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Artificial Intelligence Based Optimal Placement of PMU

Rachana Pandey, H.K. Verma, Arun Parakh, Cheshta Jain Khare

***Abstract:** The investigation of power system disturbances is critical for ensuring the supply's dependability and security. Phasor Measurement Unit (PMU) is an important device of our power network, installed on system to enable the power system monitoring and control. By givingsynchronised measurements at high sample rates, Phasor Measurement Units have the potential to record quick transients with high precision. PMUs are gradually being integrated into power systems because they give important phasor information for power system protection and control in both normal and abnormal situations. Placement of PMU on every bus of the network is not easy to implement, either because of expense or becausecommunication facilities in some portions of the system are limited. Different ways for placing PMUs have been researched to improve the robustness of state estimate. The paper proposes unique phasor measurement unit optimal placement methodologies. With full network observability, the suggested methods will assure optimal PMU placement. The proposed algorithm will be thoroughly tested using IEEE 7, 9, 14, and 24 standard testsystems, with the results compared to existing approaches.*

***Key Words:** Phase Measurement Unit, Optimization, Observability, deep Q Learning, Reinforcement Learning*

I. INTRODUCTION

An electric power system, as we all know, is a network of electrical devices, distribution. and transmission, .as well as a component of an electric system that allows for acceptable power quality at the end. An electric power system is a network of electrical components that provide power to an area, households, and businesses. The product of two separate values, electric current and electric voltage, is electric power. Both of these numbers change throughout time and are held constant in DC. Because most of our everyday appliances run on alternating current (A.C.), while others, such as computers and digital equipment, run on direct current (DC).

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A.C. power is a convenient option because it is simple to convert and create. However, D.C. remains a viable option for DC networks and is more cost-effective for high-voltage transmission. Solar energy systems, hydroelectric energy plants, thermal power production plants, wind power systems, nuclear energy power plants, and other power plants can create electricity in a variety of ways. [1] We use water to generate electricity in hydro power plants by building dams. Kinetic energy is converted to electric energy in this process. Solar energy is used to generate electricity in solar power plants. Transducers, arethe device which convert one form of energy into another just as a solar cells. At the end of the process, the solar cell produces a DC output voltage. We transform wind energy into electric energy in wind power facilities. Wind turbines are used first, followed by mechanical power generators for electricity generation. However, they have some restrictions in that they can only be utilized in regions where there is a lot of wind. To transform coal energy into electric energy, thermal power plants are employed. In this process, steam is generated by coal burning, by which turbine is rotated, converting the energy into electric energy. [2]

Most places in the world are affected by a lot of electricity outages, faults, blackouts in recent years. The absence of investment in protection devices and control system infrastructure is to blame. as well as poor maintenance and a constant growth in electric power consumption, which exceeds the power transmission and distribution system limits. New technologies are beingemployed to ensure better dependability and continuous operation of the electricity system in order to avoid blackouts. We are applying state-ofthe-art technologiestoday, and we do state estimation from measurements obtained from PMUs to achieve good controllability and great dependability. It is utilised to achieve high controllability, reliability, and real-time monitoring of the power system, as well as to please consumers by providing good power quality. [2]

The electric system's network is quite sophisticated, and it's used to send or provide power from generating stations to the load end. The electrical power system is the most complex system, and it is constantly subjected to numerous disturbances or faults (switching, lightning, andso on). As a result, they have an impact on system frequency, line voltages, and power flow. Because power systems are dynamic in nature, a control system is required to ensure that the system remains stable during or after problems, allowing our power supply to continue to the customer or load end.

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The quantity of active power consumed and loss must always equal active power product, which is one of the most difficult features of power systems. When there is extra power produced than frequency, voltage and demand, rise, and when less generation, voltage and frequency fall. Even a tiny departure from the frequency can cause harm to synchronous equipment, as well as the loss of synchronization and other appliances. As a result, we must ensure that the frequency remains consistent, which is the responsibility of the transmission system operator. As a result, monitoring of network is required so we can obtain continuous network status at all times, minimizing the impact of defects, and ensuring that our network remains stable. Similarly, as power network demand increases, the power network expands andbecomes more difficult. As load rises, our network becomes increasingly stressed. As a result, regular monitoring and control of the electric system is essential [2].

II. ARTIFICIAL INTELLIGENCE

“Intelligence: The ability to pick up new information and solve difficulties.” Computers would be referred to as” intelligent” if they could solve real-world issues by learning from their previous experiences. As a result, AI systems are more generic (rather than specific), capable of ”thinking,” and adaptable. As we all know, the ability to acquire and apply knowledge is referred to as intelligence. Knowledge refers to the information learned via experience. Experience refers to the information gained through exposure (training). Artificial intelligence is defined as "a duplicate of anything natural capable of receiving and using information gained throughexposure". [3]

AI is a technique that imposes human thinking and intellect into machine and computer systems in order to create intelligent systems that act and work like humans. Artificial intelligence (AI) is a technology that allows machines to mimic human intelligence. The notion of AI focuses around the following characteristics and is built on the usage of specifically constructed algorithms.

- Knowledge
- Problem Solving Learning
- Planning
- Reasoning
- Perception

There is no doubt that AI will have a massive impact on our day-to-day lives. In fact, its applications have already made an impact around the world, and technology will be integrated into practically every application and device in the near future. ALL of the world’s major corporations are heavily investing in AI research and development.

AI uses a number of methods, including as search and mathematical optimization, logic, probability-based methodologies, and economics, among others. The AI industry employs computer science, mathematics, psychology, linguistics, philosophy, neuroscience, artificial psychology, and other areas.

III. REINFORCEMENT LEARNING

Reinforcement learning is a subset of machine learning. It all comes down to taking the appropriate actions to maximise your return in every given situation. A variety of applications and computers utilise it to figure out the best possible action or course in a given situation. Reinforcement learning varies from supervised learning in that supervised learning includes an answer key, allowing the model to be trained with the correct response, whereas reinforce ment learning does not, and instead relies on the reinforcement agent to select what to do to complete the task. In the absence of a training dataset, it is forced to learn from its mistakes. Reinforcement scheme is shownin figure 1.2.[4]

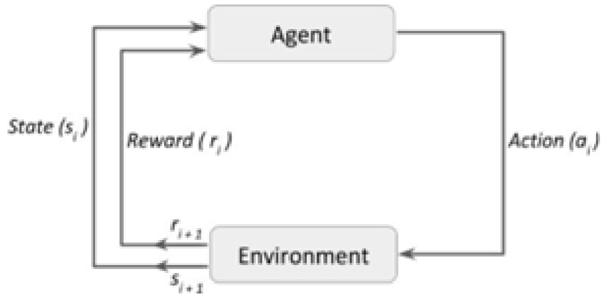

Figure 1.2: Reinforcement Scheme

IV. DEEP Q-LEARNING

The working agent might "refer to" an accurate matrix generated by the Q-Learning approach in order to maximise its long-term reward. Although this strategy is not inherently flawed, it is only practicable in relatively small settings and soon loses viability as the number of states and actions in the environment grows.

The answer to the previous dilemma derives from the knowledge that the values in the matrix only have relative relevance, that is, their importance is only relative to the other values. As a result of this reasoning, we use Deep Q-Learning, where deep neural network is used to approximate values. As long as the relative importance of the values is retained, this approximation of values is not harmful. Figure 1.3 shows the performance of learning algorithms [5].

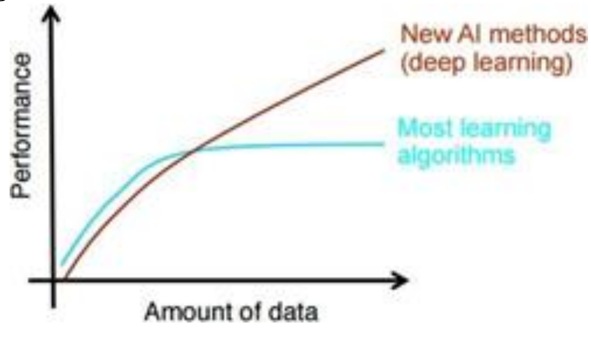

Figure 1.3: Algorithms Performance

Deep Q-main Learning’s working step is to feed the starting values into the neural network, which gives the Q-value of all possible actions as an output. Figure 1.4 shows the basic difference between Q-Learning and Deep Q-Learning [5]. When dealing with a complicated environment with multiple possibilities and outcomes, the Q-learning method soon becomes inefficient.

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Deep RL solves this problem by merging the Q-Learning approach with Deep Learning models. It mostly entails creating and training a neural network capable of evaluating the various Q-values for each action given a state.

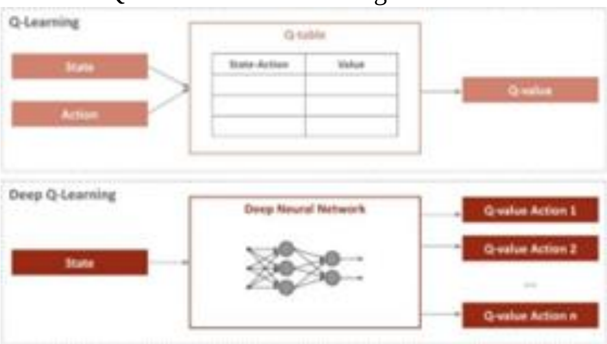

Figure 1. 4: Q-Learning and Deep Q-Learning

A. Formulation of the Problem

The basic goal of the optimal PMU placement problem is discover the smallest number of PMUs necessary, including their arrangement, in order to find total observability of the network. As a result, the OPP problem's objective function [6]can be expressed as follows:

$$min \sum_{i=1}^{D} N_{P_i}$$

$$\text{Subject to A.f(x)> b}$$

The number of buses in the system is denoted by D. Npi is the number of PMUs that need to be installed in order for the system to be observable. 'x' is a binary choice variable that has the following entries:

$$x_i = \begin{cases} 1, if\ a\ PMU\ is\ placed\ at\ bus\ i \\ 0, otherwise \end{cases}$$

'b' is an identity matrix with entries of 1 in the base case. Each bus is monitored by at least one PMU in this system. The b matrix is written as:

$$b = [111.....111]^T$$

'A' is a binary connectivity matrix. The entries of matrix 'A' are :

$$A_{i,j} = \begin{cases} 1, if i = j \\ 1, if\ bus\ i\ and\ j\ are\ connected \\ o, otherwise \end{cases}$$

PMU placement is written as [X], which is a binary decision variable vector that looks like this:

$$[X] = [x_1\, x_2\, x_3\, ...x_N]^T$$

$$x_i = \begin{cases} 1, if\ a\ PMU\ is\ placed\ at\ bus\ i \\ 0, otherwise \end{cases}$$

V. PROPOSED METHODOLOGY

We have chosen reinforcement learning in solving the problem because our problem is optimization and the way to achieve the optimization through machine learning is by reinforcement learning. In reinforcement learning there is q learning , where we generate the q table .In this learning we gives some action to the environment ,if the action is favorable to the system a reward is given .In our case the reward function is

$$min \sum_{i=1}^{D} N_{P_i}$$

$$\text{Subject to A.f(x)> b}$$

We tabulate action and its corresponding reward and try to estimate the quality of the action.Our main aim is to maximize the reward .We are doing this by deep Q learning . Here we have generated state table of 1000x9 , and it reward table of 1000x9 . We have also generated a Q table of 1000x9 which shows the quality of the actions. We have defined the quality with the help of our objective function i.e minimize the objective function. We will take the value which has maximum value of quality . Quality is more whose reward is more. Table 1.1shows the maximum quality and table 1.2 shows the position of the maximum quality with is action. Now we train our neural network by Neural Net Fitting Appin the MATLAB, according to the data we have generated. In neural network, States are the input to the NEURAL NETWORK INPUT: Features /States OUTPUT: Quality

VI. MAXIMUM QUALITY VALUES:

Table 1.1: Maximum Quality

BUS Number	Maximum Quality
1	0.0735
2	0.0372
3	0.0378
4	0.0174
5	0.0234
6	0.0117
7	0.0507
8	0.0198
9	0.0123

Table 1.2: Maximum Quality Position and Actions

BUS Number	Position in Q Table	Action
1	11	0
2	301	0
3	219	0
4	351	0
5	158	0
6	683	1
7	670	0
8	54	0
9	544	1

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The best solution for OPP or the best way to place the PMU in the system is Best Solution: POSITION: [0,0,0,0,0,1,0,0,1] This shows that for observability of the system at least 2 PMU are placed in the system at position 2,4 and the elapsed time for this is 8.942184 sec.

VII. RESULTS AND ANALYSIS

The proposed method will be applied to several IEEE bus systems. The suggested method's major goal is to locate the minimum number PMUs while maintaining total observability. The results obtained are shown below

Table 1.3: PMU location for observability using BPSO

Test System	PMU Location
IEEE 7 BUS	2, 5
IEEE 9 BUS	1, 4, 7
IEEE 14 BUS	2, 6, 8, 9
IEEE 24 BUS	2, 3, 7, 10, 16, 21, 23

Table 1.3 shows the results obtain from BPSO. It shows the location of PMU in several IEEE Bus systems. For observability of the system, a comparison is made by comparing the findings received from BPSO and AI. Table 1.4 shows the location of PMU placed in the several IEEE system number by using AI.

Table 1.4: Location of PMU for observability of the system usingAI

Test System	PMU Location
IEEE 7 BUS	2, 5
IEEE 9 BUS	6, 9
IEEE 14 BUS	3, 5, 13
IEEE 24 BUS	2, 6, 7, 11, 12, 15, 18

Table 1.5 shows the comparison of results obtain from BPSO and AI of number of PMU placed in the system . It is found that for the base case the number of PMU placed is less in AI when compared with number of PMU placed from BPSO.

Table 1.5: Number of PMU for observability of the system using BPSO and AI

Test System	Number of PMU- BPSO	Number of PMU - AI
IEEE 7 BUS	2	2
IEEE 9 BUS	3	2
IEEE 14 BUS	4	3
IEEE 24 BUS	7	7

At IEEE 7 bus system and at IEEE 24 bus system number of PMU are same for both BPSO and AI. At IEEE 9 bus system PMU placed by BPSO is 3 at location 1,4,7 , and the number of PMU placed by AI is 2 at location 3, 6 . Similarly, in IEEE 14 bus system the PMU placed by BPSO is 4 at location 2,6,8,9, and the number of PMU placed by AI is 3 at location 1,4,7. It is found that the number of PMU obtain from AI is less from the number of PMU obtain from BPSO for same number of iteration. In AI the number of PMU is less and also the location of PMU is also different from BPSO in some cases. Table 1.6 shows the comparison of time taken by BPSO and AI.

Table 1.6: Time taken by BPSO and AI

Test System	Time in sec - BPSO	Time in sec - AI
IEEE 7 BUS	187.649814 sec	8.702630 sec
IEEE 9 BUS	193.381607 sec	8.915299 sec
IEEE 14 BUS	215.716922 sec	9.459132 sec
IEEE 24 BUS	259.018240 sec	10.889092 sec

We have taken 3 different readings for both BPSO and AI and calculate the average of the readings. Table 1.7 shows 3 different readings of the time taken by BPSO and AI. It is found that the average of time, taken by AI is less then the average of time taken by BPSO. Table 1.8 shows the average time of BPSO and AI.

Table 1.7: 3 Readings of the time taken by BPSO and AI

Methods	IEEE Bus System			
	7 Bus	9 Bus	14 Bus	24 Bus
BPSO	154.807012 sec	160.694419 sec	205.626553 sec	252.014144 sec
	154.926332 sec	160.838029 sec	211.747393 sec	248.425634 sec
	155.631835 sec	159.8338 sec	213.142383 sec	248.507927 sec
AI	8.872570 sec	9.450407 sec	9.260421 sec	9.687121 sec
	8.915217 sec	8.885576 sec	8.885695 sec	9.526891 sec
	8.733375 sec	8.736029 sec	9.193070 sec	9.296002 sec

Table 1.8: Average of time taken by BPSO and AI

Test System	Average Time - BPSO	Average Time - AI
IEEE 7 BUS	155.121726 sec	8.84038 sec
IEEE 9 BUS	160.455416 sec	9.024004 sec
IEEE 14 BUS	210.172443 sec	9.113062 sec
IEEE 24 BUS	249.649235 sec	9.503338 sec

It is found that the time taken by AI is very less as compared with the time taken by BPSO for same number of iteration. AI is much faster than the BPSO. AI gives better result than BPSO in less time.

VIII. CONCLUSION

The results obtained from the proposed algorithm can solve the problem of optimal PMU placement in different case studies. The proposed algorithm has ability to find variety of PMU location sets for same number of PMUs. By comparing the outcomes, obtained from the AI and BPSO, it is found that, in some cases, the number of PMUs placed by AI is less than the number of PMUs placed by BPSO. Also by comparing the time taken by AI and BPSO, it is found that AI is more faster than BPSO and gives better results than BPSO. It is suggested that the proposed algorithm is considered as one of the great method of OPP problem which has high performance and efficiency in finding the minimum number of PMUs in the power system at different test system.

FUTURE SCOPE

1. It can be applied to other bus system also, like forIEEE 30 bus system, IEEE 50 bus system.
2. It can be applied for various practical situations,such as zero injection bus and single PMU failure.
3. It is also applied by considering weak busconstraints.

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