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POWER STABILITY MANAGEMENT FOR RENEWABLE ENERGY RESOURCES USING BIG DATA ANALYSIS

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Abstract. The power sector plays a major role in the world's economic growth. However, the high energy demand and depleting energy resources make the power sector operates in a stressed condition. In recent times, the power sectors are facing various challenges like power instability, high consumption rate, etc. In this article, a Honey Pot-based Recurrent Neural Network (HPbRNN) Big Data Analysis model was presented to predict the power instability in the grid system. Power stability determination is important in a grid system to maintain stable power flow and system operation. In the developed scheme, a huge amount of data is collected from the grid network to predict power stability. The application of big data in the grid network enables the process of this huge collected dataset by analyzing the dataset features. Initially, to make the prediction accurate and easy the dataset is splitted and pre-processed. Then the input and output attributes are tracked and extracted to predict the grid stability. In addition, to achieve the finest results the honey pot fitness solution is integrated into the optimization layer of the proposed model. Furthermore, the outcomes of the developed model are validated and the performance enhancement score is determined from the comparative analysis.

Key words: Big Data Analysis, Smart Grid System, Deep learning, Power Stability Management, Honey pot optimization

1. Introduction. The high energy demand across various industrial fields makes it unavoidable to resort to renewable energy resources [1]. Thus, in various fields renewable energy power plants are installed to offer high energy at affordable cost. Moreover, power generation from renewable energy sources makes the environment clean and reduces pollution levels across the world [2]. Renewable energy sources such as wind, hydro, and solar power offer high energy with fewer carbon emissions [3]. Hence, power stability management in grid systems is one of the challenging factors. The conventional grid energy storage system does not offer better stability [4]. Generally, the power generated is passed to four different systems namely, centralized systems, decentralized systems, distributed networks, and smart and connected systems [5]. Among these systems, the most recent system is a smart and connected network. It is also known as the "Energy Internet" [6]. This system is dependent on different technologies like the Internet of Things (IoT), cloud computing, mobile networks, and Big Data Analytics (BDA) [7]. Many researchers represented Energy Internet as an innovative energy management system, which combines distributed power stations, renewable energy sources, storage mechanisms, and electric vehicles with network technologies [8]. Moreover, they defined four different characteristics of the energy internet. The characteristics include Energy sharing, electrification of the transportation system, large-scale power generation and distribution, and renewable power generation [9]. In contrast with fuel-based power systems, renewable power stations require advanced technologies like power management, power balancing, and production capacity [10]. This advancement in power systems is attained by utilizing smart grids [11]. The smart grid system incorporates communication and information networks with conventional power grids to offer energy with enhanced reliability and efficiency with less cost and environmental impacts [12].

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Renewable energy sources are the main smart grid enablers in domestic transformers, and substations [13]. These energy sources can be installed quickly and can be controlled effectively during peak hours [14]. On the other hand, these resources must be monitored carefully to capture all possible means of energy generation [15]. For monitoring and controlling purposes, various IT tools and machines are deployed in power stations [16]. The IT machines include a geographic data system, power distribution management system, cyber-physical system, Supervisory Control and Data Acquisition System (SCADA) [17], and customer information technology [18]. These technologies are mainly used to capture the abnormalities in power stations during peak hours. The management of smart grids requires optimal efficient real-time data processing and analysis techniques [19]. This efficient data analytic tool helps in processing huge data captured from sensors, monitors, cameras, and computers to minimize latency [20]. This data processing is used in different applications like power demand management, anomalous detection, prediction process, and real-time vulnerability assessment. However, the management of this type of huge dataset through conventional techniques is difficult. Thus, "Big Data Analytics" is utilized in smart grids to monitor and process huge datasets effectively. The BDA is a computer science approach that is applied to process distinct huge datasets effectively.

The BDA approach is characterized by its four distinct factors namely, velocity, variety, veracity, and volume. The velocity factor indicates the demand for synchronized and fast processing of information. The variety represents the distinct type of dataset being used for processing. The volume indicates the ability to handle the huge dataset. Veracity deals with uncertainty in data processing and poor data quality. Recently, it is observed that BDA is used in different fields for managing and processing the huge dataset. In smart grids, it is applied to recognize the behavior of energy consumption, which helps in enhancing energy efficiency and promotes sustainability. Therefore, analyzing the stability of the complex grid system is important to achieve stable power management. Hence, various techniques like, a decision-making framework with BDA [21], Edge Computing-based IoT-based energy management framework [22], BDA integrated with smart city framework [23], etc., are implemented to obtain maximum stable smart grid system. However, they face challenges in data processing and analysis. Therefore, in the presented article a hybrid deep learning-based BDA was developed to achieve stable power management in smart grid systems.

The main contribution of the presented article is described as follows,

- Initially, the input dataset containing the grid features was gathered and imported into the MATLAB system.
- In the map reduction stage, the input dataset is splitted, and then it is pre-processed in the data wrangling stage.
- A hybrid HPbRNN model was developed in the system with optimal parameters to predict power stability.
- The honey pot fitness solution is integrated to enhance the speed of data processing, and prediction accuracy.
- Finally, the results of the developed scheme are validated with comparative analysis in terms of accuracy, error rate, and computational time.

The sequence of the article is described as follows, the recent works related to grid stability management are explained in section 2, the problems in the existing model are explained in section 3, the developed scheme was explained with the flowchart in section 4, the results of the proposed model is illustrated in section 5, and the conclusion of the article is mentioned in section 6.

2. Related Works. Some of the recent literature related to power stability management are described below,

The big data application in the power sector is considered the major component of the Energy Internet. However, the integration of smart grids with renewable energy sources is a challenging task. Hence, to address this issue Noha Mostafa et al [21] developed a decision-making framework with BDA. The presented framework involves five steps for predicting grid stability. The developed model utilizes a dataset from a decentralized smart grid, which consists of 60,000 illustrations and 12 features. Moreover, different machine learning schemes are used to analyze the grid stability. However, the amount of data deployed for the prediction process is relatively small.

Nowadays, smart grid systems are widely used in the industrial field because of their numerous advantages.

The IoT technology is utilized in a smart grid system to attain exquisite energy management by continuous prediction and monitoring processes. However, in IoT framework long-term energy management is one of the major issues. Thus, Chao Yang et al [22] presented Edge Computing-based IoT-based energy management framework with reinforcement learning to improve energy efficiency in smart cities. Finally, the effectiveness of the designed framework was analyzed. However, the system complexity is high in this model.

The IoT technology is being applied in smart cities for enhancing grid power stability, and efficiency. But the high demand for processing huge datasets is difficult in smart grid systems. Hence, Bhagya NathaliSilva et al [23] designed a BDA integrated with a smart city framework for increased power efficiency. Moreover, an authentic dataset was utilized to estimate the threshold values and gain in the data processing. In addition, a representational state transfer web of things was incorporated with a smart grid framework to reveal performance enhancement. But, the running time is more in this framework.

BDA is a dominant approach in a smart grid system, which includes a prediction of energy consumption, corruption in IoT solutions, and stable energy management. It is observed that the BDA played a significant role in the energy sector to maintain stable power management. Thus, VangelisMarinakis et al [24] presented a high-level framework of a big data platform, which supports the development, creation, exploitation, and maintenance of smart energy services by employing cross-domain data. This developed framework makes the procedure simple and reduces the system's complexity. Moreover, a web-based Decision Support System was designed based on this platform to exploit multi-sourced data within the smart city. However, this platform is a high expense.

The high demand for energy management in recent times sets attention on the proficient utilization of renewable resources without restraining power usage. To resolve this challenge, designing of intellectual system with precise forecasting, and day-ahead planning of power availability is mandatory. Hence, Prakash Pawar et al [25] planned an Intelligent Smart Energy Management Model to resolve the energy demand issue in smart cities. This model uses deep learning algorithms like the convolutional neural system to improve the working efficiency. Moreover, the developed system compares different prediction algorithms for precise forecasting of energy with day-ahead planning. On comparison, it is found that the SVM regression mechanism based on PSO optimization performed well in terms of prediction accuracy. However, the monitoring performance of this system is low.

Zhihan Lv et al [26] planned an IoT-based power management technology to facilitate large-scale IoT devices to analyze the huge dataset optimally with high efficiency, wide coverage of technical services, and low-energy wastage. This model analyzes the performance of the grid system in terms of latency, energy usage, and power wastage. In addition, BDA-based cellular narrowband IoT was used in the developed framework to analyze the large-scale IoT data optimally. Furthermore, the concept of node power utilization was deployed to improve the system's performance. The BDA utilized in this model is based on the 6th generation network (6G). This model outperformed in terms of access rate, and energy consumption. However, energy wastage is not minimized in this technique.

Gijsvan Leeuwen et al [27] suggested an energy management framework based on a blockchain approach. This designed model optimizes the energy flows in a microgrid using the bilateral trading scheme. In the microgrid, the physical conditions are controlled by employing an optimal power flow model. In addition, an alternative direction model of multipliers was deployed to empower a virtual aggregator, further reducing the need for a third party. Finally, the performance of the developed framework was evaluated in different scenarios and grid conditions. It is observed that the total energy parameters are decreased by 15%. Still, the presented model faces issues in energy management during peak hours.

Arfan Majeed et al [28] planned a smart additive manufacturing model by integrating the features of BDA, and additive manufacturing attributes. This model enables a reduction in resource usage, and energy usage in smart grids. Moreover, the application of big data with a smart additive manufacturing approach makes the system take proper decisions for sustainable energy management. Furthermore, this model helps to control and monitor the energy availability in the microgrid. Moreover, it reduces carbon emissions and provides a cleaner environment. The implementation results of this model show higher performance than other traditional schemes. However, the implementation cost of this model is high.

In smart grids, stochastic energy management plays a significant role owing to the large integration of

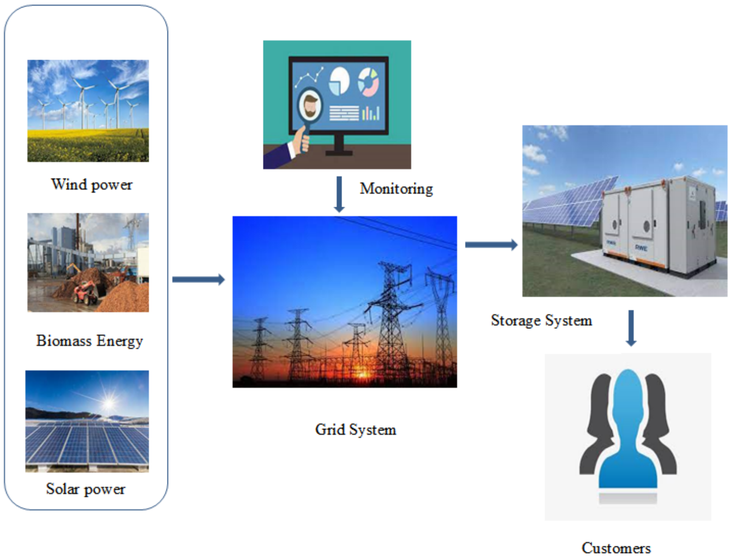

Fig. 3.1: System Model

discontinuous resources, photovoltaic systems, and wind turbines. Energy management in microgrids using traditional techniques is more complex. Therefore, Arezoo Hasankhani et al [29] presented a multi-stochastic power stability management model using the copula technique to efficiently minimize the energy resources, and cost in micro-grids. The application of this approach in the smart grid system reduces the cost of electricity. Finally, the efficiency of the proposed algorithm is verified by testing it with three sample microgrids. This model effectively decreases the electricity cost by reducing the size of the various components in the microgrids. However, this approach does not provide stable power consumption.

3. System Model with Problem Statement. In smart grid systems, it is important to predict the stability of the grid. Data analysis requires a huge amount of data that can be stored and processed promptly. The dataset consists of energy consumption rates, utilization patterns, financial information, maintenance reports, power production rate, etc. The traditional IT systems cannot process this massive dataset; hence they cannot predict/detect the energy demand/ stability in the grid system. Hence, the concept of big data analysis is being applied in a grid system to detect and monitor the energy demand, and energy consumption.

The energy demand in the future can be predicted using the BDA by analyzing the massive grid system dataset. Moreover, it helps to determine the energy availability and the grid's ability for power transmission. This reduces the time and increases the efficiency of the prediction process. However, the application of BDA alone cannot improve the efficiency of the system. It requires a decision-making algorithm to evaluate the energy demand and grid stability. Therefore, various machine learning and deep learning algorithms are introduced with BDA to support energy demand prediction in smart grids. But they do not provide optimal performance. Thus, to overcome the challenges faced by traditional detection schemes optimal power stability management was introduced in this article. The system model is illustrated in Fig 3.1.

4. HPbRNN Framework for Grid Stability Prediction. A hybrid Honey Pot-based Recurrent Neural Network model was developed in this article to predict the stability of the grid system. The proposed model integrates the attributes of the Honey Pot optimization algorithm [29], and recurrent neural network (RNN) [31]. This neural network-based prediction model helps in estimating the energy needed in the future. The developed scheme includes five steps: data initialization, map reduction, data wrangling, feature selection, and prediction analysis. Initially, the dataset was gathered and imported into the MATLAB system. Then the dataset is splitted into parts for further processing. In the data wrangling process, the errors in the dataset are removed.

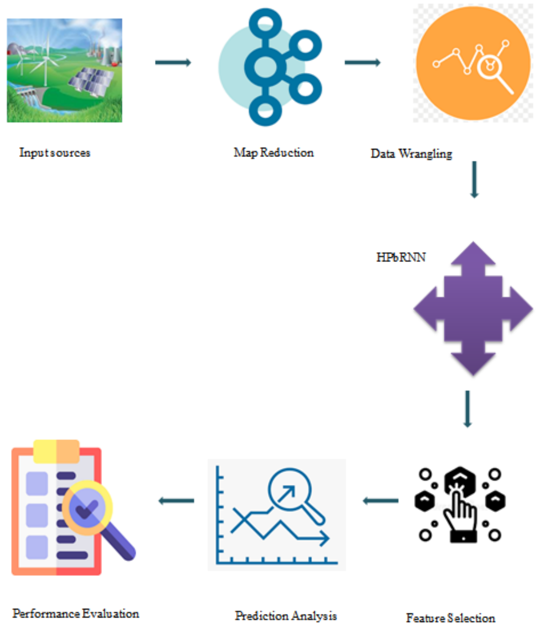

Fig. 4.1: HPbRNN Framework

These errorless dataset features are selected and analyzed using the HPbRNN model to predict the grid stability optimally. Finally, the performances of the presented model are estimated and validated by comparing them with the existing techniques. From the results, it is observed that the incorporation of a Honey pot fitness solution in BDA increases the prediction performance in smart grids. The framework of the proposed method is shown in Fig 2.

4.1. HPbRNN Layers. The proposed HPbRNN framework consists of five different layers namely: Input, Hidden, Pre-processing, Optimization, and Output. In the input layer, the data collected from renewable resources like wind, biomass, and solar power are initialized. The second layer is the hidden layer in which the collected dataset is splitted for further processing. In the pre-processing layer, the errors in the dataset are removed.

The fourth layer is the optimization layer in which the fitness solution of honey pot optimization is applied to predict the grid stability accurately. This fitness solution helps in providing the finest results in terms of accuracy. The final layer is the output layer in which the outcomes of the development are evaluated and compared with traditional schemes for validation purposes. The layer of the proposed HPbRNN was illustrated in Fig.4.2.

Data Initialization. Predicting the power stability through BDA requires a huge data for processing and analysis. Initially, these data are collected from the grid system and stored in the cloud storage for processing. The imported dataset are initialized in the MATLAB system to detect the power stability. The dataset initialization function is formulated in Eqn. 4.1.

$$F_{in}(G_D) = [Id_1, Id_2, Id_3, Id_4, \cdots, Id_k] \tag{4.1}$$

where F_{in} indicates the function for data initialization, G_D denotes the collected dataset, Id refers to the information/data present in the dataset, and n represents the total data count.

Map Reduction. Map reduction is the most important step in big data analysis. In this step, the huge dataset is splitted to reduce the processing time and system complexity. Here, the input dataset is divided into certain homogenous sections for processing. This increases the speed of data processing and makes data analysis easy.

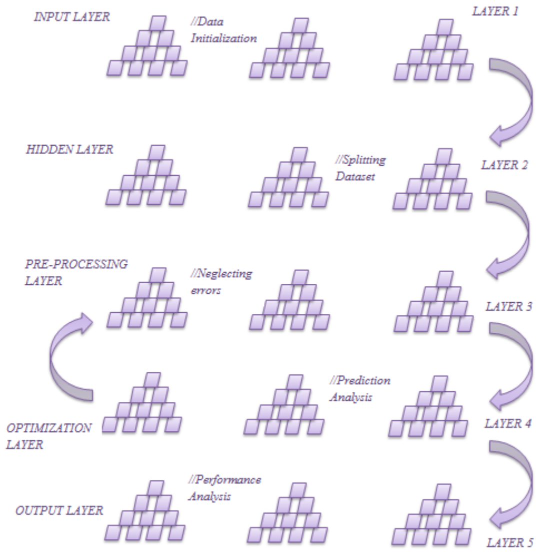

Fig. 4.2: HPbRNN Layers

Data Wrangling. The process of removal of errors from the input dataset is defined as Data wrangling. In this step, the errors, and null features are eliminated and then the complex datasets are combined to make the processing easier. The storing and organizing of huge data is important because of the availability of the huge amount of data and data sources recently.

Feature Selection. For predicting the stability of the grid system, it is important to choose the input and output features. Here, the RNN attributes are applied to select the input and output features. RNN is a type of artificial neural system that utilizes sequential data for processing. Generally, deep learning techniques are used for solving temporal problems such as speech attributes, image captioning, natural language processing, and language translation. Here, the RNN features are applied to select the input and output features. Initially, the system utilizes the data to train and learn about the input and output features of the grid system. The selection of input and output features are expressed in Eqn. (2).

$$F_S(G_D) = \lambda(Id_i.Ip_{i-1} + G_s.Op_{i-1}) \tag{4.2}$$

Here, F_S defines the feature selection, λ indicates the feature tracking variable, Id_i refers to the data, Ip_i denotes the input features, G_s represents the grid stability factor, and Op_i states the output features.

Prediction Analysis. The selected input and output features are used to predict and detect the power stability of the grid system. In the developed scheme, the honey pot optimal fitness is applied to predict the grid stability and energy demand accurately and precisely. Honey pot is a nature-inspired optimization technique, which is widely used in different applications because of its unique characteristics. The optimal fitness solution of honey pot optimization continuously monitors the dataset and predicts the grid stability and energy demand precisely. The honey pot fitness solution is represented in Eqn. 4.3.

$$P_R(G_s) = Hp_f + (o_v - i_v) \times P_c + Pa \tag{4.3}$$

where P_R denotes the stability prediction function, Hp_f indicates the honey pot fitness, o_v defines the optimal value, i_v represents the iterated value, P_C refers to the energy consumption rate, and Pa indicates the power availability. By considering the data features like energy consumption, and power availability rate, grid stability is predicted in this approach. The honey fitness solution helps in finding the optimal value in predicting the stability factor.

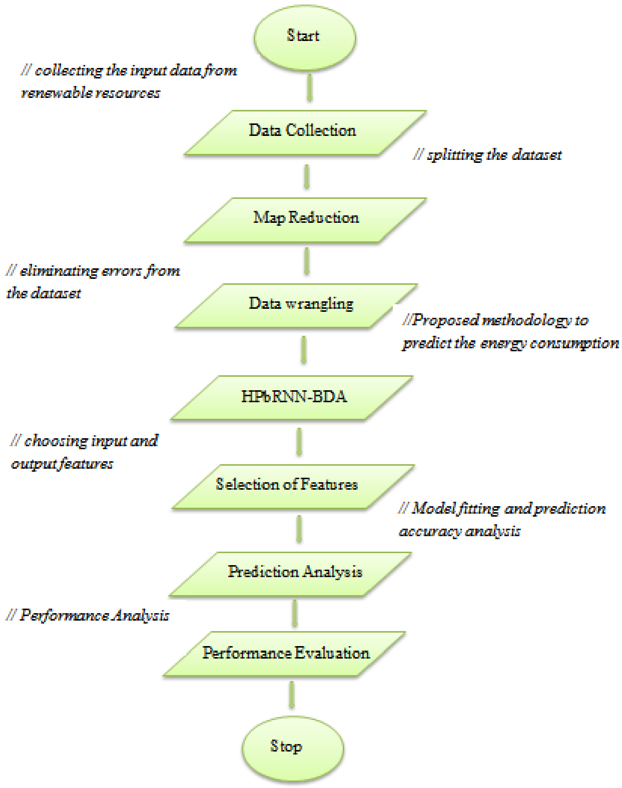

Fig. 4.3: HPbRNN Flowchart

The working process of the developed model is illustrated in Fig 4.3. In this framework, the dataset is initialized and pre-processed to remove the error data. Further, the input and output features are selected and analyzed to predict the grid stability accurately. The integration of RNN and honey pot fitness helps in reducing time consumption and increases prediction efficiency.

5. Result and Discussion. An Optimized Stability Prediction Framework Was Designed To Analyze And Detect The Energy Demand And Energy Availability In The Grid System. The Proposed Model Is Designed And Executed In Matlab Software, Operating In Windows 10. In The Developed Model, The Attributes Of Rnn And Honey Pot Optimization Are Combined To Enhance The Prediction Efficiency. Further, The Outcomes Of The Designed Model Are Evaluated And Verified By Comparing It With The Existing Decision-Making Machine Learning And Deep Learning Algorithms. In Addition, The Performance Improvement Score Is Also Determined From The Comparative Analysis.

Performance Analysis. In performance evaluation, the performance metrics such as accuracy, error, and time complexity are estimated by implementing the presented model in MATLAB software. Further, the performances of the developed framework are validated by comparing it with the existing techniques. The traditional techniques include the Random Tree algorithm (RFA) [32], Convolutional Neural Network (CNN) [33], Gradient Boosting algorithm (GBA) [34], and Decision Tree algorithm (DTA) [35].

Accuracy. Accuracy is the performance metric that represents the number of correct predictions concerning the total number of predictions. It is estimated by dividing the true positive and negative values by the true and false positive and negative. Accuracy calculation is formulated in Eqn. 5.1.

$$S_A = \frac{tr_p + tr_n}{tr_p + tr_n + fl_p + fl_n} \tag{5.1}$$

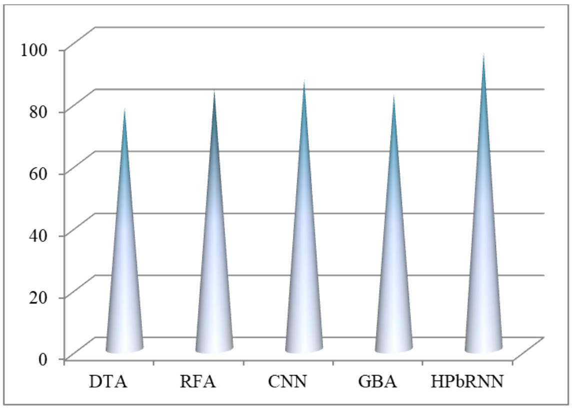

Fig. 5.1: Prediction Accuracy Analysis

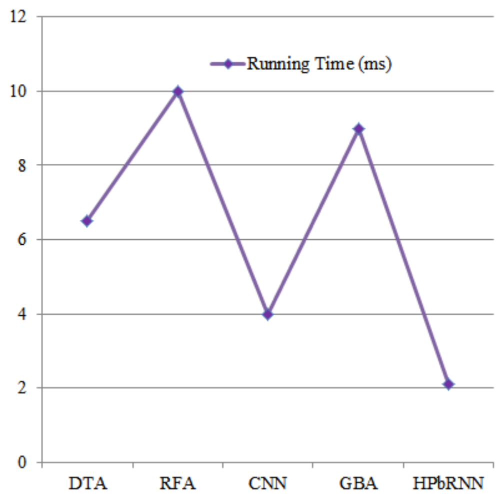

Fig. 5.2: Comparison of Running Time (ms)

where, S_A states the system accuracy, tr_p represents the true-positive, tr_n denotes true-negative, fl_p refers to the false-positive, and fl_n defines the false-negative.

To manifest that the developed scheme attained high accuracy, it is being compared with the existing algorithm's prediction accuracy. Here, the existing approaches like DTA, RFA, CNN, and GBA are applied for the collected dataset, and the grid stability prediction was established. Further, the accuracy of the prediction process was determined individually for comparative purposes. The accuracy achieved by the traditional machine and deep learning techniques like DTA, RFA, GBA, and CNN is 78%, 83.6%, 82.1%, and 87%, respectively. But the proposed approach earned higher accuracy of 96.3%. This shows that the developed scheme accurately predicts the stability of the grid system. Fig 5.1 displays the comparison of prediction accuracy.

Computational Time. Computational complexity represents the time taken by the proposed model to predict the grid stability. It highly depends on the number of resources for big data analysis. The integration of honey pot fitness in the RNN enables fast data processing and reduces the time complexity.

The comparison of the computational time of various techniques is illustrated in Fig 5.2. Here, the running

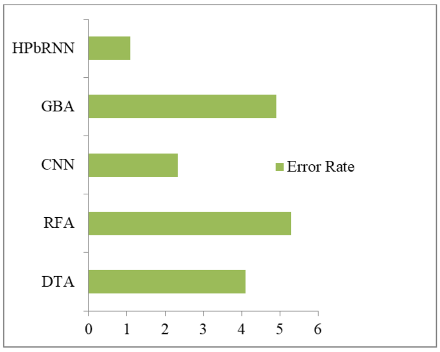

Fig. 5.3: Error Rate Comparison

Table 5.1: Comparative Analysis

Techniques	Accuracy (%)	Error Rate (%)	Computational Time (ms)
DTA	78	4.1	6.2
RFA	83.6	5.3	10
CNN	82	2.34	4
GBA	87	4.9	8.5
HPbRNN	96.3	1.06	2.1

time of various techniques is determined by implementing them in the MATLAB tool for the same dataset. The time taken by the existing algorithms like CNN, DTA, RFA, and GBA is 4ms, 6.2ms, 10ms, and 8.5ms, respectively. But the proposed model earned a less computational time of 2.1ms. This shows that the developed scheme increases the speed of data processing in BDA.

Error Rate. Error rate represents the ratio of incorrect prediction to the total number of predictions. It is calculated by dividing the false positive and negative values by the total positive and negative values. The error rate of the system is calculated from the Eqn. 5.2.

$$PEr = \frac{fl_p + fl_n}{tr_p + tr_n + fl_p + fl_n} \tag{5.2}$$

where PEr defines the prediction error rate of the system.

The error rate comparison is represented in Fig 5.3. The error rate is one of the important parameters which determine the system's performance. Hence, to validate that the presented technique earned less error rate, it is compared with the existing approaches. The error rate of the existing algorithms is estimated by executing them on the same platform. Traditional schemes like DTA, RFA, CNN, and GBA obtained high error rates of 4.1%, 5.3%, 2.34%, and 4.9%, respectively. But the presented hybrid technique earned less error rate of 1.06%.

5.1. Discussion. In this article, an optimized neural-based BDA model was designed to predict the grid stability accurately to maintain the stable power flow in the system. The developed scheme was implemented in MATLAB tool. Initially, the dataset containing the energy consumption, energy availability, etc., is pre-processed to eliminate the errors. Further, using the proposed scheme the input and output attributes are chosen and the power stability is predicted.

The honey pot fitness applied in the optimization layers helps in detecting the energy demand and power stability precisely. Finally, the estimated results like accuracy, error rate, and computational complexity are compared with traditional algorithms for validation purposes. The comparison performance of the developed scheme is tabulated in Table 5.1.

6. Conclusion. For a stable power flow, the grid stability management is important in the grid network. Hence, to predict the grid stability, an optimized neural-based BDA prediction algorithm was developed in this paper. This presented scheme deploys five steps: data collection, data splitting, pre-processing, feature selection, and stability prediction. The integration of recurrent neural systems and honey pot algorithm in BDA enables the speed of data processing with less error rate. Hence, the computational complexity, and the error rate are low in the developed scheme. Moreover, optimal honey pot fitness helps in predicting grid stability more accurately. Finally, the proposed model performances are validated by comparing them with machine learning and deep learning algorithms like DTA, CNN, GBA, and RFA. From the comparative assessment, it is noticed that in the developed model the accuracy is enhanced by 12.1%, the error rate is minimized by 1.9%, and computational time is reduced by 1.28ms. From the analysis, it is proved that the presented BDA model accurately detects the grid stability.

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