the nature of living systems.. In this regard, an important issue is the way to take into account the uncertainty resulting, inter alia, from quantum mixed states, especially those resulting from the probability modules of the occurrence of quantum mixed states. Therefore, it is important to point the pure states, which are the dominant, together with an indication of the extent of their dominance for quantum mixed qudit states, including qubits.

Certain new proposals in this regard, presented in this paper, have been verified on the example of the neural system of the Day-Ahead Market (DAM) operating at Polish Electricity Exchange (PEE), which was improved with a quantum inspired evolution algorithm. So first, in the MATLAB and Simulink environment, the Perceptron ANN model of the neural system of the Day-Ahead Market was designed and trained. And next the weights and biases of the neural model were improved using a quantum-inspired System Evolutionary Algorithm (SAE), using their own quantum AI-inspired method.

The basic aspects of the quantum inspiration method are shown, such as the quantization process leading to the obtaining of quantum binary numbers, the method of calculating quantum numbers using linear algebra and vector-matrix calculus. And finally the dequantization method using Artificial Neural Networks was shown.

1.1 Research object

The quantum inspiration of artificial intelligence methods, including Evolutionary Algorithms, concerns processing of information on classical computers and is designed to improve the quality of the given neural model, e.g. the Electricity Commodity Day-Ahead Market System, which was adopted as the research object.

They are used by analogy with artificial intelligence methods inspired by the nature of various processes occurring in the world of living beings, i.e. evolutionary algorithms inspired by the process of evolution, artificial neural networks inspired by the information processing process in the nervous systems of living creatures, including humans, artificial immune systems inspired by the functioning of immune living organisms, etc. [1, 3, 7, 18, 22, 29].

Thus, inspirations with quantum computing solutions are used only for supporting the methods of artificial intelligence, and not for providing answers to the processes taking place in quantum computers or in physics and quantum chemistry, including quantum processes taking place in them [5, 9-10, 30-31].

Thus, some terms adequate to the concepts in computer science have been introduced, including in the methods of artificial intelligence, and not in physics, chemistry or biology. The terms including the concept of a quantum number written in the notation of binary numbers (called for simplification a quantum mixed stater, describing a number encoded in a quantum state similar to numbers encoded in a binary number system, or numbers written in a decimal number system). Thus, the terms of a quantum mixed state adopted in the research does not directly translate into the concept of a quantum number defined in physics or chemistry [5, 9, 30-31], hence a quantum mixed state is a number written in the adopted quantum number system embedded in a binary numerical system, as in a sense an extension of the binary number system to record not only pure states, but also mixed states [27, 33-35].

It is important at this point to recall that in classical systems the state space is defined as a set of possible elements describing a system, process, object, etc., and the logic of classical physics is Boolean logic.

In quantum systems, however, the state space is a vector and continuous space, which is a Hilbert space as a finite-dimensional or infinitely-dimensional space. Elements of this space are called ket vectors and the Dirac notation is used [5, 9-10, 30-31]. Taking into account the uncertainty of quantum states in the notation of a binary number system Various axioms resulting from, among others, the definition of the Hilbert space, i.e. the definition of the state space from linearity, continuity and from such features as e.g. vector norm, existence of limits in vector orientation and orthogonality of vectors, i.e. a feature resulting from the angles between vectors. All this is further generalized to the n-dimensional Hilbert space, which is associated with the need to synchronize and normalize each other, and therefore with the determination of the norm, i.e. topology in terms of distance, i.e. the possibility of using the dot product of two vectors [9-10, 30-31].

Only after such a definition is a Hilbert space obtained, or a Banach space with internal product, to which various axioms and definitions lead to its definition, which from the point of view of quantum inspirations have been synthetically described, among others, by in the works: [27, 33-35], including the following:

1. There is a vector ket defined as follows [30-31]:

$$|\phi\rangle = \begin{bmatrix} \alpha \\ \beta \end{bmatrix}. \tag{1}$$

2. Replacing the vector bra with the vector ket corresponds to a complex conjugate [30-31]:

$$\langle\beta \mid \alpha >= \langle\beta \mid \alpha >^* . \tag{2}$$

3. The scalar product property allows us to define in a new space, i.e. the space with the dot product (unitary space) of the norm, i.e. the length of the vector [30-31]:

$$||\alpha|| = \sqrt{\langle\alpha|\alpha >}. \tag{3}$$

4. The orthogonality of vectors in a Hilbert space occurs when their scalar product is zero, hence the isomorphism and many other important properties of Hilbert spaces used in quantum computing are derived, such as: tensor product, operator eigenvalues, the concept of observables, density matrix, reduction of states , distribution, etc.

1.2 Quantum computing in terms of control theory and systems

In quantum mechanics and in quantum mathematics, and hence in quantum computing, the states of the system are described by vectors from the space of real numbers or the space of complex numbers. The vectors belonging to a given Hilbert space represent the so-called pure quantum states. The concept of mixed states and the density matrix are derived from the pure states. In order to simplify the notation of vectors, the Dirac notation was introduced, including: vector ket, vector bra and vector braket. These are vectors described by symbols: | > - ket, <| - bra and <| > - braket representing the dot product in the Hilbert space [10, 30-31].

Example. It is assumed that in the case of obtaining a notation in a binary number system, the dominant interval is the interval resulting from the state represented in binary by the value 0 or 1 (in a quantum notation one can speak of the appropriate pure state ket 0 (in the Dirac notation: | 0>) or ket 1 (in Dirac notation: | 1>). In the case of a single qubit, i.e. in the case of a quantum system composed of two pure states, ket 0 and ket 1 between which there are quantum mixed states) to define dominant and recessive intervals, e.g. for pure states ket 0 and ket 1, it is convenient to use the principle of superposition. Therefore, in such a case, let the probability modules of the mixed state be equal to each other, i.e. $\alpha = \beta$, from which it follows that:

$$2 \cdot \alpha^2 = 1, \tag{4}$$

hence the positive value of the solution (probability modulus) is:

$$\alpha = \frac{\sqrt{2}}{2}, \tag{5}$$

which results from the interpretation of the physical values of both the probability modulus α and the probability modulus β concerning the pure state ket 0 and the pure state ket 1, which are always positive.

Due to the equality of both probability modules, this value is approximately:

$$\alpha = \beta \cong 0,71, \tag{6}$$

which is the border value between the dominant and recessive intervals, i.e. between the interval from which the values of the dominant states can be drawn and the interval from which the values of the recessive states can be drawn.

Therefore, in the case when the dominant state is ket 0, then the values of the probability module are drawn from the interval adequate for the dominant interval, i.e.:

$$0.71 \leq \alpha \leq 1, \tag{7}$$

and the values of the probability modulus β are determined from the superposition principle, and similarly in this case the values of the recessive state ket 1 the values of the probability modulus β are determined from the recessive interval:

$$0 \leq \beta \leq 0.71, \tag{8}$$

and the values of the probability modulus α are derived from the superposition principle. In this way, two pairs of probability modules are obtained, which can be used to more precisely define the ranges of values in which the values of the probability modules α and β occur.

Therefore, in order to perform quantum-inspired calculations, we need appropriate input quantities encoded in a quantum number system (written as quantum binary numbers) and appropriate operations based on linear algebra and matrix-vector calculus, in order to finally obtain the output quantities written in the quantum number system.

The method of quantum computation, regardless of the hardware solutions used, performed using classical computers (if quantum computations are simulated) or performed using quantum computers, has not yet been properly and unambiguously defined from our point of view. Therefore, ignoring the methods of quantum computing at the lowest level with the use of quantum gates and quantum circuits, because this is not what we mean in classical computers in high-level programming languages, we can only now use linear algebra and vector-matrix calculus and real numbers or more broadly, complex numbers.

Therefore, in order to perform quantum computations on classical computers, we need appropriately written input values in quantum states (here defined as so-called quantum mixed state), in order to obtain properly encoded numbers in quantum states as a result of matrix vector calculus conducted on quantum states as output quantities.

So the basic question arises how to convert a real number written in a decimal number system into a number encoded in a quantum state (quantum number system), i.e. how to quantize e.g. real numbers written in a decimal number system into numbers written in a quantum number system and how to perform the inverse operation, i.e. the dequantization operation, i.e. the conversion of numbers written in a quantum number system into numbers written in a decimal number system.

In fact, in this approach, quantization concerns the conversion of numbers written in a binary number system into numbers written in a quantum number system (here: a binary quantum system, modeled on a binary system), and dequantization as an inverse operation concerns the conversion of numbers written in a quantum number system into a binary written numbers system.

So there are numbers written in the decimal number system, there are numbers written in the binary number system and we are looking for numbers written in the quantum number system in the presented solution modeled on the binary number system).

The literature on the subject shows that the quantum state of a qubit is defined as [10, 30-31]:

$$|\varphi\rangle = \begin{bmatrix} \alpha \\ \beta \end{bmatrix}, \tag{9}$$

or in Dirac notation as:

$$|\varphi\rangle = \alpha|0\rangle + \beta|1\rangle, \tag{10}$$

where:

α, β - probability amplitudes (complex numbers or only their real parts, without the imaginary part) with which there is a pure state 0 (notation in Dirac | 0>) and a pure state 1 (notation in Dirac notation | 1>), while maintaining the superposition principle, and so $\alpha^2 + \beta^2 = 1$.

Due to the fact that classical information in a binary system is written as a sequence of bits, attempts are made in the literature on the subject to write the quantum state also as a sequence of qubits, e.g.. [8, 11, 14-15]:

$$|\varphi_i\rangle = \left[\begin{array}{c|c|c|c} \alpha_{i1} & \alpha_{i2} & \dots & \alpha_{in} \\ \beta_{i1} & \beta_{i2} & \dots & \beta_{in} \end{array} \right], \tag{11}$$

which is a specific quantum state depending on the values of the probability amplitudes α_{ij}, β_{ij} of individual qubits j for the quantum state i.

Thus, by analogy to the number written in the decimal number system (called the decimal number) and by analogy to the number written in the binary number system (called the binary number), it is worth taking the name of the number written in the quantum number system (here by analogy to the binary system) as the number encoded in a quantum mixed state.

Due to the fact that in vector-matrix notation these numbers are vectors or matrices, hence perhaps a more appropriate name would be to operate with the name of a quantum matrix, which in turn could also be confusing, because the notation itself has nothing to do with the represented value.

The situation is similar to a binary number, which is actually written in the form of a row vector, but the represented value must be decoded e.g. after converting to a decimal number. Therefore, the interpretation of a quantum mixed state was adopted as a number encoded in a mixed quantum state, adequate to the matrix-vector interpretation, which can be read directly in the binary system and then in the decimal system [27, 30-35].

The adopted concept of quantum mixed state does not therefore have a direct reference to the concept of five quantum numbers used, not only in physics, but also in chemistry, as values characterizing discrete physical quantities, e.g. electrons, atomic nuclei, etc., i.e. a major, minor number, magnetic, spin or magnetic spin as it was already shown above. Perhaps it is only worth undertaking additional research leading to the linking of the well-known concept of quantum number formulated in the field of physics, chemistry and biology with the concept of a quantum number necessary for computing in computer science, including quantum computing, which is not discussed in this article. [9, 10, 30-31].

1.3 State and state variables in control theory and in quantum computing

In the theory of control and systems there is the concept of the equation of state and the output equation in which there are system states, similarly in quantum computing there are such concepts as quantum states of the system and measurement. In control and systems theory, the equations of state are a way to represent a mathematical model of a dynamic system (especially an automatic control system). Knowing the state of a system gives a lot, but we know even more about a system when we know the relationships of a state variable with other variables. In the description of the system (in its mathematical model), the key role is played by the relationship that governs the behavior of the state variable and, more broadly, the equation of state, while the description of the system by means of state equations is sometimes called a description in the state space or a model of state variables (fig. 1) [13, 36].

The state of the system is characterized by a system with memory, i.e. the state of the system contains information accumulated from the entire past of the system up to a point in time, but it must not undergo sudden, abrupt changes. In the case of most systems (except the simplest ones), the output of the system y at time tn depends not only on the input of the system u at time tn, but also on the past inputs of the system (at all times ti, where ti <tn).

The total effect on the system of past input values is represented by the concept of the internal state of the system. Thanks to the introduction of the concept of the system state, the analysis of the system is simplified, because in order to determine the system output y at time tn, it is enough to know only two quantities: the system input u at the current moment and the system state x at the same moment.

The set of state variables describing the linear system is not unique, that is, you can choose other variables and find the transformation that connects the resulting set with the previous set. Each such set will consist of linearly independent terms (the state variables x1, x2, ..., xn are linearly independent if the equation:

$$k_1 \cdot x_1 + k_2 \cdot x_2 + \ldots + k_n \cdot x_n = 0 \tag{12}$$

is satisfied for all x_j only if every factor k_j=0.

2 Uncertainty resulting from the quantum inspiration of qudites

Classical information is stored as a sequence of bits. Quantum information is written as a sequence of qubits. One bit is a binary unit, the value of which is 0 or 1. In quantum computing, the concept of quantum being is used, i.e. qubit.

In classical computing there is also an extended term to describe many bits, i.e. a byte, and similarly in quantum computing, the term qubbyte, and similarly to the term of many bits taken together, i.e. the classical concept dit and, consequently, the quantum term qudit, i.e. quantum dit. The qubit can take the v

The base states are referred to as the standard computing base. Generally, any two normalized orthogonal states can form the basis of qubits. Any state of a qubit $|\Psi >$ is described as a superposition of two base states:

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle, \tag{13}$$

where:

α, β - probability amplitudes,

hence:

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle = \alpha \begin{bmatrix} 0 \\ 1 \end{bmatrix} + \beta \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \tag{14}$$

where: $\alpha, \beta \in$ C,

Due to the requirement of normalization of the probability amplitudes, the values of α, β satisfy the condition:

$$|\alpha|^2 + |\beta|^2 = 1 \tag{15}$$

2.1 Determining the boundaries of the division of possible states to determine the value of the probability model of the dominant states

The uncertainty resulting from the quantum inspiration of qudits requires in each case the determination of the boundaries of the range for dominant states (and thus for recessive states), which in the case of a sufficient number of pure states comes down to the determination of appropriate boundaries:

2 (|0>, |1>): **0,71 – 1,00**, from which the value of the probability module for the dominant state can be drawn, and the value of the recessive state probability module can be determined from the state superposition principle, e.g. let α = 0.8 then β = (1-(0,8)2)1/2 = (1-0.64)1/2 =0.361/2 = 0,6 (the value of the probability module).

4 (|00>, |01>,|01>,|1 1>): **0,5 – 1,00**, from which the value of the probability module is drawn for the dominant state, e.g. | 00> and then the total of the three remaining states are recessive, the total probability module of which is determined from the state superposition principle, e.g. let the randomly drawn probability module value be: α_1 = 0.8 then then the remaining cumulative states are determined from the principle of superposition, i.e.: β = α_2+ α_3+ α_4 = (1-(0,8)2)1/2 = (1-0.64)1/2 = (0,36)1/2 = 0,6, and among the first-level recessive states there is one state dominant in the lower level, and then the value of the probability module from the recessive state is drawn 0,0 – 0,5, etc.

8 (|000>, . . . , |111>): **0,352 – 0,5**, from which the value of the probability module for the dominant state is drawn, etc. for the next number of pure states, that is: 16, 32, 64, 128, 256, 512, 1024, etc..

3 Quantum Inspired Evolutionary Algorithm

3.1 Research Experiment

Modeling is applied to the Day Ahead Market (DAM) system operating on the Polish Power Exchange S.A., where transactions are concluded 24 hours a day [19, 37].

On this basis, 24 input quantities were adopted in the form of the volume of electricity supplied and sold in each hour of the day [MWh] and 24 output quantities [37] in the form of weighted average electricity prices (ee) in each hour of the day [PLN / MWh]. The figures were downloaded from the PPE S.A. portal. in terms of quotations on the DAM during the six-month period, i.e. in the period from 01/01/2015 to 30/06/2015.

To teach the neural model of prices obtained on the TGEE DAM, the Perceptron Artificial Neural Network and the period of semi-annual data were selected, and the method of backward error propagation was selected for the learning process [2, 4, 24, 26, 28, 32]. The neural model was implemented in the MATLAB and Simulink environment with the use of its appropriate libraries.

Twenty for neurons were assumed in the input layer corresponding to the delivered and sold ee in particular hours of the day, and in the output layer corresponding to the weighted average prices obtained for the sold ee. In the perceptron architecture of the ANN, one hidden layer also with 24 neurons was designed, as well as the neuron activation function in the hidden layer logsig () and the purelin activation function () in the output layer [26-27, 33-35].

3.2 Assumptions for Quantum Inspiration

In the case of artificial intelligence models inspired by quantum computing methods, prepared for implementation on classical computers, it is necessary to define at least three algorithms:

- decimal quantization algorithm,
- algorithm for performing mathematical operations on quantum numbers,
- quantum number dequantization algorithm.

The idea of using quantum algorithms for specific practical solutions was presented, among others in the works: [26-28, 33-35]. In these methods, the important solutions adopted for use in this papers include, among others.:

- definition of a qubit with two pure states ket 0 and ket 1 with the corresponding probability modules α and β,
- writing the qubit states in the form of a two-row matrix, in which the first row represents the probability modules of the corresponding state ket 0, and the second row represents the corresponding state ket 1,
- the superposition of the probability modules and the associated property of the sum of their squares of 1,
- the possibility of performing calculations in Hilbert spaces, i.e. with the use of linear algebra and vector-matrix calculus, etc.

3.3 Weights, biases and activation function parameters in terms of quantum coded numbers

To build the Perceptron ANN as a model of the neural RDN system in terms of quantum-encoded numbers, the quantization method, the method of calculations using linear algebra and vector-matrix calculus and the dequantization method proposed in the authors' works were used [26-28, 33-35].

3.4 Creating a quantum initial population

For the purpose of creating the Quantum Initial Population (QIP), which after the first epoch will be converted into the Quantum Parent Population (QPP), an individual structure composed of two chromosomes was created, in which the first chromosome relates to the probability module related to ket 0, and the second chromosome to the probability module related to ket 1.

In the proposed method, for the purpose of accelerating the calculations in the presented example, the ANN was limited only to weights and biases of ANN, which were generated in the number of 100 for the purpose of randomly obtaining 100 PP individuals, and then converted into quantum mixed states, thus obtaining the Initial Quantum Population composed of 100 individuals, each of which was composed of two chromosomes representing the probability modules of the quantum states ket 0 and ket 1.

3.5 Assessment of the quality (value) of individuals

The fitness (quality) function was defined as the discrepancy between the value of each individual composed of two chromosomes and the real value in relation to the real value of the individual (the actual values concerned the prices obtained for electricity in each hour of the day).
Selected elements of Quantum AE are shown in detail in fig. 1 (part 1), fig. 2 (part 2) and fig. 3 (part 3) and fig. 4 (part 4).

3.6 Detailed description of selected fragments of Quantum Inspired AE

Improving Quantum Inspired ANN with Quantum Inspired AE consists in improving the parameters of weights and biases ANN using methods appropriate for AE:
Step 1. Initiation of the Initial Population by creating the structure of an individual composed of one chromosome on the basis of ANN weights and biases, hence the real values of weights and biases are converted into a 1 152-element vector that creates the structure of an individual in the Initial Population.
Step 2. Converting the value of the elements of an individual (chromosome) written in the system of decimal numbers into a binary chromosome, resulting in a 1 152 element set of numbers represented by the 12 element binary value of each of them.
Step 3. Calculating the probability amplitude of the occurrence of both pure states (ket 0 or ket 1) for individual elements of the binary chromosome, resulting in a 2 x 17 280 element matrix which is a quantum representation of an individual composed of two chromosomes, which is the structure of an individual of the quantumly represented population Initial Population on the basis of which the Initial Population will be generated.
Step 4. Creating more individuals of the Quantum Initial Population by introducing a range of gene value changes, ie a small random change, in this case the value of 0.001 in 200 randomly selected genes.
Step 5. Converting vector elements written in the system of decimal numbers into binary values.
Step 6. Calculate the probability amplitude of pure states (ket 0 or ket 1) for the input values.
Step 7. Determining the adaptation of individuals recorded in the quantum system. The procedure of improving the adaptation of chromosomes to the environment in subsequent epochs in this case is a cycle of 50 epochs (Fig. 4). The algorithm of single-point crossing of individuals recorded in a quantum system, which proceeds in a classic way, on individuals composed of two chromosomes.
Step 8. Determining the degree of adaptation of individual individuals recorded in the quantum system and on this basis, the selection related to the creation of the Parental Population (next generation) is carried out using a modified tournament method (10,000 pairs were drawn to select a winner from among them by the tournament method, i.e. the best suited individual.
Quantum Inspired AE evaluation procedure for improving weights and biases of Quantum Inspired ANN
Step 1. Identification of a single individual (two chromosomes) recorded in a quantum system from the Initial Population for evaluation.
Step 2. Create a quantum weight matrix for calculations.

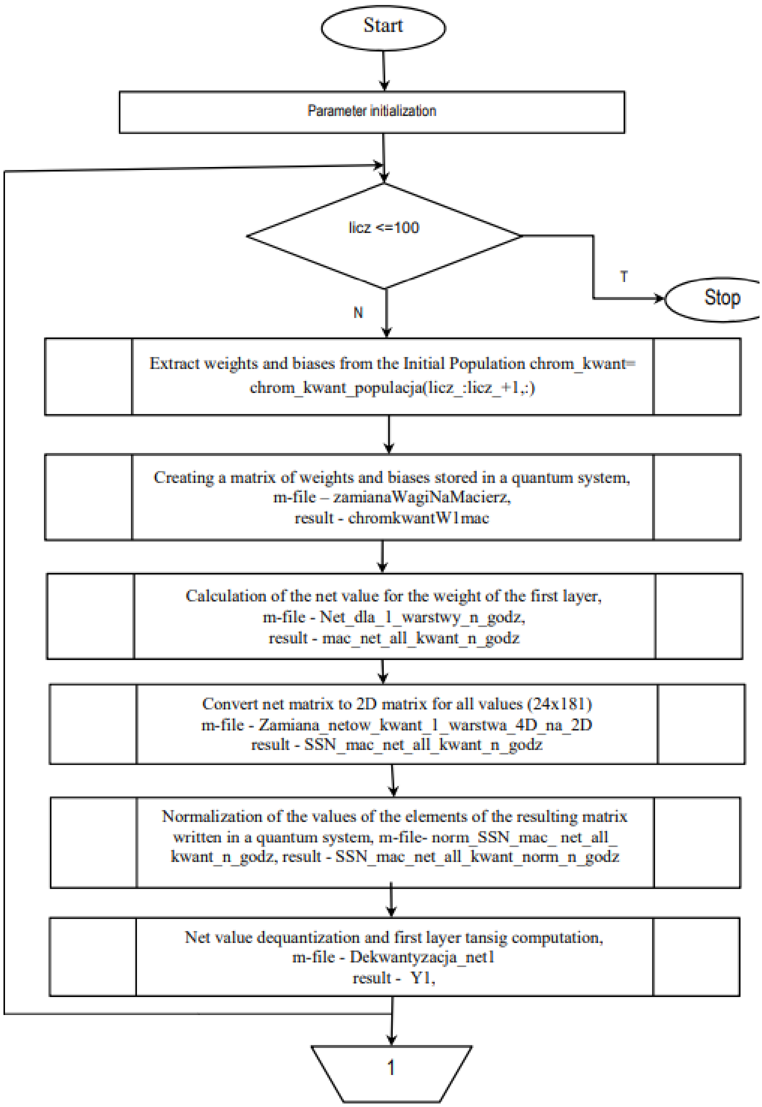

Figure 1. Quantum AE block diagram, part 1. Source: [26-27, 33-35].

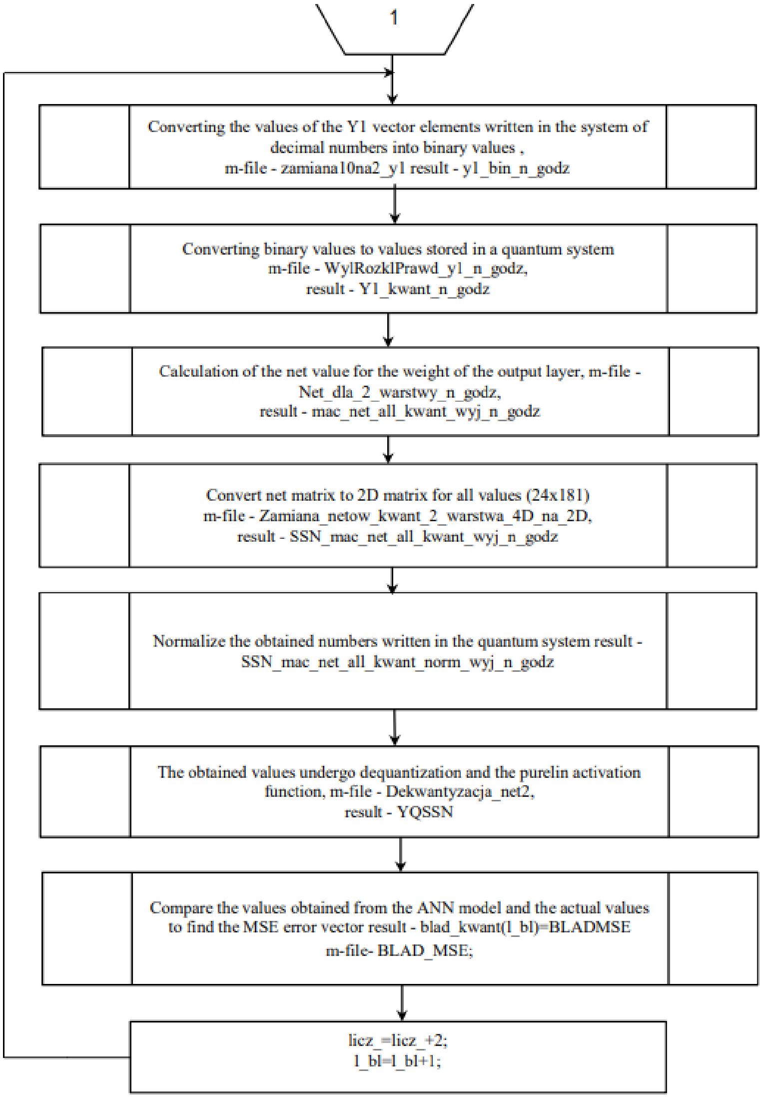

Figure 2. Quantum AE block diagram, part 2. Source: [26-27, 33-35].

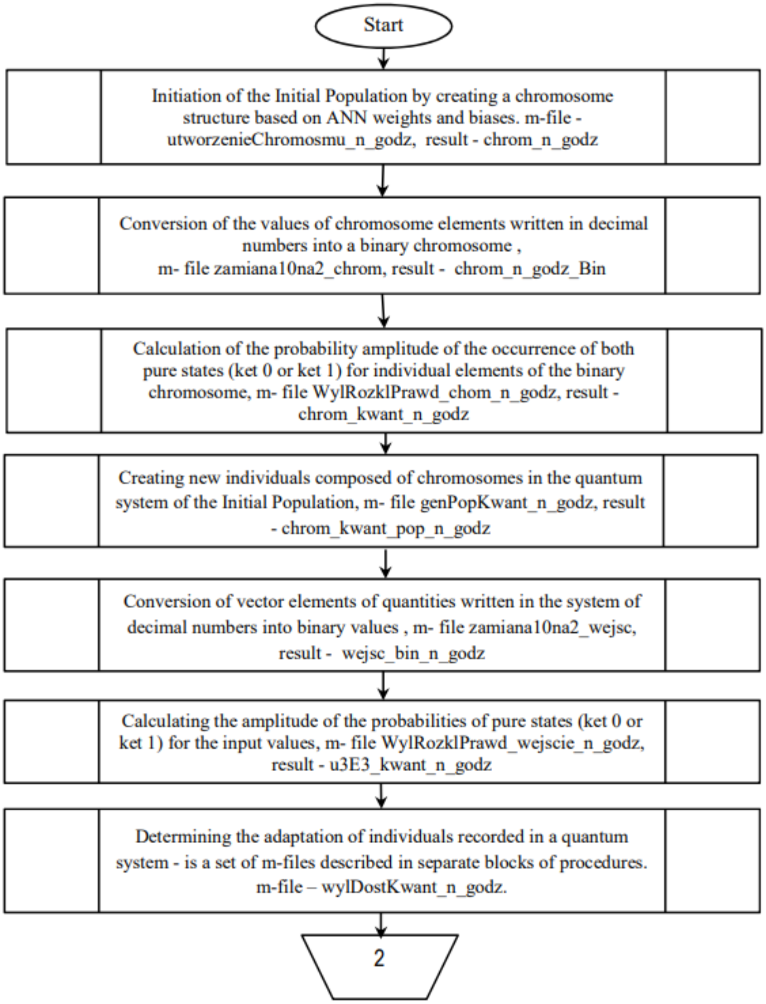

Figure 3. Quantum AE block diagram, part 3. Source: [26-27, 33-35].

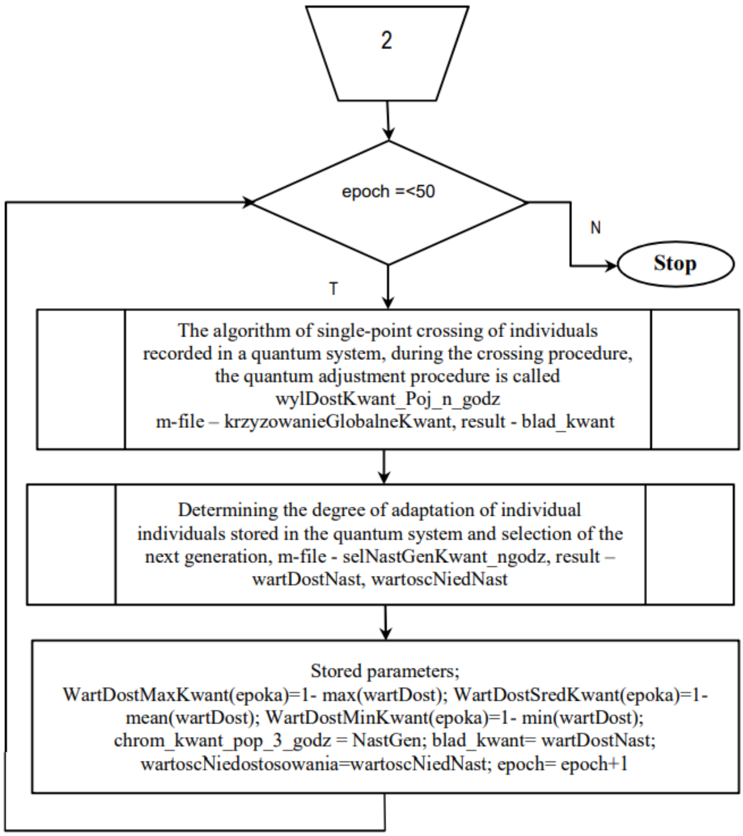

Figure 4. Quantum AE block diagram, part 4. Source: [26-27, 33-35].

Step 3. Calculating the value of the weighted net adder stored in the quantum number system for the weights of the hidden layer, resulting in 181 24-element vectors representing the individual net values of the first layer.
Step 4. Converting the matrix of the weighted adder net to a two-dimensional matrix for all weight values and input values (24x181)
Step 5. Normalization of the values of the elements of the obtained matrix stored in the quantum system for the output data.
Step 6. Dequantization of net adders and calculating the tansig () function of the hidden layer Y1 in the system of real numbers.
Step 7. Converting the values of the Y1 vector elements written in the system of decimal numbers into binary values.
Step 8. Converting binary values to values stored in a quantum system.
Step 9. Calculating the value of the quantum net adder for the output layer neurons.
Step 10. Convert net adder matrix to two-dimensional matrix for all values.
Step 11. Normalization of the obtained number written in the quantum number system.
Step 12. The obtained values were dequantized and the purelin () activation function.
Step 13. Compare the values obtained from the Quantum Inspired ANN model with the actual values recorded on the DAM in order to determine the error vector MSE. Finally, the course of the adjustment function for 50 epochs was obtained as in Fig. 4, but it turned out that, among others:

– designed and implemented hybrid neural model supported by evolution of the RDAM of PPE S.A. system consists of a neural model with modified weights by means of AE, which improved the parameters of the DAM system model depending on the hour of the day from the level of - 0.17% to 0.18% to the level of -0.11% to 0.12%,
– designed and implemented hybrid neural model supported by evolution and quantum inspired by the DAM system consists of a neural model, with modified weights by means of AE and quantum inspiration, improved the model parameters depending on the hour of the day from -0.11% to 0.12% to the range -0.04% to 0.05%, and so the result is an order of magnitude better than the previous one.

Moreover, the improvement of the quantum-inspired evolutionary algorithm measured by the fitness metric formulated as MSE error was achieved from a value of 0.990366 to a value of 0.990375.

4 Obtained results compared to similar studies available in the literature

The method presented in the dissertation is so unique that no adequate research results were found that could be compared except for the work [16], which contains the results of price modeling using MISO models and MISO models corrected using ANN.

The literature on the subject contains research results obtained using time series models, not MIMO models as used in this dissertation. The work [16] shows the results of identification modeling of the RDN system and the results of identification modeling corrected using ANN obtained on the basis of data concerning, among others, the year 2019, which were then used

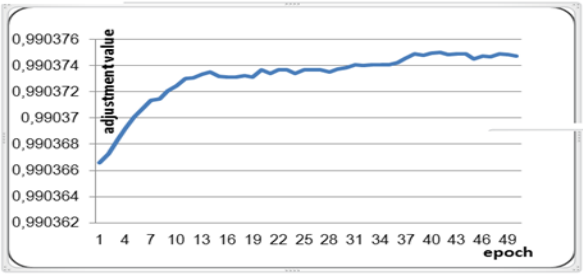

Figure 5. The course of the adaptation function of the Quantum Evolutionary Algorithm for 50 epochs. Source: [26-27, 33-35].

to model prices in 2020 for selected periods such as day, week, month, year. The presented results concern, among others, 6:00 and the MAPE error test results obtained in this thesis for the MIMO model trained on the ANN on the same 2019 data regarding the RDN system checked in price modeling in 2020 were referred to them (Table 1).

Table 1. Summary of MAPE errors [%] in price forecasting for 2020 for 6:00 using models obtained for data from 2019. Source: Own study using the selected results presented in [16].

hour 6:00	**2020**	**month**	**week**	**day**
Model MISO [16]	32.00	7.00	10.05	4.58
Model MISO with ANN correction [16]	31,33	7,24	6,96	3,83
Neuronal model (own study)	10,52	7,47	8,85	8,52

5 Conclusions and further research directions

The paper discusses the essence of the quantum-inspired System Evolutionary Algorithm, which was used to improve the weights and biases of the neural model of the Day-Ahead Market System of the Polish Power Exchange.

In order to verify the method, an appropriate Perceptron Artificial Neural Network was designed and implemented in the MATLAB and Simulink environment, which was taught to the Day-Ahead Market system model. Then it was assumed that the obtained parameters of the neural model, i.e. weights and biases, are quantum-encoded numbers, the values of which were corrected by the quantum-inspired Evolutionary Algorithm.

Finally, a hybrid model was obtained in the form of an Artificial Neural Network with weights and biases corrected by a quantum inspired Evolutionary Algorithm. As a result of the conducted research, the relative error improvement was obtained from the level for different hours of the day from 0.11% ÷ 0.12% to the level from 0.04% ÷ 0.05%, i.e. by an order of magnitude.

Quantum inspirations are associated with the introduction to artificial intelligence models of additional uncertainty resulting from quantum mixed states, including in particular the probability modules of quantum states. The essence of the method consists in indicating the dominant states and the extent of their dominance for quantum mixed qudit states, in particular qubits.

The theoretical propositions of the Quantum Inspired Evolutionary Algorithm were verified on the example of the neural model of the Day-Ahead Market of the Electricity Exchange Market in Poland, which involved designing in the MATLAB and Simulink environment, implementing and conducting appropriate research checking the functioning of three neural models, the neural model of the DAM system, a neural model with modified weights and biases using AE and a neural model with modified weights and biases using quantum inspired AE.

It shows, among others, some problems identified in the course of research, which may constitute new research directions, such as the development of a method of dequantizing quantumly written binary numbers (for simplification called quantum mixed states) into numbers written in the decimal number system, etc.

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