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Research on Improvement Calculation Method of Grid Power Losses Based on New Energy Access Model

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Abstract

This research presents an improved calculation method for grid power losses, particularly focusing on the challenges posed by new energy access models. With the integration of electric vehicles and the rise of data centers, the demand for electrical energy has surged, leading to increased strain on grid stations and subsequent power losses. The proposed model aimed at reducing these power losses, while also examining existing systems to mitigate and analyze such issues. A significant contribution of this work is the application of the Random Forest machine learning algorithm, which enables efficient and accurate power flow calculations essential for optimizing grid performance. The proposed method is expected to enhance the grid's ability to handle future energy demands and contribute to the sustainable development of electrical energy systems.

Keywords: distribution grid, random forest, AMDs, optimizaion model, power flow

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1. Introduction

Energy is the basic form of necessity where the most used form of energy is electrical energy that also define the economic development of a country, to transfer such energy efficiently to consumer, grid system comes into play where generated electric power from various sources utilized in the grid station which is then transferred to various smaller station and lastly to consumer, however with the increasing demand in the electric energy such as electric vehicles are on the verge tech industries are booming, same is autonomy where large data center consuming tremendous electricity to run databases for large languages model 24/7, demands electric power. Such high energy consumption put a huge burden on grid station thus intern leads to power losses since the grid arent yet designed for such power hungry systems, therefore in this research work we will propose a model to help reduce power losses and will discuss existings system to how to mitigate as well as analyze such issues to avoid and prepare the grid system for the future that yet to be faced. As the demand for the energy increases day by day photo voltaic cells are greatly in use but one drawback with that system is that it creates unbalance load thus intern create power losses and disrupt grid performance we have to take such system underconsidration to balance the load for the efficient power flow. Since investigating the power flow is the primary goal of this work to design and expand the power system in the foreseeable future. The power flow study gave us two major entity to work on that is phase angle of the voltage as well as the magnitude and the real and reactive power flowing in each line however admittance method can be utilizelized to solve the power flow problem as shown in the Figure below a denotes the active power, b denotes the reactive power on a typical bus.

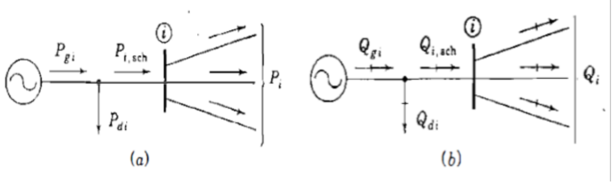

Figure 1. Line diagram of active(a) and reactive power(b) respectively

Now if the calculated power values matches with the scheduled power values for both real and reactive power then it should be contradicted that the difference in real and reactive power is zero at the bus i as shown by the following equations:

$g' = Pi, sch - Pi, calc = (Pgi - Pdi) - Pi, calc = 0$ ……………..1

$g'' = Qi, sch - Qi, calc = (Qgi - Qdi) - Qi, calc = 0$ ………………..2

How ever we have four unknown associated with each bus that is Pi,Qi, the angle of the voltage δ_{ij} adn teh magnitude of the voltage Vi, generally three buses are there in the power in the network that is Load buses, Voltage controlled buses, and slack buses to which these four quantities are δi, Vi, Ii, Pi and Q known and the remaining two are calculated.

However if we considered the above equation 1 and 2 to be mismatched for each of the N numbers of buses then we can letting i range from 1 to N and if the N number of equation are summed up altogether we get the term PL which is the real power loss in the transmission lines as well as in the transformers as shown by the folowing equation:

$P_L = \sum_{i=1}^{N} P_i = \sum_{i=1}^{N} P_{gi} - \sum_{i=1}^{N} P_{di}$

Here P_L is the total power loss, P_{gi}, is total generated power where as Pdi is the Total load.

Similarly the same can be shown in megavars for the reactive power that is the difference between megavars supplied by the generated at the busses and the vars received by the load as given by:

$\sum_{i=1}^{N} Q_i = \sum_{i=1}^{N} Q_{gi} - \sum_{i=1}^{N} Q_{di}$

It should be noted that the unschedudle bus-volatge angles and magnitude in the power flow analyzation are taken as input data and are called dependent variable or states variables. However for the ith number of buses since faster and efficient calcuateion are now possibnle thanks to multicore computers using method like gaus seidel and newton raphson canbeused in iteration until a minimum value is specified.

After the power flow analysis next problem in grid loss mostly happen due to stability problem since contemporary power systems are huge and heavily interconnected comprising of numerous machine that interact via medium of high and extra high voltage These machines have associated excitation systems and turbine-governing control systems which in some but not all cases are modeled in order to reflect properly correct dynamic performance of the system. Whilst in a steady state operation when sudden disruption occurs it should be noted that the system has gone under disturbance, it could be large or small depending upon the origin. Often large distrubances are due to trasnission system fault, sudden load changes or loss of generation unit to mitigate such problem the system should be tested in both steady as well as transiet state via an iterative model as discussed above with the help of multicore system for sake of the grid loss to work efficiency.

In one case study proposed by [1] explained that efficiency and small power consumption devices are the main aspect of design in all areas of engineers it is apparent from the study that all appliances efficiencies are denoted by the alphebtic letters where grade A being considers the most efficient one classical example is the usage of incandescent bulb vs CFL or LED bulb where incandescent being the least efficient among the two, it draws more energy have half the life and produce much heat due to the filament as compared to the led bulb which are much more efficient thus less load on the grid station intern less power loss. The graph below clearly explains the behaviour of the these bulbs.

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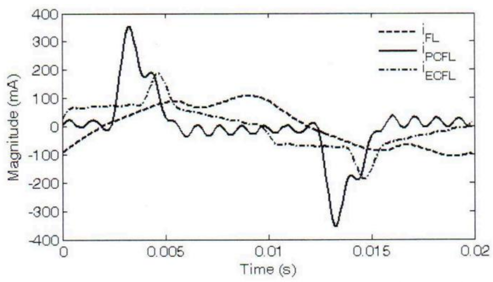

Figure 2. Different fluorescent lamp current waveforms: philips CFL (PCHL), EcoBubl CFL (ECFL), FL source [2]

That is Three distinct waveforms are visible, each corresponding to a specific type of lamp Philips CFL (PCHL), EcoBulb CFL (ECFL), and a generic fluorescent lamp (FL). These waveforms exhibit unique patterns of current fluctuation over time meaning that PCHL (Philips CFL) shown by the solid line waveform represents consistent current pattern with minimal fluctuations and ECFL (EcoBulb CFL): The dashed line waveform corresponds to an EcoBulb CFL. It exhibits more pronounced variations in current whereas FL (Generic Fluorescent Lamp) The dotted line waveform represents a generic fluorescent lamp. Its current waveform is irregular and less predictable.

These differences in waveforms highlight variations in the electrical behavior of these lamps. The specific characteristics of each lamp type impact their performance, efficiency, and reliability.

One way which was in great use is to consider all consumer load as linearly resistive where as for industries reactive load is also taken underconsideration where the difference then can be figured out from the lag lead graph of voltage and current but the drawback is that consumer may use appliances that are reactive in nature and put a burden on the system but since on line active power is considered such reactive power is being ignored so due to the change of the end user's load such method is not feasible for grid loss calculation as we have observed from the above graph that a small bulb can have large impact on grid and power losses. Yet it is proposed that harmonic load flow analysis can be used to to estimate the losses caused by the small non linear loads further the concept of distortion power can be utilized which is nothing but the difference between the apparent and active power which helps in power loss measurement furthemore the harmonic equivalent circuit can be applied to represent the grid and the load once the result is obtained

could then be implemented in smart meters thus helping in minimization of power losses in grid leading to efficient design of the system.

Energy Access Model for mitigating power losses in grid A Literature Review

According to Gerald T. Heydt there is no acceptable definition of the term electric power quality it geneally applies to the goodness of the supplied electric power the associated voltage regulation, voltage wave shape, current wave shape, impulses level, noise, frequency, and absency of the momentray outages. Heydt classified electrical power distrubance as steady state disturbance and transient state disturbance whereas the prior does more damage to the system then the later due to abrupt surge in electrical current that is the transient power qulality could cost in the range of milltion to 3 billion annualy following table 1 shows power quality problem for both steady and trasnietnt state whereas the transient problems are often termed as event whereas table 2 shows consideration of electrical power quality.

Type	Problem	Appearance	Causes
Transeint system Problem	Impulses(surges)	HV surges for shorter time, ranging in microseconds to a millisecond	Switching surges Lightning Inductive load rejection Fault in circuit breaker operation
	Instantaneous phase shift	Ac collapse that is phase angle changes by an angle φ	
	Sags ringing	Instant low voltages due to damped sinsusoidal voltages imposed on the AC wave	Faults Capicatior switching
Steady state system	Harmonics	Integral multiple frequencies having lower amplitude of ac votltages imposed on power frequency wave	Non linear loads Varying speed drives Inverters Fluorescent lamps Rectifier
	Voltage notches	Momentary low voltages of short duration due to commutated loads.	Adjustable speed drives
	Noise	Impressed on the power frequency	Static discharge, corona, and arc furnaces.
	Radio Frequency	High-frequency sinusoidal signals impressed on the power frequency (e.g., f > 500 kHz).	Radio transmitters
	Interharmonics and Fractional Harmonics	Components of noninteger multiples of the power frequency.	Cycloconverters, Kramer drives, and certain types of adjustable speed drives

Table 1. Power quality problem

Consideration	Focus	remarks
Region of analysis	Distribution systems and points of utilization of electric power.	The primary and secondary distribution system is the main region of analysis, where nonsinusoidal waves are more obvious and of high amplitude.
Types of problems	Instant outages and low voltages	There is a controversy regarding whether momentary low voltages (sags) or harmonics are more problematic in terms of cost.
Analysis methods	Circuit analysis programs, harmonic power flow studies, and focused studies on particular events using circuit theory (e.g., Pspice).	Various commercial software tools are available for both smaller and larger studies. Most methods are data-intensive and approximate
Mitigation techniques	Filters, capacitors, problematic loads, and higher pulse order systems (e.g., twelve-pulse instead of six-pulse).	In general, higher pulse order systems cause fewer problems than single-phase and six-pulse, three-phase systems.

Table 2. Electrical power quality consideration

Similary S.M. Halpin proposes that electric power quality has gained prominence due to the increased sensitivity of end-use equipment. The key areas of focus include grounding, voltage sags, harmonics, voltage flicker, and long-term monitoring. Voltage sags, primarily caused by system faults, and poor grounding practices are significant power quality issues affecting numerous utility customers. Voltage variations also cause concerns related to flicker. The Fourier series theory is applied to many periodic waveform variations, with the terms in the series, known as harmonics, potentially having frequencies above or below the fundamental power system frequency. These non-fundamental frequency equipment currents often produce voltages in the power delivery system at the same frequencies, causing voltage distortion that can disrupt the operation of end-use equipment. Accurate diagnosis of harmonics and other power quality problems requires substantial measured data, with monitoring, which can be short- or long-term, often constituting the majority of the work needed to develop power quality solutions.

Continuous line loss calculation model for distribution Generation

Jian T., et al. proposed a theoretical method for line loss calculation to figure out the source of statistical line loss abnormalities for efficient energy management. Statistical line loss is the difference between electricity supplied and sold. Whereas as theroicatical line loss is the real power loss while transmitting and distributing of the electtical energy however management line loss is related to loss in measuing error, management discrepancies, etc. [4] accoridng to the research done by Jiang T., et al. expressed that contemporary method for the calucatuion of theoritcal method like root mean square current method, power flow calculation and equivalent method [5-8] are not viable for comlex structure though rms method is simple to calculate but is more error prone that is the error could jump to 23 to 29 percent [9] similary power flow method have convergence problem because of the ambiguouis initial

value and that is due to large fluctuation in the voltage in distribution network consequently equailvalnet resistance method can be used for low to medium voltage distribtion network but it follow the same method as rms current method thus leads to same problem that calculation accuracy is lower and loss factor is not easy to calculate [10-12].
But the model proposed by Jiang T., et al. utilizes real time data from both dispatch side and DG side. By distributing supply power to each load node based on power flow calculations, having the instantenous

value of the power from first branch of teh node and DGs total input power is calculated. it aims to provide a more credible line loss value. Where as the calcuation methodology for Power flow for Disributed network with partial high density collection data have been done for medium voltage distribution network with automatic equipments, the atutomated equipments help in collectidng data since DN are structurally radial the data is scattered at many points for collecting information but technology advancemetn in equiopemnts and with proper automation data loss is almost negligible and collected data at DG end have high density characteristic sucha s real time voltage and current data which helps in articulating the calcualtion results for minimizaing power loss.

It works as to establish an automated power measuring system platform at all gates, ensuring "full coverage" and accurate data return. The system must encompass functions like statistical calculation, theoretical line loss calculation, and comprehensive management of various gateways and system parameters. It highlights the need for timely renewal of basic information following changes in grid equipment and operation modes. As desribed in the schematic diagram in Figure 3 it illustrates a 10 kV distribution network with Distributed Generation (DG) equipped with automated measuring devices (AMDs).

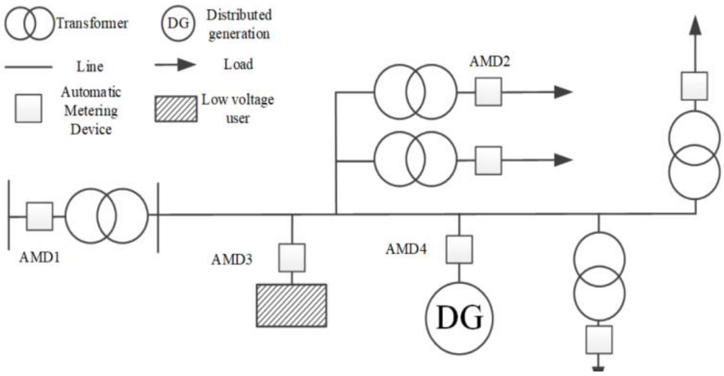

Figure 3. 10 kV distribution network with AMDs [4]

These AMDs are classified into four types based on their installation locations, each gathering specific measurement data related to voltage, current, power, and electricity.

Thus emphasizing the significance of data accuracy, especially in scenarios like the connection of distributed photovoltaic systems, where various parameters are measured and transmitted to the main station. Furthermore technical requirements for DG collection devices are outlined, specifying data upload intervals for telemetry and telematics.

Subsequently having focus on medium voltage distribution network data characteristics, it shows diverse data types, large data volumes, and inconsistent data collection density. Which distinguishes between high-density data, collected at shorter intervals for specific parameters, and low-density data, that includes power information collected at longer intervals.

Additionally,the challenges of traditional theoretical line loss calculations, which may lead to errors due to the significant volatility in load and distributed power supply output within a short period. Moreover Figure 4 illustrates the graphical comparison between actual load Fig 4.a and calculation load Fig 4. b.

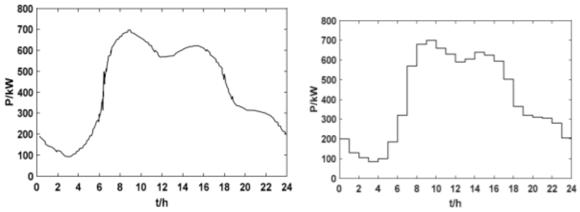

Figure 4. A. actual load b. Calculation load (active load profile [4])

it reveals a discernible difference between the calculated load and the actual load. When the actual load experiences significant fluctuations, this disparity becomes more pronounced. Consequently, the line loss calculation method based on the calculated load becomes less accurate under such dynamic conditions.

For nodes equipped with Distributed Generation (DG), the equivalent resistance method is employed.where DG is treated as a negative power load. Notably, only power information is utilized, disregarding any additional details such as fluctuation. Unfortunately, this method fails to account for the fluctuations in DG during the measurement period. As a result, it inadequately reflects the change in line loss rate caused by DG variability, leading to errors in the results.

But Distribution networks having DG accessibility, exhibit a mix of high-density data and low-density data.

Leveraging the collected high-density data effectively can significantly mitigate the error in theoretical line loss calculations arising from load fluctuations.
thus optimizing the utilization of high-density data holds the key to improving the accuracy of line loss calculations in distribution networks with DG access.

Combined Strategy for Distribution Network Power Loss Reduction Model

Xie J., et al. proposed a combined power loss reduction strategy optimization framework to improve the power loss reduction effect in a distribution networkand to enhance the optimization of a multiple loss redueation modification schemes as illustrated in Figure 5 [13] that define the structure of the proposed algorithm, which is divided into three main stages such as weak point analysis, generation of loss reduction strategy and cominbined loss reduction strategy.

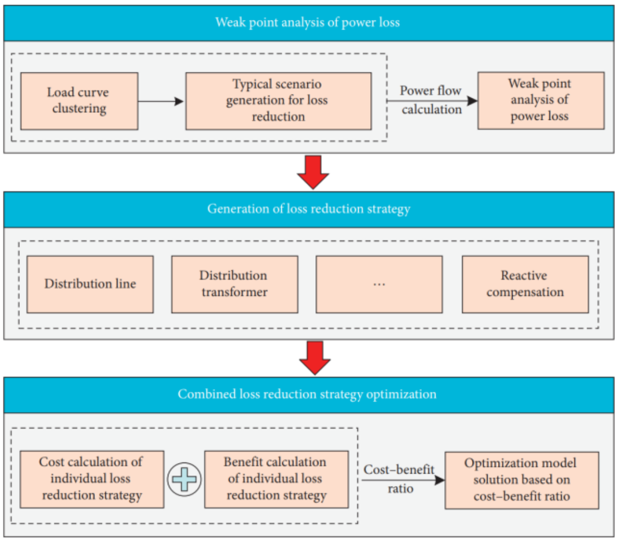

Figure 5. Combined loss reduction strategy optimization model[13]

As per the flow chart diagram, in the first stage, presumptuously distribution transformers have varying load, to make the situation align for to have the more stable result from loss reduction analysis, clustering algo. Is applied to have typical load curve for DTs(distribution transformer) to achieve a scenario for loss reduction. The calculated analysis from power flow calcuation for loss data help in the identification of the weak point of the power loss for the feeder, along with archaic branches, those bracneshes having sever power loss and DTs with low PF (power factor). Following the second stage in loss reduction strategy having the resutls from first stage, each point is analyzed to geenrate reduction strategies for every components associated in the system such as distribution line and transformers etc., in the final stage, Combined Loss Reduction Strategy Optimization, focuses on establishing a model to optimize an overall strategy for the entire distribution network. The algorithm introduces a unique method based on the cost-benefit ratio to enhance the efficiency of this optimization process. The ultimate goal is to develop a well-balanced and economically viable modification scheme for reducing power loss across the distribution network.
Xie J., et al. performed a case study with respect to the methodology, in the city of tianjin, China on a 10kv distribution network where the result was quite satisfactory and had effectively reduce the power loss and the cost of the feed as well as improvement were seen in the power factor of the feeder. The proposed method has also higher solution efficiency as compared to enumeration method.

Methdology

The increasing demand in electrical energy put a huge burden on the contemporary power grids system which have complex network that maintain the balance between generation, transmission and consumption, as the load is uneven random power losses occurs in the system thus making it uneconomcal to run it in the long term, different methodologies were discuss in the literature review to mitigate power loss problem but since the system is very complex thus leads to complex mathematical calculation since grids are constantly evolving ie renewable energy intergration and fluctuating demand such methods are not that efficient to re evaluate thus reaching their limits to avoid such problem we proposed a machine learning algorithim that helps run complex mathemcatical calculation for the optimze power flow. We will discuss machine learning model random forest with decision trees which is very effective if the data is uneven how ever deep leaning neural network can be used if their exist large even data but our focus will be here on the application of the random forest model to help mitigate loss and optimize grid performance.

Random Forest

Random Forests are a powerful machine learning technique that leverage decision trees for making predictions.
Conventionally, Random Forests rely on decision tree algorithms like ID3, ID4.5, and CART. While popular, ID3 can overfit data easily, and ID4.5's complexity makes it less efficient for large datasets. Here CART algorithm is proposed due to its effectiveness in calculating theoretical line loss, which is a crucial factor in a crucial factor line losses. As shown by the following equation it helps represent the optimum classify property.

$$\text{Gini\_ratio}(S,A_i) = \text{Gini}(S) - \sum_{v=1}^{V} \frac{|Sv|}{|S|} \text{Gini}(S_v)$$

$$\text{Gini}(S) = 1 - \sum_{k=1}^{C} p_k^2$$

A core aspect of CART which determines the optimal feature for splitting data within a decision tree involves the

Gini index Gini(S) of S, whereas (S,Ai) represent the change in gini index before and after S which is known as by the term Ai. furthermore C in the equations shows various data types in the datasets where as pk is the ratio of k samples.. The Gini index essentially measures how well a specific feature separates the data into distinct categories. However, the standard Gini index calculations encounter challenges when dealing with missing data. Directly applying these equations can lead to inaccurate results. Additionally, removing all samples with missing values can significantly reduce the available data, impacting the model's overall accuracy.
To address this issue , a slight modification to the CART algorithm is introduced. That is to assign weights to each data sample based on whether it has missing values in the feature being considered for splitting the data as shown by the following equation.

$$Gini\_ratio(S,A_i) = W_i * (Gini(S)) - \sum_{\square=1}^{\square} r^v \, Gini(S_i^v)$$

These weights are then incorporated into the Gini index calculations, enabling the algorithm to function effectively even when missing data is present. This modification ensures that the Random Forest algorithm can maintain its effectiveness even when faced with datasets containing missing information.
In essence, this improvement allows Random Forests to leverage the valuable information within datasets that might have previously been unusable due to missing values. This advancement can lead to more robust and accurate models in various applications.

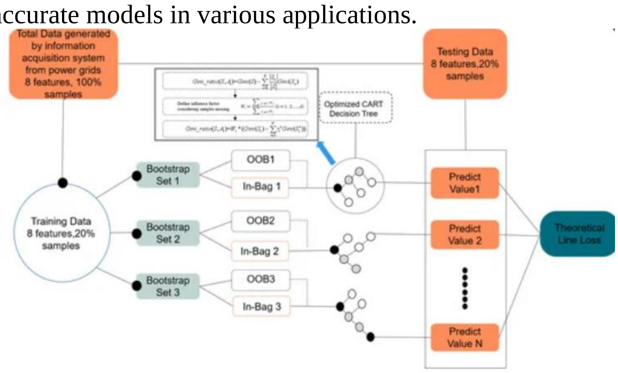

Figure 6. Flow chart diagram of random forest decision tree model

Deploying Random Forest Model

To deploy and evaluate the model we start with by feeding the training samples into the algorithm. During this process, the model parameters are trained, which includes determining the number of leaf nodes and the number of decision trees and to assess the accuracy of the model, we turn to the Root Mean Square Error (RMSE). This metric quantifies the difference between predicted values and actual values. Here's how it works:
Residual Sum of Squares (RSS):
Calculate the squared difference between each predicted value and its corresponding actual value.
Sum up these squared differences across all data points.
Mean Squared Error (MSE):
Divide the RSS by the total number of data points (samples).
This gives us the average squared error.
RMSE:
Take the square root of the MSE.
The RMSE represents the typical error between predicted and actual values.
Smaller RMSE values indicate better accuracy.
Mathematically, it is represented as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (yi - \hat{y}i)^2}$$

where:
(n) is the number of test samples.
(yi) represents the actual value for the (i)-th sample.
(yi^) represents the predicted value for the (i)-th sample.
thus RMSE serves as a valuable measure to gauge how well our model performs in predicting outcomes, especially when dealing with continuous variables.

Data Cleaning

In this research work , we focus on line loss calculation for 23,754 low-voltage grids within a specific area. Where data was collected based on charactereistics factor which are calculated on daily routine resulting in 166,283 sample records accumulated over 7 continuous days. Each

sample record represents the derived results of these characteristic factors. In data cleaning and division once data is collected we perform thorough cleaning to address abnormalities caused by data collection issues and varying data quality. Notably, some low-voltage grids lack information on factors like power supply radius and low voltage line length due to differences in documentation management levels across grids. To ensure consistency, we establish a reasonable range for various characteristic factors based on electrical characteristic calculation principles and low-voltage grid design regulations.
Abnormal sample data falling outside this range are removed during the cleaning process as shown in the table 3.

Table 3. Cleaning methodology of characteristics factor

Characteristic Factors	Cleaning methodology
Radius of power supply X_1	200,800
Torque of the power supply	0, 16000
Line total length X_2	500, 10,000
User numbers X_3	50, 500
Load rate X_4	5,60
Three phase unbalace degree X_5	0,200
Load shape Factor X_6	0,20
Power factor X_7	0.8, 1

After data cleaning 80 percent of the data were utilized to train the model and the remaning 20 percent were used to check model accuracy, after testing phase in model evaluation the accuarace of the model were assesed using the root mean square error using test sample data the RMSE measures the typical error between predicted and actual values, providing insight into the model's performance.
In summary, our approach involves rigorous data cleaning, thoughtful handling of missing factors, to enhance the accuracy of line loss calculations.

Analysis of the model

As illustrated in the figure 7 When the clean data is fed to the algorithim where leaf node and decision trees were confiugred to 5 and 75 respectively we get the rmse as 1.26to 5 wehere as preprocessing cleaning rate of the date was 46.4 percent.

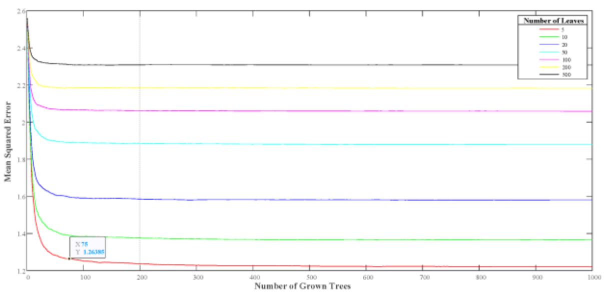

Figure 7. Parameter Selection

After examining the values of the test samples both calculated and observed as shown by figure 8

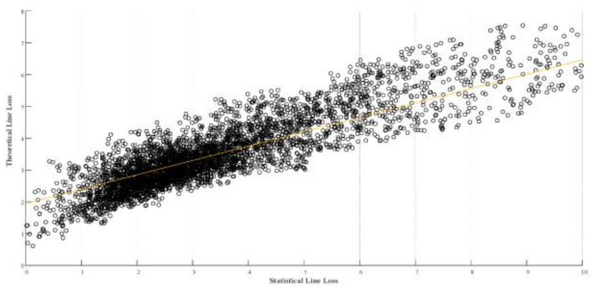

Figure 8. Random forest calculated result

Notably, here exists a linear correlation between the model's calculated values and the actual observed values. The correlation coefficient is 0.6733.
Excellent linear correlation features are observed in both the high distribution density range ([1, 5]) and the low distribution density range ([5, 8]).
Our model's prediction performance meets the accuracy requirements for theoretical line loss estimation in low-voltage grids.
This enhanced random forest model demonstrates promising accuracy, validating its suitability for practical line loss predictions.

Result

As explained in the methodology and deploying of the algorithm it is obvious that the model predicted the result with great accuracy when abnormal samples were filtered out along with reasonable ranges for various electrical characteristics based on grid definition and calculation principles after that model was trained on different test data and result was compared for which data having cleaning rate of around 95.5 % resulted in accuracy error of 1.329 which was compared with data with cleaning rate of 46.5 % having accuracy error of 1.739 however when the model was slightly modified for missing characteristics factors improved the accuracy for 46.5 % to 1.2161 thus the correlation between the model's calculated values and observed values reaches 0.6711 when using the improved random forest algorithm at a lower sample cleaning rate.This outperforms the other two situations with correlation coefficients of 0.4522 and 0.4366. So by using the modified random forest algorithm, we can preserve more characteristic samples even when dealing with missing data. This preservation leads to better accuracy during model training and calculation.
Overall, the proposed method proves effective for calculating and analyzing line losses and helps improve the performance of the grid system

Conclusion

The proposed method accurately calculates line loss even when dealing with missing samples due to varying basic data management practices across different areas. However Future work should focus on optimizing algorithm parameters to address other data-related challenges encountered in practical applications. This will further enhance the accuracy of line loss estimation and guide effective loss reduction efforts.

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