Neural Network–Based Multi-Feature Disturbance Analysis for Power Line Installation in Renewable Energy Systems

Jianjun Lan[1], Guo Li[1,] Dan Yang[2], Chunjiang Li[3], Xiaochuan Wei[3*]
[1]State Grid Sichuan Electric Power Company, Chengdu, 610041, Sichuan, China
[2]State Grid Sichuan Economic Research Institute, Chengdu, 610041, Sichuan, China
[3]Unis Software System Co., Ltd, Beijing, 100089, China
E-mail: 3396574599@qq.com, 275514069@qq.com, 297322343@qq.com, 15712810213@163.com, XiaochuanWei326@outlook.com
*Corresponding author

Keywords: Power line communication, off-grid, microgrid, ecosystem disruption, disturbance control

Received: January 21, 2026

Power line communication and installation in renewable energy–based off-grid and microgrid systems are highly sensitive to electrical disturbances, environmental variability, and appliance-induced non-stationary noise. This paper proposes an RBF neural network–based multi-feature disturbance analysis framework for power line installation assessment. The model integrates power, voltage, frequency, and environmental (P–V–F–E) features into a unified learning architecture to predict disturbance severity and transmission power losses. MATLAB-based simulations were conducted for rural, urban, and industrial environments under seasonal and appliance-induced noise conditions. Compared with traditional and static assessment methods, the proposed model achieved up to 74% reduction in power losses and improved voltage stability under high-disturbance scenarios. The results demonstrate that multi-feature neural learning enables robust disturbance characterization and provides actionable decision support for disturbance-aware power line planning in renewable energy systems.

Povzetek: Predlagani model z RBF-nevronsko mrežo združuje električne in okoljske značilnosti za zanesljivejšo oceno motenj ter zmanjšanje izgub v obnovljivih off-grid in mikroomrežnih sistemih.

1 Introduction

Technological development and economic progress have a direct correlation to an economy's ability to generate, transmit, and distribute energy. Multiple transmission lines will continue to be constructed and expanded throughout Brazil. As these projects go forward through forested and reserve regions, they often encounter environmental concerns [1]. An extension of extra-high-voltage underground transmission lines on a huge scale is being caused by the present energy system transition. When assessing the environment, it is crucial to understand the effect on soil moisture dynamics and soil temperature [2]. Neurobiological impacts may be caused by the static electric field emanating from ultra-high-voltage direct-current transmission networks. Protein expression levels while morphological features in the hippocampus of SEF-exposed mice were examined to evaluate these effects and to clarify their possible causes [3].

The extension of the power grid cannot be prevented. There is a growing need to connect renewable energy sources to the local grid, which necessitates the construction of additional transmission lines. The expansion of the distribution network is another consequence of electrification-induced increases in power consumption. On the other hand, local biodiversity will be impacted by the continued building of electricity lines [4]. Electric field environmental concerns associated with the long-distance transmission lines of ultra-high voltage direct current have long attracted the public's attention. Typically, prior to the publication of national standard GB39220-2020, the undistorted total electric field (presuming the absence of the residential building) at the site of the building must not surpass 15kV/m. The newly-issued standard requires that electric fields on building platforms and balconies be below the limit for the first time, and that building effects be taken into account [5].

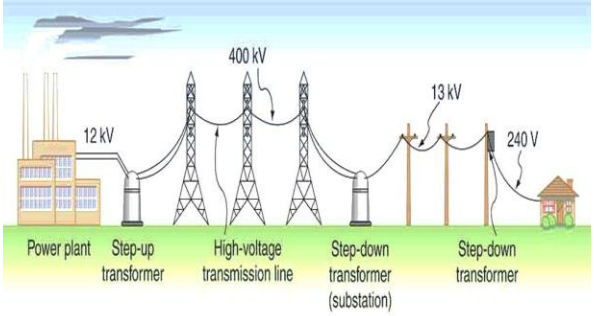


Figure 1: Power line installation

When it comes to water transmission systems, the use of an accurate leak detection device for pipes is vital. To avoid wasting energy and lessen our influence on the environment, these solutions should take the leak detection procedure's duration and accuracy into account. Modern cooling systems and oil well injection to increase oil recovery both make use of saltwater transmission lines. The increased environmental hazards posed by saltwater need a leak detection system with sufficient speed and accuracy [6]. Every day, the power demand of every substation and switchyard rises in tandem with the advancements in surface engineering for worldwide oil fields. In addition to meeting the adequate power demand, the manufacturing department has increasingly stringent technical and commercial demands on the power supply, which must be reliable and safe for the transmission lines. The design of transmission lines is crucial to the reliability of the power grid, which is the lifeblood of oil field power systems. The system's dependability is significantly affected by inherent design safety, ambient meteorological conditions, and damage caused by humans [7]. Additional power transmission lines are being laid every year to keep up with the ever-increasing demand for energy as a consequence of the world's ever-increasing annual energy consumption. Birds have been the primary subject of research on the effects of electricity transmission lines on biodiversity, with very little data available for other species [8].

Improving power networks' transmission capacity has become an urgent issue due to the ever-increasing demand for energy. The use of dynamic capacity growth technology provides a workable answer; it increases transmission ampacity without changing the current system architecture and guarantees grid safety [9]. There may be limitations on the transfer of electricity as load as well as generators is linked to the power grid. The term "voltage uprating" refers to the practice of increasing the transfer capacity of an existing transmission line by increasing its operational voltage. Compared to constructing new lines, this method may alleviate power transmission limitations more quickly, with less environmental damage, and at a lower cost [10]. Strong winds with ice cover are examples of external environmental conditions that might impair transmission lines. Wind deflection causes transmission line disruptions that have been happening more often in recent years, which is a direct result of the rise in the frequency of severe weather occurrences. Regular industrial and household operations have been interrupted, and substantial financial losses have been incurred as a consequence of these accidents [11].

As people become more conscious of the need to protect the environment, they are paying more attention to the harm that high- and extra-high-voltage power lines do. To mitigate this effect, particularly in the electric field of the power frequency, certain regulations have been passed and measures implemented [12]. Important to the operation of the electricity grid, transmission lines are exposed to a wide range of weather conditions, including wind, heat, humidity, and pollution. Although these factors have a constant effect on the transmission lines, unforeseen severe winds, wildfires, and ice may cause devastating damage and compromise the transmission lines' dependability. When combined with initial damage with electrical loads, these variables have a significant impact on the material attributes [13].

Building disturbance management and limiting ecological damage during the power line construction are not addressed in the article. Rather, it focuses in on smart grid power quality disturbances, how such disturbances influence grid performance, and how to design mitigation techniques to make networks more resilient. This research focuses on equipment damage and power loss rather than environmental problems associated to construction by using MATLAB-Simulink simulations to assess these disruptions and their cascade impacts. Here are the key contributions outlined in the research:

- **Identification of power disturbances:** The study provides a comprehensive inventory of power disturbances, including voltage sags, expands, and fluctuations, and how they might impact smart grids. The unique difficulties of smart grid stability and dependability may be better understood with this categorization.
- **Impact analysis:** This study analyses the effects of these disruptions on the grid's performance in detail using extensive MATLAB-Simulink simulations. Important operational challenges, such as malfunctioning equipment and interruptions in power, may be caused by disturbances, and this work shows how these impacts can snowball.
- **Insights into mitigation strategies:** The research highlights the importance of implementing appropriate mitigation techniques and provides significant insights into the impacts caused by electrical interruptions. Developing ways to enhance grid resilience is vital for contemporary energy systems, and this article helps provide light on the nature and consequences of these disruptions.

- **Methodological Framework:** To thoroughly investigate power outages and their consequences, MATLAB-Simulink simulations are used as a methodology. In addition to confirming the results, this method also promotes the use of modeling tools for assessing complicated systems, which will be useful for future studies in the area.

In conclusion, this study makes substantial advances to our knowledge of smart grid power disruptions and paves the road for more resilient grids by better identification and management of such events.

1.1 Research objectives

The objective of this study is to develop a neural network–based multi-feature framework for assessing power line disturbance behavior in renewable energy systems. The study aims to evaluate how power, voltage, frequency, and environmental factors jointly influence disturbance severity and power losses.

1.2 Research questions

This work addresses the following questions:

• How do multi-domain features influence power line disturbances?

• Can a neural network generalize under appliance-induced non-stationary noise?

• How can disturbance assessment support power line planning and operation?

2 Related work

The goal of the evaluation in [14] was to determine the environmental effects of power transmission lines in the Southeast area and to identify ways to lessen such effects. A Framework Based on Theory: In order to ensure that every person in the nation has access to power, it is essential to distribute power throughout the various areas. A vast electrical transmission network is required to meet the high electricity demand in Brazil's southeastern area. The installation of power transmission lines, however, has the potential to drastically alter natural habitats. Six EIRs and two EISs for the Southeast area were the basis for the environmental effects gathered throughout the power transmission lines' design, construction, and operation stages. They also looked at ways to lessen the blow of these research and publications. The design, construction, and operation of power transmission lines were found to have six, fifty-three, and forty environmental consequences, respectively.

In order to better understand the problem and maybe eradicate or significantly reduce the environmental damages produced by transmission line deployment in forest regions, researchers of [15] set out to explore these consequences. The majority of the environmental damages, according to the data collected, are caused by the clearing of trees in the right of way (or corridor) surrounding the transmission lines, which changes the flora. Micropiles, the most common form of foundation, employ a poisonous stabilizing mud during drilling, which has additional negative effects. To lessen the likelihood of environmental harm and building delays, that study's findings may serve as a foundation for future mitigation efforts.

The effects on soil moisture and temperature dynamics of an existing underground cable operating continuously at 330 kV were studied by the authors of [16]. At four research locations in Western Germany, a program for soil monitoring was set up. Soil sensors continually gathered data for one year at a depth of 130 cm. The soil around the cable route warmed to a temperature of 0.6 K on topsoil, about 1-1.4 K in the rooting zone, as well as 1.7 K in the subsoil at 140 cm depth. The effect on soil moisture dynamics, compared to the control, ranged from -1.00 wt.% in the 0-70 cm depth to -2.65 wt.% in the subsoil. Soil warming may be modest at a designed highest load capacity of 100% in normal operation, having 1.7 K in the topsoil, 2.3-3.5 K in the rooting zone, and 4.6 K in the subsoil. It is estimated that the operating cable load (average: 75%), heat loss (approx. 12 W m^{-1} per cable), along with the quality of the integrating material for the cables are the causes for the low to moderate effect of the UTL.

To measure the effects of power line collisions and electrocution on bird richness in LCA, the authors of [17] created the first technique. By using species-area correlations, power line and pylon locations, species-specific traits, and high-resolution maps of species distribution, they were able to determine the possibly vanished proportion of species. Their models were implemented in Norway, a nation with the goal of becoming a low-emission nation by the year 2050. Electrocution had characterization values ranging from 3.57×10^{-18} to 1.76×10^{-76} PDF*yr/kWh, whereas collision had characterization factors ranging from 8.48×10^{-17} to 5.8×10^{-18} PDF*yr/kWh. Harmonized models can assess the consequences of energy generation alongside the implications of electricity distribution, making it vital to include power lines' effects on biodiversity in LCA. As a result, they are making progress toward their goal of encouraging a comprehensive evaluation of energy systems.

The impact of power line electromagnetic waves on soil characteristics is the focus of the authors of [18]. Awareness of the need to comprehend the environmental impacts of electromagnetic fields has grown in tandem with the growth in electrical power infrastructure and the proliferation of electrical power use. In order to evaluate the impact of electromagnetic waves on soil characteristics, that article gives a synopsis of the present research methodologies. The key findings from studies on that area are reviewed, and both field and laboratory methods of investigating that subject are taken into account. The development of successful methods for land use management and the maintenance of ecological sustainability in the face of current human influences depend on their capacity to understand these linkages.

Selecting a leak detection device for a saltwater transmission line is the task of the experimenters in [19]. To begin, several leak detection systems' parameters are given. In conclusion, the fiber optic system is the best option for the project given the circumstances. High precision, quick leak detection, and the ability to monitor additional parameters live (e.g., temperature distribution, incursion detection into buried line sections) are the main features of that system. Enhancing safety and optimizing operational expenses are outcomes of these talents.

The possible impact of electricity transmission lines on bat populations in a specific area of Brazil's Cerrado habitat was evaluated by the authors of [20]. In particular, they acoustically sampled bats both close to and distant behind the transmission lines using a paired sample scheme. Insectivorous bat populations in the study region were not significantly affected by electricity transmission lines, according to their results. But certain bat species and families' activity patterns have changed, and there appears to be more variety in some functional categories when they're around. They consider that data to be very important for a number of reasons, including but not limited to: developing projects at various phases of construction, constructing suitable programs during environmental licensing, and monitoring programs while they are in operation.

The ampacity of transmission lines was first estimated by the researchers in [21] using a model derived from the thermal balance equations under electromagnetic loss excitation. Afterwards, electromagnetic thermal simulation is used to examine the effect of complicated environmental conditions on current carrying capacity. Lastly, a method for optimizing transmission line ampacity is suggested, which makes use of real-time sensor data. In the dynamic energy market, that holistic view is crucial for ensuring the efficient and secure running of transmission lines.

To find out how power lines affect wheat output, the authors of [22] used GIS technology to generate digital maps of irrigated soils, soil survey databases, and agrochemical property databases for fields in the Fergana region's protected zones of linear objects. Methods: Geographical, statistical, typological, system-structural, and cartographic methodologies as well as natural-economic and comparative-geographical zoning are used in the paper. They use cutting-edge GIS tools like ArcGIS 10.3(2) with SAS Planet 1.3 as its foundation. The IRRISTAT application was used for mathematical and statistical processing of the study findings. The results show that digital attribute bonus maps were created and irrigated soils of farms beneath power lines were assessed using the new updated approach. They have produced suggestions based on science to improve soil qualities and make optimal use of land resources. In essence: The impact of high-voltage electrical systems on soil electromagnetic field characteristics and protective limitations was established using study findings derived from GIS technologies, ArcGIS applications, and the principles of direct genetic soil science.

A transmission line-hanging insulators string system simulation was established using the ANSYS Workbench 2020 R2 finite element evaluation platform, according to the authors of [23]. For transmission line calculations, they varied stall spacing, height difference, wind speed, and wind attack angle. By studying how these various variables affect insulators' wind deflection, they were able to derive patterns that illustrate the variations in wind deflection angle as a function of stall spacing, height variations, wind speed, and wind attack angle. An early warning approach to wind deflection of transmission lines was developed, a model for that purpose was created, and its practical effects were assessed using data from meteorological predictions. The model was based on the particle swarm enhanced support vector machine algorithm and the generalized linear regression network. Critical information for designing and developing transmission networks with ultra-high voltage with extra-high voltage is provided by that study's results. They can also help with more sophisticated wind deflection problem identification.

The authors of [24] put forward a strategy for environmental cognition that would work on a single-board computer focused on graphics processing units. Taking into account the weight of a cognition systems as a tradeoff between flight duration, mapping efficiency, along with loss of environmental cognition skills, they build a lightweight system for real-time mapping using an unmanned aerial vehicle. While heavy systems provide strong computational performance, they quickly drain battery power and affect the flying envelope. By taking use of GPU parallelism and reducing data transmission between the embedded CPU and GPU, the suggested solution improves the performance of real-time mapping. In particular, the voxelized point cloud data obtained from light detection with ranging is converted into global coordinates. A probabilistic method is used to update the voxel occupancies in order to remove dynamic noise. Field test results show that the suggested technique successfully generated and revised the voxel mapping in real time and no losses.

In order to narrow the electric field effect zones, the authors of [25] looked at how power line design factors and conductor distribution may be altered. In order to determine the electric field and audible noise in the power line environment, that study was carried out using models that had been constructed and tested experimentally. The computational simulations were used to examine the noise levels at the boundaries of the 400 kV lines' electric field effect zones and their widths. Here, 400 kV power lines, both single and double circuit, were the center of attention. It was shown that when electric field emissions are reduced, noise emissions are increased. Nevertheless, the results of the analysis show that by carefully choosing the most crucial line design and construction factors, the electric field effect zones may be narrowed down considerably. In addition to being applicable to 400 kV lines, the results also provide guidelines for adjusting the settings of high voltage transmission lines with rated voltages higher than 100 kV. Environmental studies [14–16] are referenced to motivate the need for disturbance-aware planning; however, this work focuses on technical performance modeling rather than ecological impact assessment. The comparison table for the environmental, technical, and operational effects of power transmission lines can be seen in Table 1 (a). Table 1 (b) shows the unified comparison: power–voltage–frequency–environment (p–v–f–e) perspective.

Table 1 (a): Comparison table: environmental, technical, and operational impacts of power transmission lines

Ref.	**Study Focus**	**Study Area / Context**	**Methodology**	**Key Findings**	**Major Limitations / Gaps**
[14]	Environmental impacts of transmission lines	Southeast Brazil	Analysis of 6 EIRs & 2 EISs	Identified 6 (design), 53 (construction), and 40 (operation) environmental impacts	Lacks quantitative mitigation prioritization
[15]	Forest ecosystem degradation	Forest regions	Field data + impact analysis	Tree clearing and micropile mud cause major ecological damage	No optimization-based mitigation framework
[16]	Soil temperature & moisture	Western Germany	Long-term soil sensor monitoring	Soil warming up to 4.6 K; moisture reduction up to 2.65 wt.%	Focused only on underground cables
[17]	Bird mortality (collision & electrocution)	Norway	Species-area modeling + GIS	Quantified biodiversity loss using PDF*yr/kWh	Region-specific biodiversity modeling
[18]	EM wave effects on soil	General	Literature review (field + lab)	EM fields alter soil physical properties	No unified experimental standard
[19]	Leak detection in transmission lines	Saltwater pipelines	Comparative system evaluation	Fiber optic sensing offers high precision and real-time monitoring	Cost and deployment complexity
[20]	Bat activity near power lines	Brazil (Cerrado)	Acoustic paired sampling	No significant population loss; behavioral shifts observed	Limited species coverage
[21]	Transmission line ampacity	Power grid systems	Thermal balance + sensor-based optimization	Real-time ampacity optimization improves safety	Requires dense sensor infrastructure
[22]	Agricultural yield impact	Fergana region	GIS + statistical analysis	Power lines affect soil EM properties and crop productivity	Crop-specific and region-specific
[23]	Wind deflection of insulators	UHV/EHV transmission	FEM (ANSYS) + ML models	Accurate wind deflection prediction & early warning	High computational cost
[24]	Environmental mapping for line inspection	UAV-based systems	GPU-accelerated voxel mapping	Real-time mapping with reduced power consumption	Limited flight endurance
[25]	Electric field & noise mitigation	400 kV transmission lines	Experimental + computational modeling	Optimized conductor design reduces EF zones	Trade-off between noise and EF reduction

Table 1(b): P–V–F–E based comparison of power transmission line studies

Ref.	Power Aspect	Voltage Aspect	Frequency Aspect	Environmental Aspect	Overall Contribution
[14]	Indirect (demand-driven expansion)	High-voltage network focus	Not considered	Extensive impact assessment across lifecycle stages	Baseline environmental evaluation framework
[15]	Not quantified	Transmission corridor voltage implied	Not considered	Severe forest degradation due to ROW clearing	Highlights construction-phase ecological risks
[16]	Load-dependent thermal effects	330 kV underground cable	Constant grid frequency	Soil temperature & moisture alteration	Quantifies thermal–environment coupling
[17]	Energy transmission per kWh	High-voltage pylons	Implicit (steady-state)	Biodiversity loss (birds) via collision/electrocution	Integrates LCA with biodiversity metrics
[18]	Power infrastructure growth	HV/LV EM exposure	Not addressed	EM field effects on soil properties	Reviews EM–environment interaction
[19]	Operational power safety	Transmission line integrity	Not applicable	Environmental risk reduction via leak detection	Enhances safety and monitoring
[20]	Transmission presence	High-voltage overhead lines	Not considered	Bat activity variation	Species-specific ecological insights
[21]	Dynamic ampacity optimization	Voltage-dependent ampacity	Grid frequency assumed constant	Reduced overheating risk	Links power flow with environmental conditions
[22]	Power line proximity	High-voltage EM zones	Not considered	Soil EM impact on crop yield	GIS-based agro-environmental assessment
[23]	Mechanical load under power flow	UHV/EHV lines	Wind-induced oscillations (quasi-frequency)	Indirect (weather-induced stress)	Improves structural reliability
[24]	Power-efficient UAV systems	Not applicable	Not applicable	Real-time environmental cognition	Enables monitoring with low energy overhead
[25]	Power line configuration	400 kV single/double circuits	Audible noise frequency	Electric field & noise exposure	Design-based EF mitigation

3 Proposed work

Although there are considerable impacts on the environment associated with power generation, there are also several ways in which electricity transmission may damage the environment:

- Some power is lost during transmission and distribution on its way from the generator to the consumer. All of these losses put together are called "line loss." Power lines need regular maintenance and operation, and line loss increases with the distance that power must travel from generator to consumer. It is important to keep plants and trees away from the wires so they do not come into contact with them. Herbicides are used to manage vegetation on certain power line routes. Forests, marshes, and other natural environments may be disturbed when electricity lines and the roads that lead to them are installed in undeveloped regions.
- To minimize disruption to natural habitats, avoid sensitive ecosystems like wetlands, and use underground cabling in areas where visual impact is a major concern, when installing power lines, it is important to consider environmental impacts. Considerations such as construction disruption, electromagnetic fields (EMF), and potential impacts on wildlife from collisions with power lines should be prioritized. The goal should be to balance energy needs with environmental preservation.
- Greenhouse gas emissions, as well as emissions of air pollutants on a regional and local scale, including particulate matter, acid precipitation precursors, and other air pollutants. The building of power lines may

cause some emissions, but the impact of transmission interconnections on the scheduling and location of power plants in the linked countries will have the greatest effect on air pollutant emissions from grid interconnections. If the emissions from the generation that is used with the interconnection is lower than the emissions that would have been produced without the interconnection, then there will be significant benefits to air pollution overall (when all participating countries are considered in the interconnection project). For instance, net emissions benefits will often occur in countries where hydroelectric output displaces fossil fuel power plants in the importing nation and supplies export electricity via an interconnection. Each country's net gain or cost from increased or decreased emissions of air pollutants is proportional to the number and location of its power plants that operate more or less in the interconnection.

The purpose of this research is to provide evidence for better impact evaluations of power line infrastructure by reviewing the known affects of such lines. In order to transport energy from generators to our houses and places of work, power lines are an integral aspect of our environment. Despite its low initial investment and low maintenance requirements, above-ground power lines have a major negative impact on the environment. Examining the drawbacks of above-ground power lines with the potential benefits of subterranean ones will help us make a better-informed decision about the future of our electricity grid.

a. Environment characterization

An important part of AMI applications is environment characterization. This is to make sure that a communication technology works well in a particular area and can provide correct data for smart meters and energy management. The parameters of the vast geographical region that the SM and DC communicate across have a significant impact on the sent signal for both wired and wireless methods. Indeed, wireless signals are significantly muted by thick obstacles like buildings, walls, floors, etc., as well as by newly constructed structures or densely forested areas. Nonetheless, the PLC signal is entirely dependent on the electric network's design, and any changes or additions to this network might disrupt the current connection. Consequently, the authors categorize regions according to two factors: the density of loads as well as the density of barriers. This allows them to effectively navigate the environment's constraints and transfer data to their destination via wired and wireless communication methods. The three settings—rural, urban, and industrial—are defined here.

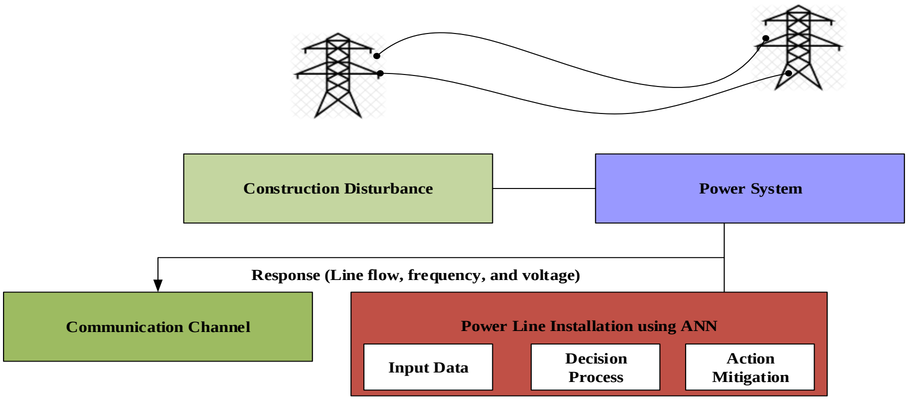


Figure 2: Power line installation using neural networks

3.1 Rural environment

One definition of a low-density region is the rural setting. Indeed, it denotes a rural or suburban area situated outside of a city or suburb that is mostly defined by its natural or agricultural setting. Access to information and communication resources is provided in rural areas via the employment of wired as well as wireless communication technologies. The benefits of each technology are unique. The utilities' individual requirements and conditions will determine the optimal option.

In remote places with preexisting power connections, PLC technology proves to be an invaluable tool. Data as well as communication signals may be reliably and affordably sent over vast distances using this method. But PLC can only work if the power cables are reliable and accessible. In some instances, the signal quality and dependability are compromised due to power cables that are either too old or poorly maintained. The communication signal quality is further diminished when PLC is subjected to interference from electrical components. Conversely, when the number of charges is extremely simple, the aerial cable length in rural networks may often be increased to 1 km.

For locations without or with unreliable power lines, RF technology is a lifesaver when it comes to providing communication services in rural areas. In addition, RF enables underserved and distant populations to have access to high-speed internet and other communication services, even in places without conventional infrastructure. Signal deterioration and interference from the environment, including weather, topography, and vegetation, may affect wireless systems. One possible explanation for the small number of pathways is that these sparsely inhabited regions that are handled remotely are less prone to causing distortions.

When deciding among PLC and RF technologies, it's important to consider the unique requirements of each rural area. In a rural setting, it's important to think about things like the current infrastructure, the quality of the signal, and how reliable it is. A continuous and dependable communication network is another potential use of both technologies. Factors including communication technology, geography, vegetation, and the existence of obstructions or interference affect the normal distance between a data concentrator and a smart meter in a rural location. The range for a PLC system may vary from just a few meters to many kilometers, contingent upon factors such as the condition of the power lines along with the existence of electrical components or disruptions.

3.2 Urban environment

Urban areas are defined by dense populations, a wide variety of gadgets in use, along with a concentration of man-made features like roads, schools, and hospitals. Residents have a plethora of communication possibilities, because to the densely packed wireless and wired communication infrastructure.

To begin, in city settings, PLCs can support specialized communication services like smart grid apps, remote monitoring, and home automation by tapping into the existing power grid to deliver high-speed connectivity without the requirement for extra infrastructure or cables. When contrasted with other forms of electronic communication, PLC does have a few limitations. Noise and electrical grid interference, along with other variables including distance, interference from other electrical equipment, and power grid infrastructure quality, all have an impact on the dependability and quality of a PLC signal. Also, when it comes to power grid operations, PLC must adhere to safety and regulatory standards.

Second, the use of radio frequency transmission is critical to the success of smart grid applications in city centers. Actually, radio frequency technology allows various grid components, including sensors, meters, and control systems, to communicate with one another. Consequently, they provide a variety of services, including the ability to read meters remotely, respond to demand, and operate and monitor the grid in real-time. One use of RF communication is AMI, which allows smart meters along with utility providers to communicate back and forth. This allows for real-time monitoring of power consumption and the ability to remotely stop and reconnect services. Nevertheless, its performance and dependability are impacted by a number of constraints that limit its SNR along with communication range. A few major constraints are signal attenuation owing to trees as well as other objects, which reduces signal strength and range, and interference when other Bluetooth devices, buildings, among other physical impediments.

In order to guarantee secure and dependable communication regardless of interferences or other disturbances, smart meters use a combination of RF communication and PLC, which both provide supplementary or redundant communication services and multi-path communication. Data concentrators and smart meters are often only effective within a few hundred meters of an urban area. Despite the fact that electric network architecture, buildings, and other structures may often block the transmission of wireless along with wired signals in urban contexts, this range is typically more than enough.

3.3 Industrial environment

Several obstacles impact the efficiency and dependability of communication networks in an industrial setting. In order to monitor, regulate, and optimize energy production, delivery, and consumption, AMI applications make use of a variety of sensors, devices for communication, and control systems. Electrical motors with welding equipment are only two examples of the many sources of electromagnetic interference, which poses a significant problem for AMI applications in industrial settings. As a result, access control is an integral part of dependable and secure communications, which are meant to guarantee the privacy and authenticity of data.

To begin with, PLC technology allows SMs to communicate with the DC in AMI applications, which in turn allows for the collection of precise and real-time data on energy usage. Electrical noise, interference from other devices, and signal strength variations caused by power line length and quality are some of the obstacles it must overcome. Alternatively, radio frequency technology allows communication without physical connections or wires, which simplifies and lowers the cost of installations. Additionally, IEEE 802.15.4g is well-suited for big industrial sites or outlying areas because to its extended operating range. In industrial settings, however, it encounters problems such multipath signal transmission, attenuation because of additional obstructions like walls and metal structures, and signal interference from other devices.

In general, there are a number of considerations that go into deciding which communication technology is most suited for AMI applications. These include the nature of the industrial setting, the accessibility of power lines, along with the overall budget and efficiency of the system of communication. When things like machinery or equipment block the communication of wireless signals, the range among SM and DC might be limited. It may be necessary to use more advanced communication technology in an industrial setting to guarantee dependable and effective communication due to the shorter distances compared to urban settings.

3.4 RF noise modeling

Wireless transmission in unlicensed bands has significant design challenges because to the AWGN and other factors, such as high interference from adjacent impractical devices and uncoordinated transmissions.

Three impulsive noise statistical models—the stable alpha-symmetric variables (SaS), the Middleton class-A, and the Gaussian mixture—describe this kind of interference. A specific instance of the GM probability density function is the MCA PDF, and the symmetric stable alphaunsystematic variable is comparable to the GM model. As far as the authors are aware, no previous publications have discussed noise modeling inside the 863-870MHz wireless spectrum range. On the basis of the assumption that the sub-1 GHz and 2.4 GHz bands are similar, the authors of model noise as a two-component mixed-signal random process and use the RFI toolbox to find the distribution that best matches the main source of radio frequency interference (RFI) in a wireless channel.

Equation (1) provides the likelihood density functions of the GMM (Gaussian mixture theory) as follows: it is calculated as the sum of complex Gaussian distributions having zero mean and unit variance σ_k^2.

$$f(x) = \sum_{k=1}^{K} \pi_k N_c(x \mid 0, \sigma_k^2) \tag{1}$$

where π_k σ_k is the variance of the k th Gaussian element and is equal to the mixing probability.

The decision between RF while NB-PLC technologies should be based on criteria such as the utility company's specialized needs, environmental geographical features, and regulatory concerns; both technologies have their pros and disadvantages. The writers describe the surrounding surroundings in the section that follows.

As a wireless signal travels over space, its power gradually decreases, a phenomenon known as path loss, which is measured in decibels (dB). Since it has an immediate impact on the dependability of the wireless communication connections between data concentrators and smart meters, it is an essential component. The authors of used a more thorough method to evaluate the connection between a data concentrator and a smart meter. They used a route loss model to calculate diffraction losses; this model takes into account information about the topographical profile of each connection. By doing so, we may more accurately predict the total average link-received power throughout the whole line connecting every SM to the DC in its vicinity. Rural, urban, as well as industrial settings are just a few of the usual locations for smart meter deployments. Therefore, variables like distance, operating frequency, and obstructions may greatly affect route loss. Its usual values in outdoor settings range from 2.7 to 6.5, depending on the features of that setting. According to studies cited in, the path loss factor is usually around 4 for cities. With a route loss exponent of around 3 in industrial regions, we can see that the signal attenuation rate is rather lower than in urban areas. Conversely, the route loss exponent is sometimes significantly smaller in rural, flat terrain. Distinct environmental features, as well as the effects of topography, obstructions, and other variables on signal propagation, are reflected in these differences in the route loss exponent.

Signals could undergo constructive or destructive disruptions due to multipath propagation if they travel over more than one path between the source and the destination. When signals with different amplitudes, phases, and delays combine from different sources (a straight route, reflections, diffractions, and scatterings), interference results. Faded signals have an effect on signal-to-noise ratios (SNRs) and bit error rates (BERs). In order to analyze and optimize networks accurately, well-constructed channel models are necessary due to the complex structure of wireless communication channels. We use the Rayleigh fading model to illustrate how wireless communications are affected by localized fading in a non-line-of-sight channel. The following is an example of how to simulate a multipath wireless network using the impulse response approach and Equation (2):

$$h(t, \tau) = \sum_{i=1}^{N(t)} a_r(t) e^{t r_r(t)} \delta(\tau - \tau_r(t)) \tag{2}$$

where $a_r(t)$ A variable denoted as $\tau_r(t)$ indicates the delay, N(t) the number of pathways that are dependent on t, and θ_r (t) denotes the amplitude.

Reliability in network communication is critical for the proper administration of microgrids, which are tiny electrical networks. Contemporary microgrid control systems regulate power generation and consumption, power consumption and switching of electrical appliances, charging and discharging of EVs, and linking the microgrid to an external distribution network (switching among on-grid and off-grid modes). Reliable communication ensures that both the control device's commands (such as a switching command) and the end device's data (such as measured data) reach each other. In its most basic version, the noise model accounts for both the distance in kilometers from the site of observation and other variables that impact the intensity of the produced sound. The following is the generalized model for a power transmission line:

$$L_A = k_1 \cdot f_1(E_, E_0) + k_2 \cdot f_2(n) + k_3 \cdot f_3(r) + k_4 \cdot f_4(l) + L_0, \quad (3)$$

where: L_A-SPL(dB) at distance I, E-maximum electric field strength (kV/cm) on the surface of the wire, E_0-SPL(dB) at distance I, E-maximum electric field strength (kV/cm) on the surface of the wire, $n -$ number L_0-noise reference level (dB), r-radius (cm) of the bundle component wire, l distance (m) among observation point B and the wire, and the number of conductors in the bundle.

Most known lines acoustic noise simulations have been standardized on the above structure, even if their coefficient values and, at times, the shapes of specific functions vary.

The loudness of extra-high voltage power lines may be estimated by knowing the highest possible levels of electric field strength E at the wires' surfaces. K points are chosen at random on the surface of every wire and spread equally over its outermost m (e.g., =360), in order to achieve this goal. Here is where the intensity of the electric field is determined. The outermost layer of a particular wire is assigned its maximum strength value. When calculating the sound pressure level for a bundle of component wires, the averaged highest values on the exteriors of the individual conductors are used.

According to Peek's empirical formula, the corona effect occurs with an electric field intensity E_0 (kV/cm) greater than a certain threshold:

$$E_0 = 21.2\delta m_1 m_2 \left(1 + \frac{0.301}{\sqrt{\delta r}}\right) \quad (4)$$

Where: $\bar{\delta}$-relative density of air, m_1 — coefficient that varies with wire quality and environmental factors ($m_1 =$ 1-for a smooth and dry surface; $m_1 = 0.6 \div 0.8$-for a wet surface; $m_1 = 0.3 \div 0.6$- water droplets, icicles, or significant surface contaminants; m_1=0.25 (heavy rain), m_2-coefficient (rain) equal to 0.8 (weather conditions), and r-wire radius (cm).

Research on a 400 kV cable allowed for the development of noise models that could be used to determine levels of sound pressure $L_{Aw(r)}$ and $L_{Aw(nr)}$ when it is raining and while it is not raining, respectively. The overarching structure of these models looks like this:

$$L_{Aw(r)} = 10\log\left\{E^{8.5}\left[1 - \exp\left(-0.11\delta_r(E - E_0)^{4/3}\right)^{1.8}\right]\right\}$$
$$L_{Aw(nr)} = 10\log\left\{E^{8.5}\left[1 - \exp\left(-0.04/m_5(E - E_0)^{4/3}\right)^{3.7}\right]\right\} \quad (5)$$

Geographical Features

$$F_g = \{\text{ terrain slope, elevation, soil type, distance }\} \quad (6)$$

Environmental Features

$$F_e = \{\text{ protected areas, vegetation density, climate risk }\} \quad (7)$$

Electrical Features

$$F_p = \{\text{ power capacity , voltage level, loss factor }\} \quad (8)$$

Economic Features

$$F_c = \{\text{installation cost, maintenance cost, land acquisition }\} \quad (9)$$

Infrastructure Constraints

$$F_i = \{\text{ road access, grid proximity, substation availability }\} \quad (10)$$

Unified Feature Vector

$$X = [F_g, F_e, F_p, F_c, F_i] \quad (11)$$

The rain fall (in millimeters per hour), the coefficient (m_s) which varies with the state of the wire (├ m_s∈<0.4;1.0⟩, m_s=1-wire that is smooth and undamaged, m_s=0.4-wire that is dirty and/or has a damaged surface).

From the i-th wire of the line, the total noise levels L_Ai may be computed using the formula:

$$\begin{aligned} L_{At(n)} &= L_{Aw(r)} + \Delta L_{ns} + \Delta L_r + \Delta l - L_0 \\ L_{At(n)} &= L_{Aw(n)} + \Delta L_{ns} + \Delta L_r + \Delta l - L_0 \end{aligned} \quad (12)$$

Where: L_0-reference level of 63 dB ,

$$\begin{aligned} \Delta L_{ns} &= 10\log(n), \\ \Delta L_r &= 45\log(r) \\ \Delta l &= -10\log(l) \end{aligned} \quad (13)$$

The relationship is used to compute the summation noise emission level L_A from k phase wires:

$$L_A = 10\log \sum_{i=1}^{k} 10^{0.1 L_{At}} \quad (14)$$

The study described in this work was conducted using Matlab software and suitable numerical calculation methods that were built based on the aforementioned assumptions and Equations above:

3.5 Robustness and generalization considerations

The proposed neural network model is designed as a data-driven disturbance analysis framework rather than a control-law-based adaptive controller. Robustness is achieved empirically through multi-environment training across rural, urban, and industrial scenarios, combined with diverse noise modeling that includes both Gaussian and impulsive interference. Seasonal variations and appliance-induced non-stationary disturbances are incorporated during training to enhance generalization. Although explicit Lyapunov-based stability proofs are not derived, the model demonstrates consistent performance under varying disturbance intensities, indicating strong empirical robustness suitable for power line disturbance assessment.

4 Results

We contribute for designing the 330kV transmission network, which is the principal line and spans a distance of more than 200 kilometers and unites all of the load centers and producing stations into a unified infrastructure. The next step involves the application of the many forms of faults that may be used by the transmission network, including symmetrical and unsymmetrical faults. In order to develop the protection model and estimate the distance relay protection, we use the RBF network approach to identify fault identification and isolation. Both of these processes are performed. In the 330kV transmission network that we constructed, we analyze the outcome in terms of fault current, losses, and accuracy.

Our first plan is to construct a 330kV transmission network that will serve as the principal line and span a distance of more than 500 kilometers. This network will link all of the producing stations and load centers into a single grid. Furthermore, the problem that may be using the transmission network should be applied.

Figure 3: 500KMs of coverage for power line installation

Table 2: Power losses during power line installation

Power Losses (kW, kVar)	Proposed Model	Traditional Method	Static Method
Summer	12.18	46.78	39.82
Winter	83.03	127.34	117.48

Compared to traditional and static assessment methods reported in recent literature, the proposed neural network demonstrates substantially lower power losses under both seasonal scenarios, confirming its effectiveness for disturbance-aware planning.

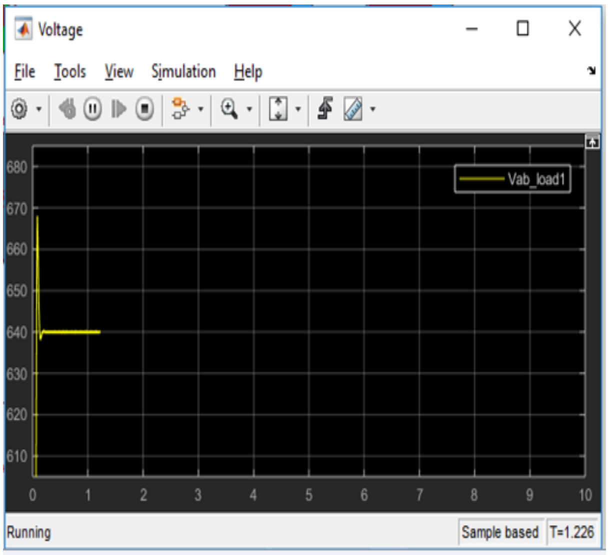


Figure 4: Voltage analysis

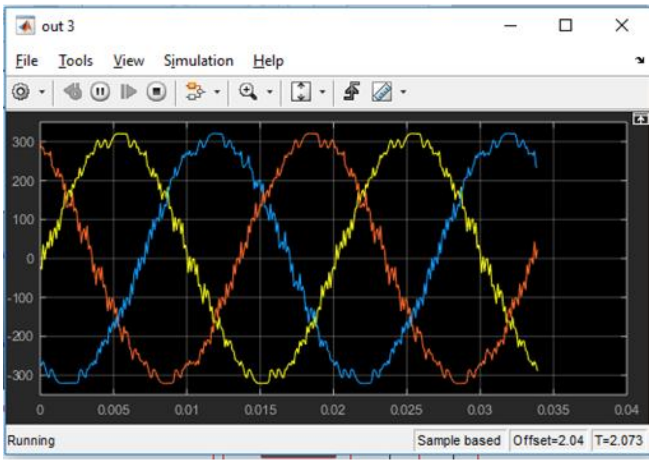
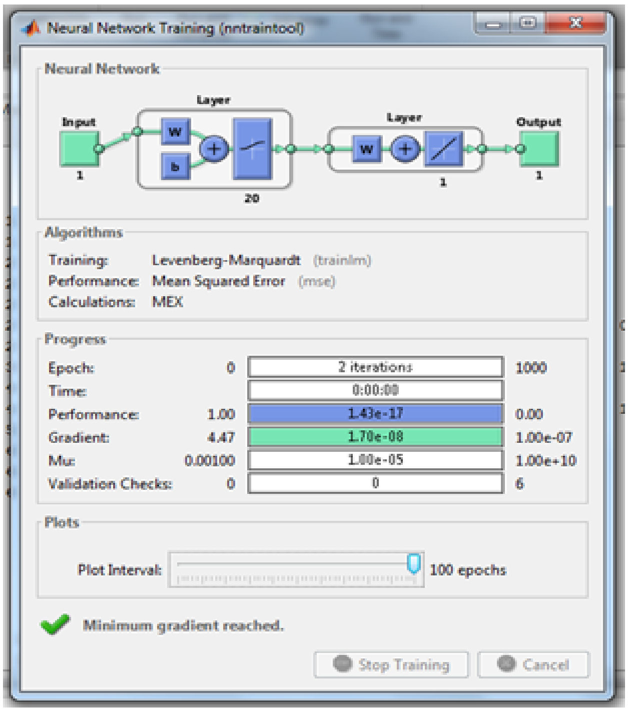


Figure 5: Output analysis



Algorithms

Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Calculations: MEX

Progress

Epoch: 0 | 2 iterations | 1000
Time: | 0:00:00 |
Performance: 1.00 | 1.43e-17 | 0.00
Gradient: 4.47 | 1.70e-08 | 1.00e-07
Mu: 0.00100 | 1.00e-05 | 1.00e+10
Validation Checks: 0 | 0 | 6

Plots

Plot Interval: 100 epochs

✓ Minimum gradient reached.

Figure 6: Neural network analysis

When it comes to installing power lines, the three most important characteristics are power, frequency, and voltage. These three factors affect the reliability and security of power transmission systems. In order to keep the system stable and minimize losses, power lines normally run at frequencies of 50 Hz or 60 Hz. Power lines are designed with voltage levels that minimize interference from electromagnetic waves and guarantee safe transfer of electrical energy over long distances. For power line performance optimization and risk mitigation, the interaction of these elements is crucial.

4.1 Power voltage and frequency

In power line operations, the induction of voltages and currents is influenced by power frequency, which is usually 50 Hz or 60 Hz. High precision in parallel power transmission lines is achieved by using accurate simulation techniques, such ANN model to determine power-frequency induced voltages and currents.

Control procedures are necessary to minimize damage and guarantee dependability in the case of overvoltage circumstances, which might arise as a result of imbalanced faults or unique designs in the lines of transmission.

4.2 Current and induced voltage

Electricity lines, particularly high voltages transmission lines, may cause substantial induced voltages and currents. In order to keep these generated voltages under control and guarantee precise parameter readings, suppression circuits are used.

Power lines create magnetic and electrical fields that may cause currents to flow through surrounding conductive items, including people, which might be harmful to their health. To minimize biological consequences, it is vital to understand and manage these areas.

4.3 Transmission over power lines

In order to send data, power line telecommunications (PLC) make use of low and medium voltage networks that already exist in the form of power lines. Applications in energy management and internet access might be made possible by this technology, which allows for high-speed data transfer.

Problems like electromagnetic interference and health hazards from induced fields are inherent to power line installations, despite their intended purpose of optimizing power, frequency, and voltage for efficient energy transmission. In order to ensure safe and effective functioning of electricity lines, it is crucial to address these concerns via the use of modern simulation tools, control measures, and regulatory compliance, such as those described in the Fig 7, Fig 8 and Fig 9, respectively.

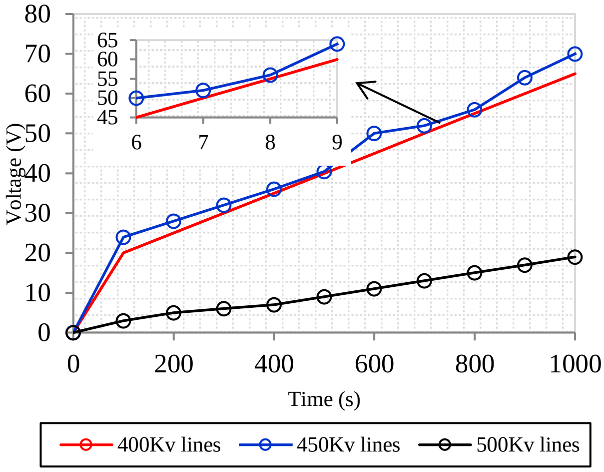


Figure 7: Voltage vs. time

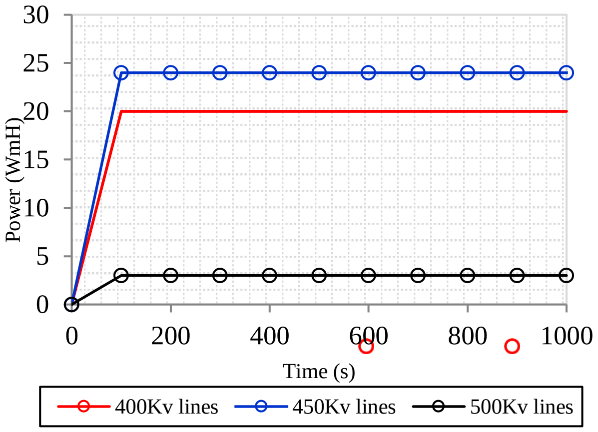


Figure 8: Power vs. time

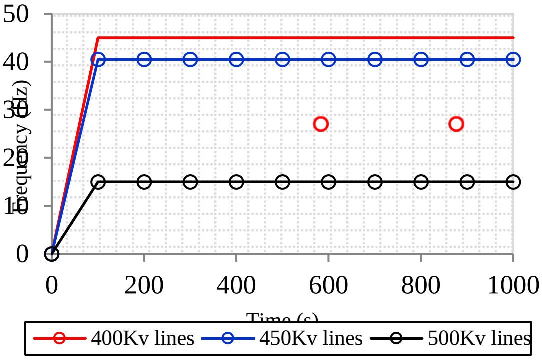


Figure 9: Frequency vs. time

5 Discussion

The obtained results confirm that integrating power, voltage, frequency, and environmental features significantly improves disturbance characterization compared to traditional and static approaches. The neural network effectively captures nonlinear interactions among multiple influencing factors, leading to reduced power losses and improved voltage stability across different operating environments. Seasonal variation and appliance-induced noise were observed to play a critical role in disturbance severity. While the results are based on simulation studies, they provide strong evidence for the applicability of multi-feature neural networks in disturbance-aware power line installation planning. Future validation using real field measurements will further strengthen the proposed framework.

Previous research has concentrated on the environmental impact of power systems used on building sites, with a specific emphasis on the noise produced by open-air caterpillar generators. It suggests noise mitigation monitors, acoustic barriers, and regular equipment maintenance as ways to lessen the impact of noise on employees working in construction. Although it doesn't aim to solve the problem of ecosystem disruption caused by power line the installation process, which it does show how important it is to have adequate pollution control measures to lessen construction-related disruptions that may have an indirect influence on nearby ecosystems, which is given in Table 3.

Table 3: Dimension-wise strength comparison (qualitative)

Dimension	**Conventional Studies**	**Limitations**	**Need for Unified Models**
Power	Thermal limits, ampacity	Static or local optimization	Global, adaptive power modeling
Voltage	EM fields, insulation, EF zones	Trade-off with noise & land use	Multi-objective voltage optimization
Frequency	Mostly ignored	Renewable intermittency overlooked	Frequency-aware planning
Environment	Biodiversity, soil, forests	Fragmented assessments	Integrated environmental intelligence

5.1 Integration with power system control and planning

The disturbance indices predicted by the proposed neural network can be used as decision-support inputs for power system planning and operation. In renewable energy–based microgrid and off-grid systems, the disturbance assessment can support installation route selection, adaptive scheduling, and disturbance-aware load management. The predicted disturbance severity can also assist in frequency-aware planning and preventive maintenance decisions. Although real-time control implementation is outside the scope of this study, the proposed framework provides actionable information that enhances practical power line installation and operation strategies.

Considering environment and operational problems is necessary to minimize harm to ecosystems during power line construction. Insights into many facets of power system disturbance management are offered in this document, which may be used while installing power lines. Some of the things we've learned include ways to keep the system stable, manage noise pollution, and prevent power dispatching disruptions.

Research highlights

- **Disturbance Management in Power Systems:** The dependability of energy systems may be impacted by disruptions that originate from both electricity and non-electrical sources. Power forecasting technologies is tested and made more resilient by simulating disturbances settings. This way, they can withstand interruptions with failures spreading down the system. Considering the likelihood of environmental impact, this method may be modified to handle disruptions that occur during the construction of electrical lines.
- **Noise Pollution Control:** Workers and the natural world are both negatively affected by the excessive noise levels produced by generator sets that are used on construction sites. To limit disturbance to local animals and neighborhoods, efficient noise management strategies include constructing noise barriers, employing quieter machinery, and timing loud operations around less sensitive periods.

- **Stability and Control:** In order to stop disruptions from spreading and triggering breakdowns in distributed power systems, meticulous monitoring is required. The stability of the system is improved with the use highly sophisticated algorithms that estimate and regulate oscillations. By using these tactics during the construction of electricity lines, we may reduce the negative environmental impact while keeping operations stable.
- **Disturbance Control:** Communicating electrical systems is possibly be better managed with the help of the Disturbance Control Standard (DCS). Power line installation projects may reduce the probability of environmental disturbances by implementing these standards, which assure safe and reliable operations.

Although these plans center on practical considerations, environmental considerations like habitat preservation and species conservation must also be given serious thought. More sustainable power line installations may be achieved by balancing innovations in technology with environmental conservation initiatives. Unlike flatness-based or nonlinear optimal controllers that directly modify system dynamics, the proposed framework complements such approaches by providing disturbance-aware intelligence that can be integrated into higher-level control and reconfiguration strategies. Compared to prior studies that analyze isolated environmental or electrical effects, the proposed approach jointly models power, voltage, frequency, and environmental factors within a unified learning framework. This integration explains the observed reduction in power losses and improved voltage stability relative to static and traditional methods.

5 Conclusion

This study demonstrates that there is a multifaceted problem with minimizing power line influence zones' detrimental effects on the environment. The novel approach to this issue is based on multiple features based on natural, social and economic environments, and modeled using neural networks which are complimentary and have been tested experimentally. Not only do the findings apply to lines with a rated voltage of 400 kilovolts, but they also provide guidelines for the development of transmission lines with higher rated voltages (over 100 kilovolts). It should also be noted that one aspect of the power energy transition procedures that is now underway is the decrease of the environmental effect of power infrastructure. This study paves the way for further investigation into smart grid power quality disruptions by discussing the problems and restrictions that have so far been identified. In order to make smart grid systems more efficient and resilient, it paves the way for more research into immediate identification and control methods. In future, hybrid DL model will be used for transmission line installation in smart grid aided applications. Future work will focus on hybrid deep learning models and real-world validation to extend the proposed framework toward real-time smart grid applications.

Declarations

Ethics approval and consent to participate: I confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country.

Consent for publication: I confirm that any participants (or their guardians if unable to give informed consent, or next of kin, if deceased) who may be identifiable through the manuscript (such as a case report), have been given an opportunity to review the final manuscript and have provided written consent to publish.

Availability of data and materials: The data used to support the findings of this study are available from the corresponding author upon request.

Competing interests: Here are no have no conflicts of interest to declare.

All authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

Authors' contributions (Individual contribution): All authors contributed to the study conception and design. All authors read and approved the final manuscript.

There is no human participate involved in this research. this article manuscript is created from collection of data set.

Acknowledgements : All authors contributed to the study conception and design. All authors read and approved the final manuscript.

Clinical Trial Number: Not applicable

Funding: This study was supported by the research on environmental impacts and soil erosion prevention and control technologies related to the ecological sensitive areas of the Sichuan Chongqing Ultra High Voltage Project (Project Number: SGZB0000TGJS2300103).

References

[1] Prakash, K., Naghibolhosseini, M., & Zayernouri, M. (2024). Multi-Scenario and Stochastic Thermo-Electro-Mechanical Modeling of Failure in Power

Transmission Lines. ArXiv, abs/2407.18857. DOI:10.48550/arXiv.2407.18857

[2] Gan, J., & Li, L. (2020). Research on Foundation Type Selection of Overhead Transmission Lines under Different Environmental Conditions. IOP Conference Series: Earth and Environmental Science, 558. DOI:10.1088/1755-1315/558/5/052035

[3] Xu, T., Tu, M., Zhang, Y., Zhang, H., Han, O., & Ding, T. (2022). A Stochastic Security-Constrained Unit Commitment Model Considering Uncertain Dynamic Capacity-Increase of Transmission Lines. 2022 IEEE 5th International Electrical and Energy Conference (CIEEC), 3787-3792. DOI:10.1109/CIEEC54735.2022.9846437

[4] Laninga, J., Jacob, N.D., & Kordi, B. (2024). Unexplained Flashovers on High Voltage Direct Current Transmission Lines under Negative Polarity Voltages. 2024 IEEE Electrical Insulation Conference (EIC), 225-228. DOI:10.1109/EIC58847.2024.10579344

[5] Hanhoerster, C.E., & Mendes, L.C. (2023). Cable-stayed towers in transmission lines. Concilium. https://doi.org/10.3390/buildings14113416

[6] Javed, M.R., Hussain, M.I., Usman, M., Asghar, F., Shahid, M., Amjad, W., Lee, G.H., & Waleed, A. (2023). Experimental study on impact of high voltage power transmission lines on silicon photovoltaics using artificial neural network. Frontiers in Energy Research. DOI:10.3389/fenrg.2023.1267947

[7] Arafat, E., Porkar, B., & Ghassemi, M. (2024). Electric Field Calculation and Comparative Analysis of Conventional and Unconventional Transmission Lines. IEEE Access, 12, 178038-178046. DOI:10.1109/ACCESS.2024.3508764

[8] Cherkashina, V., Litvinchuk, S., Lesko, V., Kravets, S., Netrebskiy, V., Sikorska, O., Mamyrbayev, O.Z., & Imanbek, B. (2022). STUDY OF THE ELECTROMAGNETIC IMPACT OF THE OVERHEAD TRANSMISSION LINES OF 330 KV ON ECOLOGICAL SYSTEMS. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska. DOI:10.35784/iapgos.2933

[9] Ma, X., Fan, S., & Li, W. (2020). Use of Meteorological Information for Condition Monitoring of Transmission Lines in Plateau Areas. DOI: 10.23977/isspj.2020.51005

[10] Mohsin, M., Sadia Kazmi, S., Imran, M., Rashid, J., & Abubakar, M. (2024). Fragile Lines: Climate-Security Nexus on Power Transmission Infrastructure. Journal of Asian Development Studies. DOI:10.62345/jads.2024.13.3.111

[11] Chen, G., Tu, Y., Wang, C., Wang, J., Yuan, Z., Ma, G., Wang, J., Qi, B., & Li, C. (2021). Environment-friendly Insulating Gases for HVDC Gas-insulated Transmission Lines. DOI:10.17775/CSEEJPES.2019.01060

[12] Andrés, A.M., José, C.R., Orlando, O.M., & Armando, M.M. (2021). Simulation of Low Frequency Electromagnetic Fields in 132kV Overhead Transmission Lines Using 2D Finite Element Analysis. 2021 XIX Workshop on Information Processing and Control (RPIC), 1-6. DOI:10.1109/RPIC53795.2021.9648438

[13] Jiang, M., Guo, J., Jiang, Y., Li, L., & Lu, M. (2020). Dust contamination on surface of transmission line insulators in air-polluted regions in China: statistical characteristics, adhesion mechanism, and environmental impact factors. Environmental Science and Pollution Research, 27, 23643-23654. DOI:10.1007/s11356-020-08692-6

[14] Pereira, G.D., Silva, B.D., Almeida, A.A., Freitas, F.C., & Almeida, F.S. (2024). Environmental Impacts of Electricity Transmission Lines in the Southeast Region of Brazil. Revista de Gestão Social e Ambiental. DOI:10.1007/s11356-020-08692-6

[15] Barros, I.R., & Vasconcelos, R.P. (2021). Analysis of Environmental Impacts Caused by the Construction of Power Transmission Lines in Brazil. International Journal for Innovation Education and Research. DOI:10.31686/ijier.vol9.iss6.3174

[16] Emmerling, C., Hoffmann, C., Herzog, M., Schieber, B., Stöckhert, F., Koschel, S., Kurtenacker, M., & Trüby, P. (2024). Soil warming by electrical underground transmission lines impacts temporal dynamics of soil temperature and moisture. Journal of Plant Nutrition and Soil Science. DOI:10.1002/jpln.202400554

[17] Gilad, D., May, R., Stokke, B.G., & Verones, F. (2024). Between the lines: Life cycle impact assessment models of collision and electrocution impacts of power lines on bird diversity in Norway. Journal of Industrial Ecology, 28, 426 - 438. DOI:10.1111/jiec.13488

[18] Marupov, A., Turdikulov, K., Khakimova, K., & Abdukadirova, M. (2024). Methods for researching the influence of electromagnetic waves of power transmission lines on soil properties. E3S Web of Conferences. DOI:10.1051/e3sconf/202450807002

[19] Boroomand, M.R., Razavi, N., & Eshghi, A. (2021). Investigation leak detection systems for saltwater transmission lines.

[20] Falcão, F.C., Mira-Mendes, C.V., & Herrera-Lopera, J.M. (2024). Between Wires and Wings: What Are the Impacts of Power Transmission Lines on the Diversity of Insectivorous Bats? Sustainability. DOI:10.3390/su16135639

[21] Huang, L., Liang, Y., Jiang, K., Sun, X., & Wang, S. (2024). A Calculation Model and Optimization Strategy for Transmission Lines Ampacity Considering Environmental Factors. 2024 IEEE 6th Advanced Information Management, Communicates, Electronic and Automation Control Conference

(IMCEC), 6, 435-440. DOI:10.1109/IMCEC59810.2024.10574976

[22] Marupov, A. (2023). Application of GIS technologies to implement environmental monitoring of laboratory studies of soils under power transmission lines in the Southern foothills of Fergana region. E3S Web of Conferences. DOI:10.1051/e3sconf/202342004023

[23] Liu, Y., Guo, Y., Wang, B., Li, Q., Gao, Q., & Wan, Y. (2024). Research on Influencing Factors and Wind Deflection Warning of Transmission Lines Based on Meteorological Prediction. Energies. DOI:10.3390/en17112612

[24] Kim, S., Jeong, S., Kim, D., Jeon, M., Moon, J., Kim, J., & Oh, K. (2022). GPU-Oriented Environmental Cognition of Power Transmission Lines Through LiDAR-Equipped UAVs. IEEE Systems Journal, 16, 4541-4551. DOI:10.1109/JSYST.2021.3100278

[25] Tarko, R., Kochanowicz, K., Nowak, W., Szpyra, W., & Wszołek, T. (2021). Reduction of the Environmental Impact of Electric Field Generated by High Voltage Power Transmission Lines. Energies. https://doi.org/10.3390/en14196388